MOTOROLA SOLUTIONS

Standards and Guidelines for Communication Sites



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CHAPTER 1 Introduction

This manual provides Motorola Solutions' requirements and guidelines for installing mission-critical communications equipment, infrastructure, and facilities. This manual is primarily based on recognized industry codes and standards, as well as engineering best practices. This edition has been updated to reflect recent changes to applicable industry codes and standards. This manual is a supplementary reference guide and does not replace, supersede, or modify any national, state, or local electrical codes, building regulations, or other statutory requirements. In all cases, the laws, codes, and regulations enforced by the authority having jurisdiction (AHJ) **shall** prevail and take precedence over the requirements and guidelines in this manual.

The intent of this manual is to provide requirements and guidelines that will result in a sufficiently robust installation that promotes personnel safety, equipment reliability and availability, and compliance with industry codes and standards. See APCO ANS 2.106.1-2019 for more information.

This manual was first released in 1987 as a Motorola reference ("R") document, number 56. Though the document was later assigned the publication number **68P81089E50**, it is still commonly referred to as the R56 manual.

IMPORTANT: Read and understand all disclaimers on the inside front cover before using this manual.

IMPORTANT: All construction, electrical work, and equipment installations **shall** comply with all applicable codes as required by the authority having jurisdiction (AHJ).

NOTE: The requirements and recommendations in this manual revision apply to new communication sites built after the manual publication date. Sites built prior to publication of this revision are not required to be upgraded. New equipment installations into existing sites **shall** comply with this revision as much as practicable.

1.1 R56 Committee Members

The R56 Committee is responsible for the ongoing development, technical accuracy, and standardization of this manual. While many have contributed to the R56 manual over the years, the committee members listed below contributed the majority of the effort for this edition. Each committee member has extensive experience and technical expertise in one or more of the included topics.

To email the committee with questions or suggestions about this manual: R56man@motorolasolutions.com.

For R56 technical questions and/or consulting, please contact your local Motorola Solutions representative.

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1.2 Organization of This Manual

This manual is organized into chapters, each of which provides requirements and guidelines for a major aspect of site development and equipment installation. Each chapter contains the following information about the subject it covers:

- Requirements that must be followed. Requirements are indicated by the use of the word "**shall**" in boldface type.
- Guidelines that describe preferred methods, but which are not requirements. Guidelines and recommendations are indicated by the use of the word "should."
- Useful information about planning, designing, and developing communications sites.

NOTE: If a section is referenced in any chapter, it **shall** be assumed the reference also includes all applicable subsections.

This manual is a living document. The Motorola Solutions Documentation Portal will be used to publish manual updates and/or corrections as necessary. To view the portal:

1. Go to https://docs.motorolasolutions.com/
2. Log in as required.
3. Search for R56 using the Search Documentation Bar. All R56-related documents will be displayed.
4. Download the desired documents.

1.3 General Statements

General statements included in this manual alert you to important and noteworthy information. General statements in this manual are of the following types:

IMPORTANT: Important notes help identify information of importance.

NOTE: Notes emphasize information that requires special attention.

1.4 Safety Information

The following sections describe how safety information is presented in this manual.

1.4.1 Safety Statements Defined

Safety statements included in this manual alert you to potential hazards to personnel or equipment and precede the step or text to which they apply. Safety statements in this manual are of the following types:

WARNING: Warnings indicate danger of injury or death to personnel. Warnings can indicate chemical, electrical, or other types of hazards. If the information in a warning note is disregarded, the lack of regard may result in death, serious injury, or serious product damage.

CAUTION: If the information in a caution note is disregarded, the lack of regard may result in minor or moderate injury or serious product damage. Caution notes may also indicate that a system may be interrupted or unavailable as the result of performing a task.

1.4.2 General Safety Requirements

The following are general safety precautions that must be observed:

WARNING: All Motorola Solutions employees and contractors and other personnel SHALL be required to use an appropriate electromagnetic energy (EME) monitoring device when working in the vicinity of fixed transmission sources of RF energy, unless they are able to conclude clearly that RF energy levels where they are working do not exceed those permitted by applicable standards and regulations. See Appendix A for additional information.

WARNING: To avoid injury or death caused by electric shock, do not wear a grounded wrist strap when working with high-voltage equipment.

WARNING: Before disturbing the surfaces in an existing structure, ensure that asbestos is not present. Surfaces containing asbestos can result in an inhalation hazard when disturbed by drilling, cutting, sanding or demolition. Asbestos removal SHALL be performed by certified asbestos abatement professionals only. A certificate of occupancy SHALL be secured where such abatement has been performed.

WARNING: Do not sweep dry floors if rodent droppings are evident. To prevent hantavirus infection, the floor SHALL be mopped in a safe and sanitary manner using a 5:1 water/bleach mixture. Personnel working at the site SHALL wash their hands before eating and avoid touching their mouth, nose, or eyes until the site is sufficiently clean.

WARNING: When operating any kind of power tool, always wear appropriate safety glasses and other protective gear to prevent injury.

WARNING: Climbing of ladders and towers poses significant safety risks. Only personnel trained in this practice and who possess the proper equipment SHALL perform such work. The Motorola Solutions Contractors Fall Protection Program SHALL be observed.

CAUTION: To avoid risk of injury, objects heavier than 18.2 kg (40 lb) should be lifted by two or more people.

- All Motorola Solutions employees, contractors, and other personnel working at communication sites **shall** be familiar with the information contained in this manual and **shall** follow the appropriate requirements and guidelines.

- Motorola Solutions requires all contractors to assume full responsibility for complying with all applicable regulations in the countries in which they operate. All partners and contractors performing high risk services for Motorola Solutions **shall** comply with the contractor requirements of Motorola Solutions, Inc. Refer to https://www.motorola-contractor.com/ for information on contractor programs.
- Personnel performing installation and maintenance should wash their hands before eating and avoid touching mouth and nose while handling equipment and/or debris.
- In environments where explosion hazards may exist, non-incendive intrinsically safe electrical components **shall** be used. Note that certain locations may be entirely unacceptable for housing electronic equipment.
- Communications equipment **shall not** be installed in elevator equipment rooms unless specific, code-allowed measures have been taken to mechanically isolate any wiring from moving equipment.
- All applicable health and safety codes **shall** be followed when performing tasks discussed in this manual.
- Utility locator services **shall** be used to locate buried utilities before conducting any subsurface explorations.
- To ensure personnel safety, all excavations **shall** be conducted in accordance with OSHA safety and excavation regulations and/or local safety regulations (whichever is more stringent).
- The fire department **shall** be notified as soon as a fire is discovered. Notification **shall not** be delayed in order to assess the results of fire fighting efforts using on-site portable fire extinguishers.
- In the United States:
  - All applicable OSHA requirements **shall** be adhered to.
  - All work **shall** be in compliance with local ordinances and applicable laws of the authority having jurisdiction.
  - Ladders **shall** be OSHA-approved for electrical work.
  - In installations at nuclear power plants and fuel processing facilities, the laws, rules and regulations of the Nuclear Regulatory Commission (NRC) policy and customer policy **shall** be observed.
  - **PROPOSITION 65 WARNING:** Some dust created by using power tools contains chemicals known to the state of California to cause cancer, birth defects or other reproductive harm. Some examples of these chemicals are:
    - Lead from lead-based paints.
    - Crystalline silica from bricks and cement and other masonry products.
    - Arsenic and chromium from chemically-treated lumber.
    - Your risk from these exposures varies, depending on how often you do this type of work. To reduce your exposure to these chemicals: work in a well-ventilated area and work with approved safety equipment. Always wear OSHA/NIOSH approved, properly fitting face mask or respirator when using such tools.

1.5 General Applicability and Site-Specific Limitations

While the requirements and recommendations set forth in this manual represent industry best practices, it is recognized that strict adherence may not be practicable at all locations due to unique, site-specific constraints. In instances where physical, environmental, or infrastructural limitations prevent full compliance, every reasonable effort **shall** be made to fulfill the core intent of these guidelines and implement equivalent alternative solutions. However, in all cases, the requirements of the authority having jurisdiction (AHJ) **shall** be followed. When developing site-specific deviations, consultation with the AHJ, MSI Engineering, or another qualified engineering firm may be necessary to evaluate and validate the alternative measures.

1.6 Motorola Solutions Inc. R56 Support Services

Motorola Solutions Inc. provides the following R56 services:

- Training
- Site design
- Installation
- R56 compliance audits using R56-certified auditors
- R56 certification via third-party certification organization
- R56 forensics analysis

Contact your local Motorola Solutions Inc. representative to learn more about these support services.

1.7 Standards

Table 1-1 lists published standards cited throughout this manual. All local and jurisdictional codes and safety standards, whether incidental or superseding to standards specified in this manual, **shall** be followed while developing a site, installing equipment, or performing maintenance.

Table 1-1. Referenced Standards

Publication	Title
ANSI ISEA Z308.1	American National Standard - Minimum Requirements for Workplace First Aid Kits and Supplies
ANSI Z535.3	Designing Effective Safety Symbols
ANSI Z87.1	American National Standard for Occupational and Educational Personal Eye and Face Protection Devices
ANSI/ESD S1.1	Wrist Straps
ANSI/ESD S20.20	Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
ANSI/ESD STM12.1	ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items - Seating - Resistance Measurements
ANSI/ESD STM4.1	ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items - Worksurfaces - Resistance Measurements
ANSI/ESD STM7.1	Flooring Systems Resistive Characterization
ANSI/ESD STM97.1	ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items - Floor Materials and Footwear - Resistance Measurement in Combination with a Person
ANSI/NEMA C84.1-2020	Electric Power Systems and Equipment - Voltage Ratings (60 Hz)
APCO ANS 2.106.1-2019	Association of Public-Safety Communications Officials (APCO) Public Safety Grade Site Hardening Requirements
AS/NZS 5070.1:2008	Siting and operation of radiocommunications facilities, Part 1: General guidelines for fixed, mobile and broadcasting facilities including fixed location satellite earth stations independent of the operating frequency
ASTM A615 / A615M-25	Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
ASTM C150/C150-M24	Standard Specification for Portland Cement (July 2024)
ASTM D0698-12R21	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

Table 1-1. Referenced Standards (continued)

Publication	Title
ASTM D1557-12	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
ASTM E488/E488M-22	Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements
ASTM G57-06R12	Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method
ATIS-0600012.05	Electrical Protection Considerations for Broadband Systems
ATIS-0600036.2017	Electrical Protection for Ethernet Systems (April 2017)
ATIS-0600037:2016	Testing Guidelines for Copper Theft Deterrents In the Telecom Industry
ATIS-0600311.2017(R2023)	DC Power Systems - Telecommunications Environment Protection
ATIS-0600313.2019(R2024)	Electrical Protection for Telecommunications Central Offices and Similar Type Facilities
ATIS-0600318.2021	Electrical Protection Applied to Telecommunications Network Plant at Entrances to Customer Structures or Buildings
ATIS-0600321.2020	Electrical Protection for Network Operator-Type Equipment Positions
ATIS-0600333.2013(S2023)	Grounding and Bonding of Telecommunications Equipment
ATIS-0600334.2019(R2024)	Electrical Protection of Communications Towers and Associated Structures
ATIS-0600336.2020	Design Requirements for Universal Cabinets and Framework
BICSI ITSIMM	Information Technology Systems Installation Methods Manual (ITSIMM)
BICSI N1-2019	Installation Practices for Telecommunications and ICT Cabling and Related Cabling Infrastructure
BICSI N3-20	Planning and Installation Methods for the Bonding and Grounding of Telecommunication and ICT Systems and Infrastructure
BS 1377-3:2018+A1:2021	British Standards Institution (BSi) Methods of test for soils for civil engineering purposes - Chemical and electro-chemical testing
BS 6651:1999	British Standards Institution (BSi) Code of Practice for Protection of Structures Against Lightning (superseded by IEC 62305-2)
BS 7430:2026	British Standards Institution (BSi): Code of Practice for protective earthing of Electrical Installations
CAN-ULC-503	Canadian Standard: Standard for Carbon Dioxide Fire Extinguishers (Covers requirements for construction and performance exclusive of fire tests)
CAN-ULC-504	Standard for Dry Chemical Fire Extinguishers
CAN-ULC-566	Standard for Halocarbon Clean Agent Fire Extinguishers
CAN-ULC-S508	Canadian Standard: Standard For The Rating And Fire Testing Of Fire Extinguishers Fourth Edition (Covers requirements for performance during fire tests)
CFR 29 Part §1910.133	Code of Federal Regulations Title 29 Occupational Safety and Health Standards Subpart 1910:133: Eye and face protection
CFR 29 Part §1910.134	Code of Federal Regulations Title 29 Occupational Safety and Health Standards Subpart 1910:134: Respiratory protection
CFR 29 Part §1910.147	Code of Federal Regulations Title 29 29 CFR 1910.147 The control of hazardous energy (lockout/tagout)
CFR 47 Part §1.1310	Code of Federal Regulations Title 47 47 CFR 1.1310 - Radiofrequency radiation exposure limits

Table 1-1. Referenced Standards (continued)

Publication	Title
CFR 47 Part 17	Code of Federal Regulations Title 47 Part 17 - Construction, Marking and Lighting of Antenna Structures
CFR 47 Part 68	Code of Federal Regulations Title 47 Part 68 Connection of Terminal Equipment to the Telephone Network
CSA B72:20	Canadian Standard: Installation Code for Lightning Protection Systems
CSA C22.1:24	Canadian Electrical Code, Part 1 (26th Edition), Safety Standard for Electrical Installations
CSA C22.2 NO. 41:22	Grounding and bonding equipment (Trinational standard with NMX-J-590-ANCE and UL 467)
CSA ISO/IEC 30129:20	Information technology — Telecommunications bonding networks for buildings and other structures (Adopted ISO/IEC 30129:2015, 1st Edition, 2015-10)
dbSpectra	dbSpectra TECHBOOK Series available from https://www.dbspectra.com/products/dbspectra-techbook-series/
Department of Homeland Security	Electromagnetic Pulse Shielding Mitigations Best Practices for Protection of Mission Critical Equipment
ESD STM12.1	Seating - Resistance Measurement
ETA® International	Mobile Communications & Electronics Installer
FAA-STD-019G	United States Federal Aviation Administration Lightning and Surge Protection, Grounding, Bonding and Shielding Requirements for Facilities and Electronic Equipment
FCC 96-326	Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation
FCC 97-303	SECOND MEMORANDUM OPINION AND ORDER AND NOTICE OF PROPOSED RULEMAKING
FCC OET Bulletin 65 (1997)	Federal Communications Commission Office of Engineering Technology Bulletin: *Evaluating Compliance With FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields.* https://www.fcc.gov/general/oet-bulletins-line#65
FCS1362:2022	UK Code of Practice for the Installation of Mobile Radio and Related Ancillary Equipment in Land Based Vehicles
FEMA 413	Installing Seismic Restraints for Electrical Equipment
Ford Motor Company	Mobile Radio Installation Guidelines
General Motors	Radio Telephone / Mobile Radio Installation Guidelines
General Motors Upfitter Integration	GM Upfitter Integration UI Bulletin #119, August 2014 Available from http://www.gmupfitter.com
IBC 2024	International Building Code
IEC 60364-1:2005	Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, and definitions
IEC 60364-5-54:2011	Low-voltage electrical installations - Part 5-54: Selection and Erection of Electrical Equipment - Earthing Arrangements and Protective Conductors
IEC 60529	Degrees of Protection Provided by Enclosures (Ingress Protection Code)
IEC 61000-4-x series	Electromagnetic Compatibility Package: Electromagnetic Compatibility Testing And Measurement Package - Parts 1 to 35
IEC 61000-5-x series	Electromagnetic Compatibility Installation and Mitigation Guidelines
IEC 62037-1	Passive RF and microwave devices, intermodulation level measurement -– Part 1: General requirements and measuring methods

Table 1-1. Referenced Standards (continued)

Publication	Title
IEC 62305-3:2024	Protection Against Lightning – Part 3: Physical damage to structures and life hazard
IEC 62368-1:2023	Audio/video, information and communication technology equipment - Part 1: Safety requirements
IEC 62561-7:2024	Lightning protection system components (LPSC) - Part 7: Requirements for earthing enhancing compounds
IEEE 1100-2005 (IEEE Emerald Book)	IEEE Recommended Practice for Powering and Grounding Electronic Equipment
IEEE 1159-2019	IEEE Recommended Practice for Monitoring Electric Power Quality
IEEE 142-2007 (IEEE Green Book)	Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE 1692-2023	IEEE Guide for the Protection of Communication Installations from Lightning Effects
IEEE 3003.1-2019	IEEE Recommended Practice for System Grounding of Industrial and Commercial Power Systems
IEEE 485-2020	Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
IEEE 519-2022	IEEE Standard for Harmonic Control in Electrical Power Systems
IEEE 80-2020	IEEE Guide for Safety in AC Substation Grounding
IEEE 802.1X-2020	IEEE Standard for Local and Metropolitan Area Networks--Port-Based Network Access Control
IEEE 81-2025	IEEE Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Grounding System
IEEE C2-2023	IEEE Standards Association: 2023 National Electrical Safety Code® (NESC®)
IEEE C62.41.2-2002	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and less) AC Power Circuits
IEEE C95.1-2019	IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
IEEE C95.2-2018	IEEE Standard for Radio-Frequency Energy and Current-Flow Symbols, (Revision of IEEE Std C95.2-1999), vol., no., pp.1-28, 5 Oct. 2018, doi: 10.1109/IEEESTD.2018.8486934.
IEEE 2944-7/91/0000/0866	D. Hibbard, "Vehicle mobile radio installation guidelines," [1991 Proceedings] 41st IEEE Vehicular Technology Conference, St. Louis, MO, USA, 1991, pp. 866-868, doi: 10.1109/VETEC.1991.140619.
IFC-2024	2024 International Fire Code (International Code Council®)
International Association of Electrical Inspectors, ISBN 978-1890659363	Soares Book on Grounding and Bonding, 9th Edition
International Association of Electrical Inspectors, ISBN 978-1890659653	Soares Book on Grounding and Bonding, 12th Edition
International Telecommunication Union (ITU)	Earthing and Bonding Handbook
ISO 11271	Soil quality – Determination of Redox Potential – Field Method
ISO/IEC 11801-1:2017	Information technology — Generic cabling for customer premises
MIL-HDBK-419A	Grounding, Bonding and Shielding for Electronic Equipments and Facilities

Table 1-1. Referenced Standards (continued)

Publication	Title
MIL-STD-188-124B	Grounding, Bonding and Shielding for Common Long Haul/Tactical Communications Systems Including Ground Based Communications Electronic Facilities and Equipments
MIL-STD-188-125-1	High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-based C^4I Facilities Performing Critical, Time-Urgent Missions, Part 1 Fixed Facilities
MIL-STD-188-125-2	High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-based C^4I Facilities Performing Critical, Time-Urgent Missions, Part 2 Transportable Systems
Motorola Solutions, Inc. 6878215A01	APX™ Mobiles Control Head Installation Manual
Motorola Solutions, Inc. 6881095C99	RF Energy Exposure Training and Product Safety Information for Mobile Two-Way Radios installed in Vehicles or as Fixed Site Control Stations
NECA 1-2023	Good Workmanship in Electrical Construction
NEMA	National Electrical Manufacturers Association
NENA-STA-027.3-2018	NENA E9-1-1 PSAP Equipment Standards
NFPA 1	Fire Code
NFPA 10	Standard for Portable Fire Extinguishers
NFPA 12	Standard on Carbon Dioxide Extinguishing Systems
NFPA 13	Standard for Installation of Sprinkler Systems
NFPA 17	Standard for Dry Chemical Extinguishing System
NFPA 70	National Electrical Code® & International Electrical Code® Series
NFPA 70 Handbook ISBN 978-1455931705	NFPA 70, National Electrical Code (NEC) Handbook (2026)
NFPA 70B	Standard for Electrical Equipment Maintenance
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 75	Standard for the Fire Protection of Information Technology Equipment
NFPA 101	Life Safety Code®
NFPA 110	Standard for Emergency and Standby Power Systems
NFPA 111	Standard on Stored Electrical Energy, Emergency and Standby Power Systems
NFPA 704	Standard System for the Identification of the Hazards of Materials for Emergency Response
NFPA 780-2026	Standard for the Installation of Lightning Protection Systems
NFPA 855	Standard for the Installation of Stationary Energy Storage Systems
NFPA 1221	Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems (2019)
NFPA 1225	Standard for Emergency Services Communications
NFPA 2001	Standard on Clean Agent Fire Extinguishing Systems
NIJ Guide 500-00	National Institute of Justice: Guide to Test Methods, Performance Requirements, and Installation Practices for Electronic Sirens Used on Law Enforcement Vehicles
NWSM 30-4106:2017	United States National Weather Service (NWS) Manual Lightning Protection, Grounding, Bonding, Shielding and Surge Protection Requirements
PolyPhaser publication	Rand, Ken R. “Lightning Protection and Grounding Solutions for Communication Sites” Polyphaser®, 2000. https://www.no1pc.org/radio/Polyphaser-Guide.pdf

Table 1-1. Referenced Standards (continued)

Publication	Title
SAE J1128_202508	Society of Automobile Engineers International Surface Vehicle Standard - Low Voltage Primary Cable
SAE J1849_202002	Society of Automobile Engineers International Surface Vehicle Standard - Emergency Vehicle Sirens
SAE J378_201802	Society of Automobile Engineers International Surface Vehicle Standard - Marine Propulsion System Wiring
Stellantis	Chrysler Corporation Radio Communication Equipment Installation Recommendations
STM97.1	ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Floor Materials and Footwear – Resistance Measurement in Combination with a Person
Telcordia® GR-1275-CORE.i12	Central Office/Network Environment Equipment Installation/Removal Generic Requirements
Telcordia® GR-3171-CORE.i02	Generic Requirements for Network Elements Used in Wireless Networks Physical Layer Criteria
Telcordia® GR-487	Generic Requirements for Electronic Equipment Cabinets
Telcordia® GR-63-CORE.i05	NEBS Requirements: Physical Protection
TIA-222-I	Structural Standard for Antenna Supporting Structures, Antennas, and Small Wind Turbine Support Structures
TIA-568-E	Commercial Building Telecommunications Cabling Standard
TIA-569-E	Telecommunications Pathways and Spaces
TIA-606-D	Administration Standard for Telecommunications Infrastructure
TIA-607-E	Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises
TIA-942-C	Telecommunications Infrastructure Standard for Data Centers
UBC	Uniform Building Code (superseded in 2000 by International Building Code (IBC)
UL 1426	Electrical Cables for Boats
UL 1436	Standard for Outlet Circuit Testers and Similar Indicating Devices
UL 1449	Surge Protective Devices
UL 1449 5th Edition	Surge Protective Devices
UL 154	Carbon-Dioxide Fire Extinguishers
UL 2129	Halocarbon Clean Agent Fire Extinguishers
UL 268	Smoke Detectors for Fire Alarm Systems
UL 299	Dry Chemical Fire Extinguishers
UL 467	Grounding and Bonding Equipment
UL 497A	Secondary Protectors For Communication Circuits
UL 497B	Protectors for Data Communication and Fire-Alarm Circuits
UL 497C	Standard for Protectors for Coaxial Communications Circuits
UL 711	Rating and Fire Testing of Extinguishers (Covers requirements for performance during fire tests)

CHAPTER 2

Site Design and Development

Site development refers to the civil, structural, mechanical, and electrical design, engineering, construction, and installation of supporting equipment at a communications site. This chapter primarily covers new site construction. Adding to or installing a site in an existing facility requires the scope of work, design, and drawings to be specific to these locations. Consultation with Motorola Solutions' Site Design and Integration Team is recommended for new construction, co-location, and renovation work. This chapter is intended as a high-level guide for the project manager and is not intended to be a comprehensive step-by-step procedure. Each site is unique, and the task list and task order may vary.

This chapter contains information on the following topics:

- “Motorola Solutions Site Design and Integration Team” on page 2-1
- “General Task Outline” on page 2-2
- “Planning” on page 2-2
- “Compliance with RF Energy Exposure Standards” on page 2-6
- “Site Walks” on page 2-6
- “Permitting, Zoning, Code and Regulatory Considerations” on page 2-7
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Site design and development is critical for safe and efficient operation of the communications system and the safety of installation and maintenance personnel. Implementing and following safety programs during construction cannot be overemphasized.

A licensed engineering firm should provide all final construction drawings and specifications for a new site. This ensures the design is adequate for the site conditions and helps ensure accurate records of site construction are available.

2.1 Motorola Solutions Site Design and Integration Team

The Motorola Solutions National Site Design and Integration Team (NSDIT) provides consistent, cost-effective design and construction solutions, and is available to support activities discussed in this chapter. The NSDIT has expertise in site acquisition and leasing, zoning, architectural engineering, environmental services, construction management, site preparation, site construction (including tower foundation and tower erection), site co-location (including water towers and rooftops), outdoor cabinets, and tenant build-outs. To engage the NSDIT, contact your Motorola Solutions account executive or project manager.

2.2 General Task Outline

IMPORTANT: Legal review by the customer and Motorola Solutions is required for leases and other contractual documents, as applicable.

The following is a high-level list of significant site development tasks, in the typical order of performance.

- Planning and site design drawing preparation
- Site surveying/staking
- Installing temporary facilities if necessary
- Clearing land of vegetation
- Installing erosion control barriers
- Excavating and building access road
- Installing utility/electrical metering base
- Excavating and establishing sub-grade and drainage requirements
- Excavating and installing foundation for shelter and any ancillary structures
- Excavating and installing tower foundations
- Installing equipment shelter and ancillary equipment, including backup power systems
- Installing electrical conductors and other utilities
- Energizing equipment shelter
- Installing tower, antennas and RF transmission lines
- Installing tower lighting system
- Installing fencing and gates
- Backfilling and final grading
- Startup and testing of facility equipment
- Performing final cleanup and obtaining customer approval signatures

2.3 Planning

Planning and organizing the development of a communications site is crucial to completing the project efficiently. The project team leverages knowledge and experience in site planning, design, and procurement to achieve project objectives. All project team members, including subcontractors, should be involved in project planning and constructability review at the start of the project.

- Establish roles and responsibilities of team members
- Review project scope with all project team members
- Review project scope against the requirements of this manual

2.3.1 Locating Utility Entrances

As practicable, locate all utility entrances to the facility (for example, AC power, phone, RF cables, water supply, and gas supply) in the same general area of the shelter (see IEEE 1100-2005).

IMPORTANT: All utilities and communications cables must enter the facility in the same general area to achieve true single-point grounding. See Chapter 4, “External Grounding (Earthing) and Bonding”, and Chapter 5, “Internal Bonding and Grounding (Earthing)” for more information.

2.3.2 Locating AC Power Neutral-Ground Bond

The location of the AC power neutral-ground bond affects equipment performance and a communications site's susceptibility to lightning damage. See “Location of Neutral-Ground Bond” on page 6-5.

2.3.3 Site Development Drawings

To help ensure site development plans are developed according to jurisdictional codes and specifications, an engineering firm **shall** be consulted. Site development drawings typically include (but are not limited to):

- Site layout relative to surroundings
- Access road location if applicable
- Location of existing utilities
- Road profiles (cut and fill requirements)
  - Existing road profile
  - New road profile depicting road grade, if needed. A grade of less than 10% is recommended if practicable; cranes, concrete trucks, and other heavy construction or delivery shipments must have access to the site.
- True north/south and east/west construction baselines, as represented from tower center or center of site structure
- Guy anchor location data schedule (if applicable). Typically, the bottom of an anchor head should be 305 mm (12 in.) to 457 mm (18 in.) above final grade.

NOTE: Concrete-encased electrodes (Ufer grounds), if used, must be engineered and installed before the concrete is poured. See “Concrete-Encased Electrodes” on page 4-23.

- Foundation plan, showing the following:
  - Foundation layout (depth, length, and width) and elevations of all required foundations
  - Cross-sectional view of foundations for rebar placement where required
  - Location and quantity of concrete-encased electrodes, if included in grounding electrode system design.
- Grading plan, showing general grade elevation and slope of compound and access areas
- Sediment control plan, showing location of hay bales or silt fences to prevent soil erosion
- Grounding electrode system design, showing all typical exterior grounding and bonding requirements (see Chapter 4, “External Grounding (Earthing) and Bonding”). Soil resistivity measurements may also be depicted (see Appendix B, “Soil Resistivity Measurements”).
- Typical access road cross section and culvert detail, showing the following:
  - Cross section of access road
  - Drainage requirements
  - Curb cut requirements

- Utility plan and installation details, showing the following:
  - Layout and installation routes for required utilities
  - Types of instrumentation required if applicable
  - Electrical one-line and service installation details, showing electrical service installation
- Telephone line installation details, if required
- Fence enclosure and guy anchor fence plan showing fencing installation

2.3.4 Surveying and Site Development Staking Considerations

Before finalizing site development plans, the site surveying firm should supply the following items at a minimum:

IMPORTANT: Topographic and property boundary surveys **shall** be signed and sealed by a Registered Professional Engineer (or as required by jurisdictional law).

- Property boundary surveys, in electronic and paper formats, showing all easements, rights-of-way, and boundaries. The property survey should be overlaid on the topographic survey to show property boundaries with respect to surface conditions.
- Topographic surveys, in electronic and paper formats, showing all relevant surface conditions and characteristics, including contour lines to convey relative surface height or depth.
- East/West and North/South construction baseline delineation.
- Latitude, longitude and elevation of proposed center of tower in relation to the communication compound.

Site staking should be performed upon completion and approval of site development plans. It is recommended that the original surveying firm also do the site staking. The contractor performing the fieldwork and the surveyors should have a kickoff meeting to set expectations and agree to a process that ensures timely execution.

Electronic and paper copies of the completed construction drawings **shall** be provided to the surveyor to minimize the chance for errors in determining property boundary encroachment or engineering errors. At a minimum, site development staking should include:

- Temporary and permanent easement/right of way locations
- Temporary and permanent roadways
- Roadway curb cut and radius locations
- Location of center of tower and centers of tower legs
- Site fence corners
- Building foundation corners
- For guyed towers, center of inner and outer guy anchor locations

2.3.5 Temporary Facilities

The following items are typically required during construction. Plan for these items before construction begins so they will be available when needed.

- Staging, fabrication, and construction areas
- Drives, walks, and bridges
- Public access
- Telephone if cellular coverage is unavailable
- Sanitary and cleanup facilities

- Drinking water
- Light and power
- Heat
- Workshop enclosures and storage (do not use the equipment shelter as a workshop)
- Dumpsters and trash removal services. Trash **shall not** be burned onsite.
- Personnel and tool trailers

2.3.6 Geotechnical Considerations

Geotechnical investigations **shall** be required for all projects that involve subsurface foundation installations. Geotechnical data obtained in these investigations **shall** be provided to the tower and foundation designers and site engineering firm in a compatible electronic format.

Unless otherwise specified, tower foundation and anchor design **shall** conform to the latest revision of ANSI/TIA-222 (or other applicable local Standards body design requirements).

It is highly recommended that the customer, tower and foundation designer, site-engineering firm, and the appropriate Motorola Solutions representative hold a meeting to set expectations, requirements, parameters, and approval process to ensure timely design completion.

NOTE: Some contracts and geographical locations may require additional geotechnical information. Consult a reputable geotechnical firm and the tower and foundation designer to ensure all required geotechnical information is included in the report.

The following are general geotechnical guidelines:

- Pocket penetrometer tests should not be substituted for unconfined compression tests.
- For each layer of soil encountered, the following items should be determined by field or laboratory testing and summarized in the soils report depending on the types of foundations recommended:
  - Standard penetration values
  - Soil classification and elevations
  - Angle of internal friction
  - Unconfined compression strength and cohesion
  - Tension and compression skin shear (for piles, caissons or drilled piers)
  - In-situ soil density and moisture content
  - Expected ground water fluctuations
  - Where drilled piers are feasible, the plasticity index and over-consolidation ratio **shall** be determined.
- The recommended type(s) of foundations to be considered should be based on the soils report, with corresponding design parameters for uplift, compression and lateral load.
- Construction techniques to ensure the design parameters are obtained should be discussed.

2.4 Compliance with RF Energy Exposure Standards

The site operator or site owner is responsible for compliance with RF energy exposure limits. Therefore, responsibility for each aspect of compliance assurance should be defined. See Appendix A, "Electromagnetic Energy Information".

IMPORTANT: All work **shall** conform to applicable codes and regulations imposed by the authorities having jurisdiction. All personnel working onsite **shall** receive appropriate RF Energy Exposure training.

In planning, installing, or modifying any antenna tower or other antenna site, compliance with regulations and standards concerning human exposure to RF energy is required. Factors to be considered include:

- Location, direction, transmission power, frequency, physical characteristics, and design of all antennas and other equipment at the site.
- Current or possible human occupation or usage of adjacent areas
- Methods to limit or control human access to adjacent areas, including fencing, limited-access doors, and signs.
- Appropriate operational procedures and training to ensure ongoing compliance with RF energy exposure regulations and standards.

2.5 Site Walks

Site walks familiarize involved parties with the development plan for a proposed site. A site walk **shall** take place after contract award to examine as much detail about the site as practicable, and to define responsibility for all aspects of site development. It is recommended where practicable that all involved parties participate in site walks. This includes, but is not limited to, geotechnical, site engineering, the site design team or their designee, contractor, and customer personnel.

Complete the following tasks at a minimum during the site walk:

- Note the type of property (existing facility, building top, private, state or federal property).
- Choose the facility location. If survey information is not available or applicable, precise location information is required for future reference and equipment deliveries. The construction location should be relatively clear of trees and brush. For efficiency, an adequately sized layout/fabrication area should be available adjacent to the construction area.
- Note general condition of the site and surrounding area, including flooding or erosion conditions. Also note characteristics of the site and the surrounding properties. The construction location should be on level, firm land free of drainage and soil erosion problems.
- Reach agreement on preliminary site layout and development concerning the site and its characteristics.
- Verify the location of the nearest commercial utility/electrical service. If available, note the service provider's name and a service pole number or approximate location of nearest service pole.
- Investigate site accessibility. This is of the utmost importance and should be thoroughly investigated. Note and investigate any obvious easement or security issues.
- Investigate and note weight (load) restrictions, whether on the access road, elevator, or floor. Obtaining special permits if required to access a site may be time-consuming.

NOTE: Load restrictions can prevent a site from being used.

- Note potential environmental concerns such as wetlands, dump sites, oil spills, garbage piles, or truck stops/fueling stations nearby.

- Determine if the location has permafrost, which requires isolating the building from the surrounding earth to prevent the temperature differential of the building from melting the surface soil, leading to structural and foundation damage. Solutions include building the structure on stilts or insulated pilings. It is also possible to construct on bedrock, if special methods for anchoring and grounding are used.

NOTE: Adding more antennas to an existing tower or structure may be impractical or impossible due to the retrofitting required or the physical limitations of the tower, structure, or foundations.

- Determine if an existing tower or structure is to be used to support proposed additional antennas and transmission lines. If so, then a structural and foundation analysis **shall** be performed.
- If an existing tower or structure will support proposed new antennas and transmission lines, assess the site for potential electromagnetic energy (EME) issues. An interference analysis should be performed to determine interference that may exist at the location.

These additional tasks may be recommended based on the initial site walk:

- On existing facilities, R56-certified personnel should perform a preliminary R56 compliance inspection to advise the customer of potential issues.
- Perform testing and measurement of existing ground system integrity, if practicable.
- Perform four-point soil resistivity testing if required. See “Soil Resistivity Measurements” on page B-1.

2.6 Permitting, Zoning, Code and Regulatory Considerations

IMPORTANT: Some municipalities require communications installations that share public safety facilities (such as police stations or hospitals) to be constructed to standards under the State “Essential Services Act.” Significant additional costs may result from such requirements. Legal review for “Essential Services Act” or other catch-all requirements is recommended.

Obtaining permits and complying with local codes, ordinances, and regulations can be complicated and time-consuming. It is highly recommended that all involved parties carefully plan and execute this portion of the project. To avoid unexpected problems, confer with all authorities having jurisdiction (AHJ) before beginning construction and provide them with clear execution plans. Consultation with Motorola Solutions’ NSDIT is recommended for assistance with permitting, zoning, code and regulatory requirements.

2.6.1 Americans With Disabilities Act

NOTE: The Americans With Disabilities Act (ADA) may apply to sites within US jurisdiction. Other jurisdictions may have similar or more stringent requirements. In all cases, the more rigorous requirement takes precedence.

If required by the AHJ, site design **shall** comply with ADA access requirements. Consider ADA requirements and the requirements of the Universal Building Code when designing site buildings and access. Compliance at the time of construction is less costly than retrofitting an existing structure to meet ADA requirements.

See https://www.ada.gov/law-and-regs/ada/ for the content of the ADA of 1990, as amended in 2008.

2.6.2 Federal Clean Water Act

Site development **shall** comply with the Federal Clean Water Act (FCWA). FCWA programs administered by local governments may vary, with different requirements and enforcement for specific locations, such as requiring common heating, ventilation, and air conditioning (HVAC) system condensate water to be carried to a legal building drain system instead of discharging into the soil. This may require condensate pumps on HVAC systems and plumbing the HVAC condensate water to a sewer system.

2.6.3 Fire Suppression

IMPORTANT: Consult the AHJ regarding local fire safety requirements.

Fire detection and suppression systems are typically required at occupied communication sites. Communications sites/facilities **shall** be designed according to applicable local jurisdictional codes.

2.7 Electrical Service Installation

The items listed below may help manage and coordinate electrical service installation. Not all items apply to all projects.

- Ensure the electrical installation process is tracked, managed and documented by responsible parties.
- Identify the utility supplier. Utility installations are jurisdictional. This is best achieved with a site meeting.
- Establish a point of contact at the utility company. Ensure the utility's work order tracking methods and processes are understood. Typically a customer tracking number is assigned.
- Obtain an installation cost estimate from the utility company.
- Obtain required easement documentation. Easement information **shall** be provided to the utility.
- Coordinate other utility installations such as closed-circuit television (CCTV) and telephone service provider.
- Provide an electrical utility information form to the utility.
- Where practicable, keep overhead lines and poles at least 61 m (200 ft) from the site compound area during construction. This helps prevent accidental contact between power lines and construction equipment and hazards associated with ice falling from the tower during construction.
- To facilitate single-point grounding, request that electrical service lines enter the site building on the same wall as, and near, the entry point for the antenna transmission lines.
- Separation between overhead electrical service conductors and antenna transmission lines **shall** be a minimum of 0.6 m (2 ft) (NFPA 70-2026, Article 810.13). The site development engineer must coordinate with the shelter manufacturer to ensure consistency in layouts.

NOTE: Additional site-specific load or use information, such as type of equipment, generator, or uninterruptible power supply (UPS) may be required.

NOTE: Working with governmental agencies for land transfers or easements may take considerably longer than working with private landowners.

- A copy of the utility site installation sketch, staking sheet or overlay **shall** be obtained. It is imperative to confirm that the utility company interpreted the service request correctly and that they conform to easement restrictions. Correcting problems in the design phase is simpler than after service installation has started.
- The electrical service connection to the meter pedestal is typically completed after the utility has been paid.

- The township or county typically assigns the property address. Provide the address to the utility. It is usually required before power can be connected.
- A jurisdictional electrical inspection is usually required before the utility company connects power.
- Verify responsibility for providing the electric meter. The utility typically supplies the electric meter, but not the meter pedestal.
- Electrical service installations in frigid climates are typically much more expensive and likely to lengthen the installation schedule.

2.8 Foundation Design and Installation

These guidelines and requirements apply to communications site concrete foundations, including prefabricated communications shelter foundations and tower foundations.

NOTE: Where a soil boring test is performed, test the local soil resistivity, soil pH, and the type and concentration of dissolved salts to aid in designing the grounding electrode system (TIA-222). See “Corrosion Related to Soil Type” on page 4-56.

2.8.1 Foundation and Geotechnical Services

NOTE: Firms offering foundation monitoring services may be able to provide a checklist to use as a guideline for the project.

Foundation monitoring services are required when performing foundation work or handling structural soils. They may also be required for certain other sub-surface and surface work. Monitoring services report whether the soils and concrete conform to design limits specified by either the tower and foundation designer or site engineering firm before, during, or after installation. If the specified design limits are not met, the foundation monitoring service **shall** notify the contractor and Motorola Solutions to ensure that the noncompliance is corrected. This service is sometimes performed by the geotechnical firm.

2.8.2 Foundation Planning

CAUTION: To prevent accidental damage to underground utilities, always have the local utility company or utility locator service locate utilities before excavating or digging at a site.

NOTE: Concrete-encased electrodes (Ufer grounds), if used, must be engineered and installed before the concrete is poured. See “Concrete-Encased Electrodes” on page 4-23.

- Foundation design for prefabricated shelters and other equipment **shall** be based upon site soil conditions as noted in the geotechnical report.
- A Registered Professional Engineer or contracting firm **shall** determine whether the soil is adequate to properly support the concrete foundation or slab. The Registered Professional Engineer or contracting firm **shall** determine the excavation depth and the required fill, if required.
- All excavations **shall** be conducted according to Occupational Safety and Health Administration (OSHA) safety and excavation regulations, or other applicable Occupational Safety and Health standards and/or local safety regulations (whichever is more stringent).
- All foundations **shall** be designed by a Registered Professional Engineer and the design **shall** be included in the construction drawing package.

- A concrete foundation is typically used for building and shelter installations. If a foundation is used, the foundation **shall** be appropriate for the structure.
- Foundation construction **shall** be performed by a qualified contractor specializing in this work.
- If a site is to use concrete-encased grounding electrodes within the foundation or other concrete structures, appropriate measures **shall** be taken to accommodate the grounding system within a concrete structure before the concrete is poured. See Chapter 4, “External Grounding (Earthing) and Bonding.”
- Prefabricated shelter foundations **shall** be built per the manufacturer's specifications and site-specific soil conditions. The architectural/engineering firm providing the construction drawings will coordinate and include final foundation designs in the drawings.
- Foundation design **shall** consider any precipitation conditions unique to the location, such as flood-prone areas or excessive snowfall. Special foundation designs include:
  - Footings
  - Piers: elevated platforms to help prevent floodwater from entering
  - Columns
  - Grade beams
  - Elevated foundations used to prevent snowfall from burying the site

2.8.3 Foundation Preparation

- All excavations on which concrete is to be placed **shall** be substantially horizontal, on undisturbed and unfrozen soil, and **shall** be free of loose material and excess ground water. Methods for removing excess ground water **shall** be provided if required.
- The foundation area **shall** be graded to provide water runoff and prevent water from standing. The final grade **shall** slope away in all directions from the foundation.
- Concrete forms **shall** be used as required for execution of the plain and reinforced concrete work. Sufficient quantities **shall** be used to execute and expedite work without endangering the safety or strength of any part of the construction.
- All forming **shall** be true and rigid, thoroughly braced, and sufficiently strong to safely carry all dead and live loads to which it may be subjected. The elimination of forming by a monolithic pour against undisturbed soil **shall** be allowed **only** if approved by a soils engineer and/or a qualified Motorola Solutions representative.
- All steel reinforcement **shall** be furnished and installed according to the approved foundation drawing. Unless otherwise specified or shown on plans, reinforcement **shall** consist of preformed bars of intermediate grade, manufactured from new billet stock. Metal reinforcement **shall** conform to the requirements of the latest version of *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement,* ASTM A615 / A615M-25, or applicable jurisdictional code, whichever is more stringent.
- Anchors, bolts and miscellaneous ironwork **shall** be set as shown in the drawings before pouring concrete. Embedded items **shall** be held rigidly during placement and curing of concrete. Placing rebar in position as the concrete is poured **shall not** be permitted.

2.8.4 Pouring Concrete

- At least one week before the concrete pour, the proposed concrete mix design **shall** be submitted to Motorola Solutions or its contractor to verify design specifications. Concrete pouring **shall not** take place until Motorola Solutions or its contractor has verified the design specifications.
- When concrete is placed, certificates **shall** be furnished for each delivery vehicle or every 5.4 m^3 (7 cubic yd), showing the mix proportions, additives, compressive strength, and the brand name and type of cement.
- Concrete **shall** be so deposited that there will be no separation or segregation of aggregate. Maximum free drop **shall not** exceed 2.43 m (8 ft).
- Concrete **shall not** be placed when the outdoor temperature is below 4.5°C (40° F) nor when the concrete is likely to be subjected to freezing temperatures before the final set, except when adequate provisions have been made for protection.
- A suitable means **shall** be provided to maintain the concrete temperature above 10°C (50°F) for 7 days. Materials **shall** be heated before mixing to prevent concrete from freezing.
- When deposited in the forms, the concrete **shall** have a temperature of not less than 15.5°C (60°F) and not more than 32°C (90°F).
- Concrete **shall** be vibrated and thoroughly consolidated around all embedded items.

2.8.5 Backfilling

- After completion of the foundation and other construction below-grade, and before backfilling, all excavations **shall** be clear of vegetation, trash, and debris.
- A soils engineer **shall** determine if the onsite excavated materials are suitable for use as backfill material. If not suitable, then the soils engineer **shall** determine whether engineered soils are needed.
- Foundation backfill **shall** be placed in layers no more than 305 mm (12 in.) deep before compaction. Each site's backfill requirements differ based on site conditions.
- A foundation for an outdoor communications cabinet **shall** be level and sealed.

2.8.6 Concrete and Soils Installation Monitoring

The required tasks in Table 2-1 **shall** be completed as appropriate for the site.

Table 2-1. Foundation and Soils Monitoring Requirements

Requirement	Type of Foundation			
	Drilled Piers (Caissons)	**Deep Mat**	**Guy Tower Sites**	**Eqpt. Shelter Foundations**
Confirm and obtain concrete mix design from the foundation designer.	✓	✓	✓	✓
Perform a penetrometer test at the base of the mat or tower excavation to verify soil bearing conditions. The number of test locations is dependent on soil conditions. The Geotechnical firm **shall** provide bearing values for specific locations. **NOTE:** Penetrometer tests are not required at the bottom of guy anchor thrust block excavations.		✓ minimum three (3) to five (5) locations	✓ minimum two (2) to three (3) locations	✓ minimum two (2) to four (4) locations

Table 2-1. Foundation and Soils Monitoring Requirements (continued)

Requirement	Type of Foundation			
	Drilled Piers (Caissons)	Deep Mat	Guy Tower Sites	Eqpt. Shelter Foundations
Collect a bulk sample for Modified Proctor compaction testing. Expedite the sample to the lab to accommodate a seven-day concrete cure period. If a high early-type mix is used, then a shorter turnaround is required.		✓	✓	✓
Identify specific caisson(s) being installed and include them in the daily field log and concrete report.	✓			
Confirm and note caisson diameter and depth in the concrete report.	✓			
Confirm, and note that caisson bottom is clean and free of debris.	✓			
For caissons, confirm and note the placement of the reinforcement cage and ensure it is centered in the caisson pier. For other foundations, confirm and note reinforcement steel placement with respect to foundation design.	✓	✓	✓	✓
Confirm and note that the method of concrete placement is as specified by foundation designer(s).	✓	✓	✓	✓
Perform concrete field tests (slump, temperature and air content) and cast a minimum of one set of test cylinders (four cylinders per set) for every 19.1 m^3 (25 cu. yd.) of concrete placed. Perform a new set of tests and cylinders once five yards beyond the 19.1 m^3 (25 cu. yd.) increment. Examples: •61 m^3 (80 cu. yd.) = four sets of test cylinders •23 m^3 (30 cu. yd.) = two sets of cylinders)	✓	✓	✓	✓
Confirm and note that a working vibratory wand is used to consolidate the upper 3 m (10 ft) of concrete placed in each caisson or the tower mat foundation.	✓	✓	✓	✓
Ensure newly formed test cylinders are placed in an insulated cure box or other heated area to protect against freezing temperatures. Other curing methods may be acceptable.	✓	✓	✓	✓
Test concrete cylinders according to the latest version of the American Concrete Institute (or authority having jurisdiction) standards and note the results in the concrete test log.	✓	✓	✓	✓
Note unusual events such as rejected concrete, weather or construction delays, difficulty setting anchor bolts, or stuck casing.	✓	✓	✓	✓

Table 2-1. Foundation and Soils Monitoring Requirements (continued)

Requirement	Type of Foundation			
	Drilled Piers (Caissons)	Deep Mat	Guy Tower Sites	Eqpt. Shelter Foundations
Perform, confirm, and note density tests on each new lift of tower foundation backfill to verify it is compacted to 95% of the Modified Proctor maximum density value test (ASTM D1557-12 (2021)). Note the type of compacting equipment used.	✓	✓	✓	✓
Note the anchors or locations worked on and the order in which they were poured.			✓	
Ensure backfill and undercut areas for non-structural applications (such as around prefabricated shelter foundations) are compacted to 90% of the maximum dry density value determined by the latest version of Standard Proctor test (ASTM D698-12R21).				✓

2.9 Tower Design and Construction

The following regulations apply to tower design and construction and **shall** be observed:

- In the United States, the Federal Aviation Administration (FAA) regulates and approves towers, including tower height, location, marking and lighting. Each state or jurisdiction may have additional regulating agencies that may designate specific marking or lighting requirements in addition to FAA requirements. It is recommended that the authority having jurisdiction be identified and consulted before final tower design and construction begins.
- CFR 47, Part 17 – "Construction, Marking and Lighting of Antenna Structures" **shall** be followed to determine required paint markings and tower lighting. Equivalent local jurisdictional requirements **shall** be followed outside the United States.
- A preconstruction notice **shall** be submitted to the FAA or local authority having jurisdiction (AHJ) at least 30 days before the proposed construction or alteration is scheduled to begin, before a construction permit application is filed with the Federal Communications Commission (FCC). Ensure the FAA (or AHJ) acknowledges receipt of the notice before beginning tower construction. The FAA may require additional notices on a case-by-case basis.
- All FAA, FCC and jurisdictional regulations **shall** be strictly followed during tower design, construction, and after tower completion. It is highly recommended that the appropriate AHJ be consulted before starting tower design and construction.
- Unless otherwise specified, tower foundation and anchor design **shall** follow the latest revision of TIA-222 or requirements of the local AHJ, whichever is more stringent.

2.9.1 General Tower Requirements

A Registered Professional Engineer specializing in tower structure design **shall** perform all tower and tower loading designs. If a structure other than a tower will be used to support a communication system antenna, the tower designer and/or a Registered Professional Engineer specializing in tower structure design **shall** be contracted to analyze whether the structure can safely support the proposed load. Tower mapping may also be required. Because tower twist and sway affects the performance of microwave links, loading information for each tower **shall** be supplied to the tower designer to help ensure that the tower meets TIA-222 (or other applicable local Standards body) requirements.

Tower height is determined by a number of factors including, but not limited to, the following:

- Required RF coverage
- Location
- Seismic risk probability
- Available area
- Existing structures in the vicinity
- Terrain
- Required antenna height
- Federal Aviation Authority (FAA) or jurisdictional approval
- Future tower capacity

Unless otherwise specified, all towers and foundations **shall** be designed to the latest version of TIA-222 unless jurisdictional laws or codes mandate otherwise. The following tower design requirements apply:

- A minimum of one safety climb **shall** be engineered, supplied and installed on every tower.
- EME precautions **shall** be as described in Appendix A, "Electromagnetic Energy Information".
- Rest platforms **shall** be designed and installed per OSHA or other applicable standards, or as recommended by the tower manufacturer.

If adding additional antennas to an existing tower, or if a structure other than a tower will be used to support a communication system antenna, the original tower vendor (if available) and/or a Registered Professional Engineer specializing in tower structure design **shall** be contracted to analyze whether the tower or structure can safely support the additional load. Tower mapping may also be required.

Table 2-2 provides a brief comparison of the three most common tower types.

Table 2-2. Comparison of Tower Types

Factor	Self-Supporting	Guyed	Monopole
Cost	High More material required Foundation more expensive	Moderate Higher assembly cost Land costs may be higher because more area is required for guy wires.	Moderate based on loading
Rigidity	High Self-supporting structure is typically more stable and better able to resist wind loading.	Moderate Resistant to wind sway, but susceptible to torquing, especially when dish antennas are installed.	Low Wind resistance less than other types.

Table 2-2. Comparison of Tower Types (continued)

Factor	Self-Supporting	Guyed	Monopole
Land Required	Low	High Guy anchors must be located far from tower, requiring more property. May be unsuitable for populated areas due to land requirements.	Low Well-suited for urban areas with limited land availability.
Height	Moderate	High Guyed towers may exceed 366 m (1200 ft).	Low
Growth Potential	Moderate	Moderate	Low due to added cost Monopoles capable of supporting growth with room to rent space to other users may cost significantly more to build.

2.9.2 Tower Design Drawings

The final tower foundation drawings **shall** minimally show the following information:

- Reference to the soil/geotechnical report used in calculations and design, including file number, date, and the issuer of the report
- Concrete compressive strength requirement, measured at 28 days
- Grade and type of reinforcing bar
- Concrete coverage requirements
- Whether welding of rebar is permitted
- If cold joints are permitted, the joining procedure **shall** be specified.
- Whether permanent steel casings are permitted for caisson installations
- Whether temporary steel casings are or may be required due to the expected soil conditions
- Any recommended concrete installation techniques such as a tremie
- References to all codes (and sections of codes) applicable to the design
- Plan, elevation and section views depicting a minimum of the following:
  - Length, depth and width
  - Diameter
  - Finish grade with respect to top of foundation
  - Rebar size and placement
  - Anchor bolt size, type and placement
  - Above finish grade requirement for anchor heads (typically a minimum of 305 mm (12 in.)
- Estimated cubic yards of concrete per pier, caisson, mat, block, or other type of foundation
- Backfill requirements:
  - Material type

- Lift thickness (typically lifts no more than 305 mm (12 in.) thick are acceptable).
- Applicable compaction requirements, such as 95% of modified proctor maximum dry density.
- Applicable sub-grade compaction requirements, such as for a guy anchor. Upon completion of the excavation the designer may require specific compaction densities.

- Any other pertinent information that may be abstracted from the soils report, such as a high water table or large boulders.
- Any other pertinent construction or design information or considerations.

2.9.3 Design Considerations to Help Reduce Effects of Lightning

Site design and physical layout can affect a communications site's susceptibility to lightning damage. The following are options for helping reduce risk of lightning damage at a communications site.

2.9.3.1 Lower Height of RF Transmission Line Entry Point

Reducing the height at which the RF transmission lines (coaxial cables) leave the tower and enter the building can reduce a communications site's susceptibility to lightning damage (see Figure 2-1).

The reduction in height reduces the voltage on the RF transmission lines before they enter the facility. A suggested practice is for the coaxial cables to enter the facility at a maximum height of 610 mm (2 ft) above the facility floor (see the United States National Weather Service Manual (NWSM) 30-4106:2017, "Lightning Protection, Grounding, Bonding, Shielding and Surge Protection Requirements"). For more information, see the PolyPhaser publication "Lightning Protection and Grounding Solutions for Communication Sites."

NOTE: The entry point for RF transmission lines is critical at normally-occupied facilities, such as dispatch centers, and facilities located on above-ground platforms (usually for flood control). See Figure 3-5 for an example of a shelter on an above-ground platform.

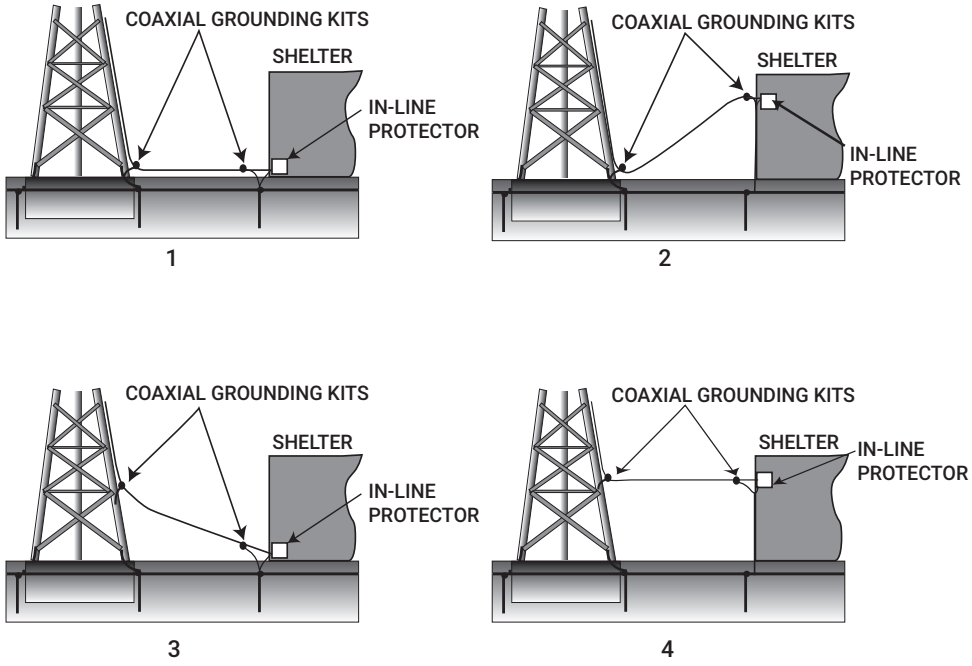


Figure 2-1. Transmission Line Entry Points (In Order of Preference)

2.9.3.2 Increase Distance Between Tower and Building

When designing a tower site with a related equipment shelter, it is recommended that the tower be placed a minimum of 9.1 m (30 ft) from the shelter where practicable. This distance balances between line loss in the antenna transmission line and the reduction in electromagnetic energy (EME) induced into the shelter if there is a tower lightning strike. The separation also helps increase the ability of the tower grounding electrode system to dissipate the lightning energy before it reaches the shelter. See IEEE 1692-2023 for more information.

Increasing the distance between tower and shelter from 3 m to 9.1 m (10 ft to 30 ft) reduces the amount of EME induced into the building by a factor of 9 (EME reduction factor = distance factor^2).

Increasing the distance between the tower and the shelter has the following benefits and may reduce a communications site's susceptibility to lightning damage. A separation distance of 9 m (30 ft) is considered a good compromise between lightning protection benefits and length added to RF transmission lines (IEEE 1692-2023, section 8).

- It decreases the magnetic field associated with lightning coupled to the building. The amount of magnetic field coupled into the building decreases by the square of the distance. For example, a magnetic field coupled to a building would decrease by a factor of 9 if the distance between the tower and the building is increased by a factor of 3.
- It reduces the energy that reaches the building via the RF transmission lines because the longer transmission lines have an increased inductance.
- It reduces the lightning energy propagated through the earth from the tower grounding (earthing) electrode system to the building grounding electrode system.

2.9.3.3 Eliminate Metallic Telecommunications/Data Lines

Wherever practicable, metallic telecommunications/data lines should be eliminated from the facility because they provide an unwanted conductive path for lightning energy. Eliminating metallic telecommunications/data lines by using fiber optic cable (or other isolation device) provides isolation from lightning-induced ground potential rise (GPR) and lightning energy. See IEEE 1692-2023 for more information.

2.9.3.4 Isolate Building And Tower From Ice Bridge/Cable Bridge

To reduce the amount of lightning energy diverted toward the building/shelter, and to provide seismic isolation between the building and tower, physical isolation (air gap) in the ice bridge/cable bridge near the building or tower is recommended. This is typically achieved using support posts near the building or tower rather than a direct connection to the building or tower. The air gap should be a minimum of 10 cm (4 in.) but not so large as to expose cables to possible damage from falling ice. For building and tower-supported ice bridges (non-self-supporting), a nonconductive slip joint can be fabricated to provide physical support and electrical isolation instead of an air gap. See IEEE 1692-2023, section 9.2 for more information.

2.9.3.5 Use Air Terminals on Towers

Air terminals (lightning rods) should be installed on top of communication towers to help protect antennas and other equipment mounted on top of the tower from direct lightning strikes. To protect the antennas and other equipment, air terminals must be installed at least 25 cm (10 in.) above the equipment being protected (see Figure 2-2 for an example). The system engineer **shall** approve the installation of air terminals near antennas due to their potential impact on RF coverage.

NOTE: If an air terminal (lightning rod) is installed at the top of a tower to help protect the antennas, the lightning rod **shall** extend at least 25 cm (10 in.) above the antennas. See FAA-STD-019G, section 4.3.6; NFPA 780-2026, section 4.5.2.1; and NWSM 30-4106:2017, section 2.7.8.1.

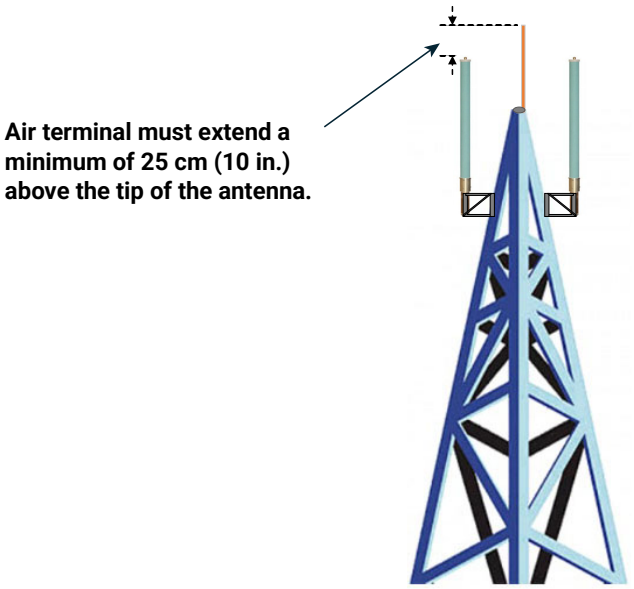


Figure 2-2. Air Terminal Protecting Side-Mounted Antennas

While several listed air terminals are available in different lengths, air terminals long enough to extend 25 cm (10 in.) above the antennas may not be available. In these cases, a tower manufacturer-designed extension pole for mounting the air terminal could be an option. See Figure 2-3 for examples.

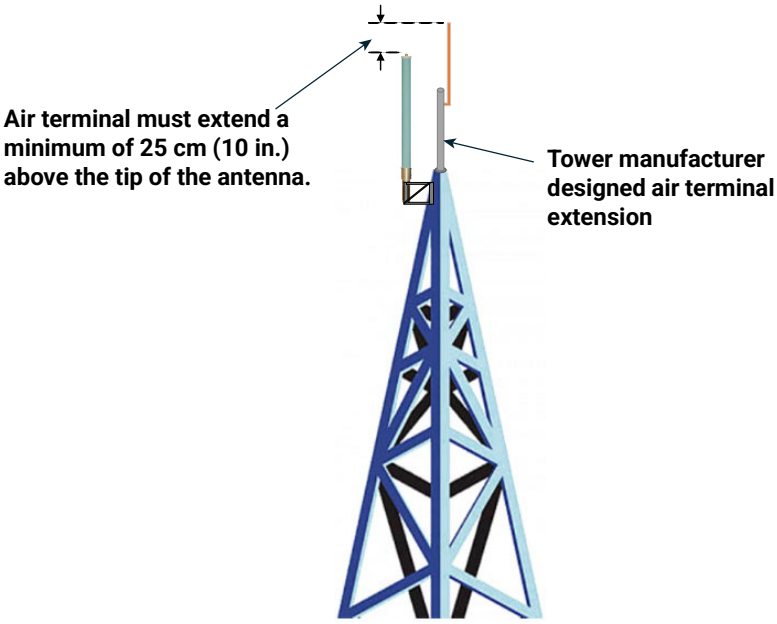


Figure 2-3. Air Terminal Extension Example

Side-mounted antennas are vulnerable to direct lightning strikes if installed at a height greater than 45.7 m (150 ft), and may be protected by using horizontal lightning rods attached to the tower, just above and below the antenna (Figure 2-4).

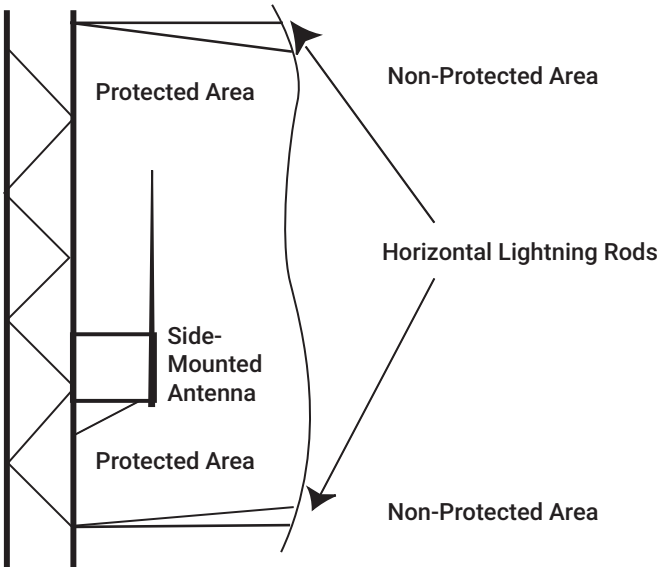


Figure 2-4. Horizontal Lightning Rods Protecting Side-Mounted Antenna

IMPORTANT: Air terminals (lightning rods) **shall** be installed on towers where FAA (or equivalent) regulations require aircraft warning lights to be placed on top of the structure (Telcordia GR-3171-CORE.i02). See Figure 2-5.

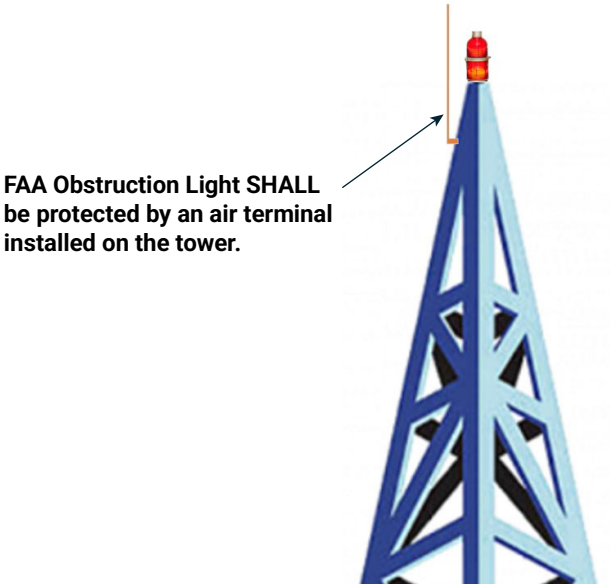


Figure 2-5. Air Terminal Protecting FAA Obstruction Light

2.9.4 Tower Safety

Always observe the following safety guidelines when constructing or working with towers.

- Towers **shall** be erected and installed by bonded and licensed (where applicable) contractors specializing in such work.
- Access to areas involving tower construction **shall** be restricted to prevent unauthorized personnel from entering.
- Fall protection measures **shall** be observed and implemented at all towers and structures, regardless of ownership, where climbing is required.
- All applicable regulations regarding tower climbing **shall** be observed and implemented. The most stringent regulations **shall** supersede other regulations.
- Subcontractors **shall** be required to submit their written comprehensive Safety Program to Program Management and obtain approval before starting any work.
- All tower climbing **shall** follow the Motorola Solutions Contractor Fall Protection Program.
- Towers **shall not** be overloaded.
- OSHA or other applicable regulations **shall** be observed during tower construction and maintenance.

2.9.5 Antenna and Dish Antenna Loading

NOTE: All loading on a tower **shall** conform to the latest revision of ANSI/TIA-222.

Antenna loading requirements are one of the most critical aspects of tower design. Tower loading requirements include, but are not limited to, the following:

- RF antenna quantity, size, type, manufacturer, frequency, and elevation
- Future RF antenna loading requirements, if applicable
- Microwave dish antenna quantity, size, manufacturer, frequency, azimuth, elevation and radome
- Future microwave dish antenna loading requirements, if applicable
- Transmission cable diameter and type
- Sidearm length and location
- Lighting requirements
- Additional ice or wind loading requirements applicable to the selected site
- Safety apparatus such as climbing ladders and rest platforms
- Miscellaneous optional equipment, such as ice shields

See Figure 2-6 for an example of a tower loading report.

MOTOROLA SOLUTIONS

Site Designator 7XXX
MSP No 7XXX
City NewTown **Phase** 3
County Charles **District** 7

Tower Loading Information

Tower Type: Self Support *21-Dec-2025*
Tower Height: 475
Tower Reference Azimuth: 0
Ant. Engineering File Number:

Microwave Antenna System Information

Path No	Path Destination	Path Density	Radio Capacity	Azimuth	Path Distance	Antenna Height (CL)	Dish Size	Space Diversity	Diversity Ant. Ht (CL)	Div Dish Size	EIRP (dBi)	Polarization
91	7203b	high	28	43	14.8	135	6	☑	95	6	66.8	Vertical
88	7302p4	medium	12	121.4	10.6	142	6	☑	102	6	66.8	Vertical
89	7001b	high	28	160.605	11	160	6.1	☑	99	6	64.8	Vertical
90	7904p1	High	28	237.145	15.8	125	8	☑	80	6	69.3	Vertical
101	7804c	high	28	333.9	11.4	106	6	☑	71	6	66.8	Vertical

MOTOROLA SOLUTIONS

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Path No	Path Destination	Path Density	Radio Capacity	Azimuth	Path Distance	Antenna Height (CL)	Dish Size	Space Diversity	Diversity Ant. Ht (CL)	Div Dish Size	EIRP (dBi)	Polarization

800 MHz Antenna Information

One 800 MHz Rx Ant. Ht: 445
Number of 800 MHz Tx Ants: 2
Mounted at a Height of: 475
Model Number of Antennas: PD100175a

NOTES:
All Line for the 800 MHz Antenna Systems will be 1 5/8" Heliax

1 5/8" Snap in hanger required for the site. 61

Relocated Existing Antenna Systems Loading Requirements

Model Number of Antennas: DB212
Mounted at a Height of: 200
Quantity of Antennas: 3

NOTE:
All Line for the non 800 MHz Antenna Systems will be 7/8" Heliax
If tower is less than 250' mount relocated existing antennas at highest available location.

Tower Marking and Lighting Requirements

Marked (Painted): ☐
Medium Intensity White: ☐
Dual Medium Intensity (White and Red): ☑
High Intensity White: ☐
Dual High Intensity (White and Red): ☐
Conventional Red Lighting: ☐
Requires No Lighting: ☐

Notes:
1. Compliance with future loading requirements mandates doubling all RF antennas listed above when calculating tower loading.
2. All Microwave Antenna Systems use EWP-63 Elliptical Waveguide.
3. All Microwave Antennas are Solid Dish Antennas with a Solid Molded Radome.
4. EWP63 hangers required at the site. 49 Packs of 10

Figure 2-6. Example of a Tower Loading Report

2.9.6 Tower Construction

Tower construction **shall** be performed according to the latest edition of ANSI/TIA-222-I (or as otherwise required by the AHJ). Tower construction general requirements are summarized below.

- Tower climbers **shall** comply with applicable safety codes and standards, using the appropriate personal protective equipment and personal fall arrest system (100% tie-off).
- Tower climbers **shall** be appropriately trained and certified as required by OSHA, the authority having jurisdiction, and other applicable codes and standards.
- Antenna mounts **shall** be installed as recommended by the manufacturer. Mounting devices **shall** be made of corrosion-resistant material.
- The highest point of the antenna and lightning rod **shall not** exceed the licensed height.

2.9.7 Tower Cable Installation Requirements

Transmission line installation requirements are summarized below.

- Tower lighting cables **shall not** be bundled with transmission lines or other conductors anywhere within cable ladders or the building interior.
- Each transmission line run **shall** have entry port boots (inside and outside), lightning protectors (surge protective devices) and associated mounting brackets.
- If the installation requires transmission lines that use air or nitrogen as the dielectric material between the conductors, a dehydration system **shall** be installed to maintain the optimum humidity of the dielectric.
- Strain relief devices **shall** be installed at intervals not exceeding 60.8 m (200 ft) during transmission line installation and **shall** remain in place to support the cable after installation. A support cable should be used between the grips to prevent damage to the transmission line caused by lifting from only one point.
- Coaxial cable transmission lines **shall** be bonded and grounded according to Chapter 4, “External Grounding (Earthing) and Bonding.”
- To minimize the formation of condensation and ice on transmission lines, a drip loop **shall** be created where the direction of the transmission lines changes from vertical to horizontal (see Figure 2-7). To lessen the likelihood of moisture on the cables entering the shelter, the cables should be installed with a slight upward incline as they approach the shelter.

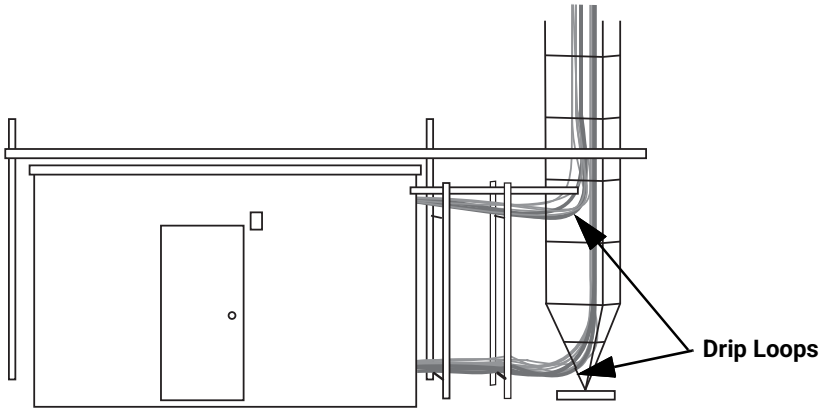


Figure 2-7. Example of Antenna Transmission Line Drip Loops

- Transmission lines **shall not** be installed in a way that will impede climbing or use of safety devices.
- Transmission lines **shall not** be mounted to climbing ladder rungs or climbing pegs.
- Transmission line installation should be planned with consideration for future expansion.
- Excess transmission line **shall not** be stored (coiled or looped) on the tower.
- All transmission line connectors, splices, terminations, and jumpers **shall** be weatherproofed.
- All clamps and securing hardware **shall** be corrosion-resistant.
- Transmission lines **shall** be secured to the tower using manufacturer-recommended hardware for that type of tower. The line manufacturer determines the spacing of securing hardware, based on the line's type and size. Hangers and/or angle adapters are typically installed at 914 mm (3 ft) intervals, including ice bridge paths.
- Transmission lines **shall** be permanently identified using metal tags (or equivalent methods) located at the antenna, at the bottom of the tower, at the shelter cable entrance, and inside the shelter or building.

2.9.8 Ice Bridge and Cable Support Requirements

Below are general requirements for sites using ice bridges and cable support systems from the tower to the shelter:

- Ice bridges and cable support systems **shall** be adequately supported and constructed from galvanized steel.
- The ice bridge should be isolated as described in "Isolate Building And Tower From Ice Bridge/Cable Bridge" on page 2-17.
- The ice bridge support posts **shall** be bonded to the grounding electrode system according to "Cable Bridge/ Ice Bridge Grounding and Bonding" on page 4-117.
- A non-self-supporting ice bridge **shall** be connected with a nonconductive slip joint to provide electrical isolation.

2.9.9 Securing the Tower

After construction, unauthorized entry to a tower **shall** be controlled as follows:

- Unless the tower is restricted from public access, a fence **shall** be installed around the tower according to "Site Security" on page 3-35 (see APCO ANS 2.106.1-2019, section 3.2.2.1).
- To help prevent damage to guy wires, the guy anchor points of guyed towers **shall** be fenced with a gate and lock, according to "Site Security" on page 3-35, unless the guy anchor is restricted from public access (see APCO ANS 2.106.1-2019, section 3.2.2.1). A damaged or weakened guy wire could cause the tower to collapse.
- If the tower has climbing pegs, the pegs should be removed from the bottom 6.1 m (20 ft) of the tower to deter unauthorized climbing.
- If the tower has a climbing ladder or elevator, it **shall** be appropriately secured to prevent unauthorized access.
- Appropriate signage notifying restricted access to the tower area and identification of the tower **shall** be affixed to the fence in a conspicuous location.

2.10 Site and Facility Acceptance Testing

When site development is complete, including tower construction, antenna and transmission line installation, utility connection, building construction or shelter placement, and roadway construction, all applicable areas of the site **shall** be inspected and tested to ensure all installations and alarms are functioning correctly before the site is presented for customer acceptance. All aspects of the inspection and testing **shall** be documented. Items to inspect and test may include, but are not limited to, the following:

- Concrete compressive strength requirements
- Site AC power and alarms
- Transfer switch functionality and alarms
- HVAC equipment and alarms (including high and low temperature and high humidity)
- Generator functionality and alarms
- Fire or smoke detection devices
- Emergency lighting
- UPS functionality and alarms
- Tower installation conforms to the latest version of TIA-222 (or other applicable local Standards body design requirements)
- Tower lighting functionality and alarms
- Antenna and transmission line installations
- Dehydrator functionality and alarm (if used)
- Security measures such as door alarms and deadbolts
- Site and building are clean and free of trash and debris
- Site, building, and tower drawings accurately document as-built design
- R56 audit (performed by a certified R56 auditor)

2.11 Site Drawings of Record

All drawings developed during site design **shall** be accurately maintained to show the intended site design, and how the site was built (as-built drawings). Drawings should be marked up to indicate modifications made during site construction. A map of the tower installation should also be maintained. Copies of all drawings and other information supporting the as-built site **shall** be provided to the customer upon site completion.

Parties responsible for future site installations or upgrades **shall** update the drawings to show all subsequent modifications to the site.

CHAPTER 3

Site Building Design and Installation

This chapter provides requirements and recommendations for designing communications site buildings, including equipment shelters and outdoor cabinets. The following topics are included:

- "Site Categories and Definitions" on page 3-1
- "Building/Shelter Design and Location Considerations" on page 3-3
- "Foundation Considerations" on page 3-6
- "Floor Loading" on page 3-7
- "Ceilings and Floors" on page 3-7
- "Weatherproofing/Sealing" on page 3-9
- "Heating, Ventilation, and Air Conditioning" on page 3-11
- "Cable Trays" on page 3-15
- "Lighting" on page 3-19
- "Fire Protection and Safety" on page 3-21
- "Safety Equipment" on page 3-30
- "Onsite Communications" on page 3-32
- "Signage" on page 3-32
- "Site Security" on page 3-35

3.1 Site Categories and Definitions

Table 3-1 describes typical communications equipment site configurations. See Chapter 4, "External Grounding (Earthing) and Bonding" for Type A, Type B, and Type B2 definitions and site grounding requirements.

Table 3-1. Standard Definitions of Communications Equipment Sites

Site Type	Description	Notes
Building	A purpose-built permanent structure built on a foundation.	The building should contain all necessary ancillary support systems, and may contain other unrelated equipment and/or facilities. A building **shall** be suitable for human occupancy during equipment installation, maintenance, and use.
Shared Facility	A dedicated radio room within a new or existing building. This may include renovation in an existing building or room that is modified or retrofitted to accommodate a new communications system.	These facilities may include shared commercial space in existing buildings, dispatch centers, central office installations, and other sites that are typically occupied. **Example:** A dedicated dispatch center and communication equipment site within a dedicated, permanently occupied facility.

Table 3-1. Standard Definitions of Communications Equipment Sites (continued)

Site Type	Description	Notes
Prefabricated Shelter	Prefabricated equipment shelters of concrete/ fiberglass construction placed on a foundation or pad. **Example**: See Figure 3-1.	A prefabricated permanent structure placed on a foundation. It contains communications equipment and related ancillary support systems. The shelter may be installed at an existing tower site, a new tower site, or on the roof of an existing building. The Motorola Solutions Standard Building (MSB) is a predesigned, all-inclusive, self-contained equipment shelter.
Shipping Container	A shipping container outfitted as a self-contained radio site.	A shipping container site must meet the same requirements as a building or prefabricated building, including HVAC, thermal insulation, bonding and grounding, weather sealing, equipment spacing, RF entry, and surge protection.
Outdoor Cabinet or Enclosure	An outdoor-rated, weather-proof enclosure that houses communications equipment and ancillary systems only, designed so that equipment contained within can be accessed without needing personnel to enter the cabinet. An enclosure is typically pre-wired and its equipment is pre-installed. See Figure 3-3 for an unmanned, weather-tight enclosure example.	A cabinet/enclosure can be installed indoors or outdoors on a small foundation, wall/pole mounted, on rooftops, etc. A cabinet installed indoors uses the existing building environment (heat and air conditioning) to maintain temperature. It can be used indoors as a “site within a site.” An outdoor cabinet contains its own environmental controls. Outdoor cabinets are frequently used in areas where zoning restrictions or limited site availability pose challenges. These cabinets are sometimes used in combination with camouflaged towers or antennas to address aesthetic concerns.
Vault	An enclosure that houses communications equipment and ancillary systems only, and is fully or partially buried in soil. The vault supports personnel only on a limited basis for installation and maintenance functions.	Similar to a cabinet/enclosure, except the enclosure is buried below ground level.
Greenfield	A new site on undeveloped land.	



Figure 3-1. Typical Prefabricated Equipment Shelter

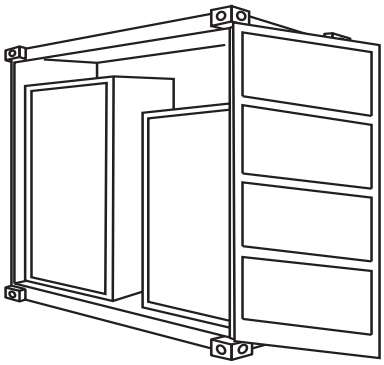


Figure 3-2. Metal Shipping Container Enclosure



Figure 3-3. Typical Outdoor Enclosure Cabinet on Raised Platform

3.2 Building/Shelter Design and Location Considerations

Prefabricated buildings, shelters, cabinets and vaults may have equipment installed prior to building shipment, requiring additional building specifications to allow lifting with equipment installed. Weight and size become a consideration if the site has limited access. For shipping, these structures must meet strict dimensional requirements, including protrusions such as HVAC, RF entry assemblies, or AC entrances. In the United States, state certification may be required if prefabricated buildings are manufactured in a state other than where they are deployed. Similar requirements regarding out-of-state or province manufacture may also apply in non-domestic situations.

The following are general considerations regarding sites utilizing a new building or shelter capable of human occupancy:

- Consideration **shall** be given to the amount and type of equipment to be housed, along with adequate space for movement and expansion within the structure. The amount and type of equipment housed will typically determine the suitability of prefabricated structures. See Chapter 6, “Power Sources,” and Chapter 9, “Equipment Installation”.
- Equipment configuration dictates the structure design. The desired size and composition of a prefabricated shelter, along with the weight of transporting it to the site, **shall** be considered.
- All sites utilizing a constructed structure or a prefabricated structure with manned access **shall** utilize exterior lighting. See “Lighting” on page 3-19 for requirements for various categories of structures.

- Consider not only the initial equipment loading of the site but future growth as well. The design should always include the shelter size, air conditioning, UPS, DC battery system, generator, and electrical system.
- A “single point” grounding system is required for optimum protection at the site (see Chapter 4, “External Grounding (Earthing) and Bonding”, and Chapter 5, “Internal Bonding and Grounding (Earthing)” for details). This includes a single ground busbar located at all outside shelter or equipment room penetrations (RF, AC power and generator, GPS, tower light controllers, equipment, and phone lines). This design will affect the overall equipment layout. DC power systems should be located close to this ground point. While this configuration occupies wall and floor space, it allows communications equipment to be expanded systematically outward (see Figure 3-4).
- A design that conforms to the single point ground concept **shall** be used if practical. This requires a single entry point for all RF and communications cables and all utilities entering the building in the same general area. In addition, a single Primary Bonding Busbar (PBB) **shall** be installed inside the shelter for equipment bonding. Also, an External Ground Busbar (EGB) **shall** be installed at the RF entry point (see Figure 3-4). See Chapter 4, “External Grounding (Earthing) and Bonding”, and Chapter 5, “Internal Bonding and Grounding (Earthing)” for details.

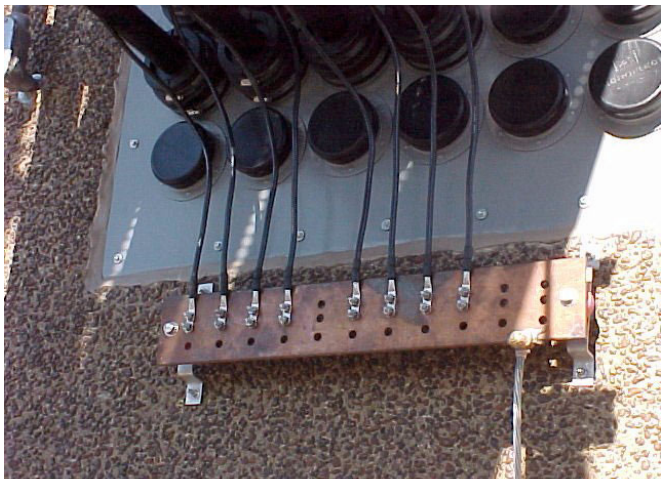


Figure 3-4. External Ground Busbar Installed at Cable Entry Point

NOTE: When a soil boring test is performed, test the local soil resistivity, soil pH, and the type and concentration of dissolved salts to aid in designing the grounding electrode system (TIA-222). See “Corrosion Related to Soil Type” on page 4-56.

- Though not usually required for building foundations, some sites with unique soil conditions may require soil boring tests. Soil borings reveal the soil strength and water content and are used to design a suitable foundation.
- In earthquake-prone areas (Seismic Design Category D or higher), foundation design and equipment anchoring **shall** address seismic requirements.
- For information on using concrete-encased electrodes (Ufer ground) as supplemental ground, see Chapter 4, “External Grounding (Earthing) and Bonding,”
- All buildings and shelters **shall** be designed to prevent moisture intrusion and entry of animals and insects into the structure. The design should also help discourage the nesting of birds and small animals on exterior features of the structure.
- Buildings may require compliance with human accessibility standards, such as the Americans with Disabilities Act (or equivalent where required). These requirements must be considered during layout and procurement of the facility.

- Buildings and shelters should utilize a locked chain-link fence where appropriate and appropriate deadbolt locks on standardized steel doors. Shelters and outdoor equipment cabinets **shall** be of the type designed for electronic equipment housing and accordingly fitted with locking doors.
- Buildings and shelters should utilize an alarm system capable of notifying a remote location of tampering, cable breakage, power outage, or system failure.
- During equipment rack installation, prioritize staging racks farthest from the access door first to ensure unobstructed clearance for subsequent equipment.
- When considering available equipment enclosures, the customer's current and reasonable future needs should be understood. The customer should be fully aware of the types of enclosures available.
- Shipping a prefabricated structure to a site may require special road use permits and/or special transportation methods (crane, double-length truck, helicopter, etc.).

3.2.1 Location Considerations

Sites should be selected for construction with the following considerations: cost, limited site preparation, environmental impact, public acceptance, accessibility, and future growth.

Rooftop shelters require a structural engineering analysis for both initial and final configurations. Verify that all portions of the access route to the installation site, including stairways and elevators, are also capable of supporting the weight of the enclosure. If the equipment must be lifted to the rooftop by a helicopter it will add significant cost to the project.

3.2.2 Equipment Shelter Off-Loading

CAUTION: To help prevent injury and/or damage to equipment, all appropriate safety precautions SHALL be taken during shelter off-loading.

IMPORTANT: For Motorola Solutions-related projects, crane operator personnel must inspect and test all cranes prior to any lift. Construction supervisory personnel **shall** insist that the crane operator demonstrate that the crane has been inspected. Any questions regarding this requirement **shall** be directed to the Motorola Solutions Project Manager.

The equipment shelter type determines the method and means by which it is off-loaded from the truck that transported it to the site. Typically, shelters require extensive rigging and a large hydraulic crane to off-load and set.

3.2.3 Seismic Considerations

In seismically active regions, appropriate seismic design factors must be incorporated into the building or shelter construction or layout. Site locations with Seismic Design Category D or higher require seismic design standards described elsewhere in this manual.

US seismic maps and graphs are available on the following US Geological Survey (USGS) web page:

https://earthquake.usgs.gov/earthquakes

Seismic information can be found on the USGS home page at:

http://www.usgs.gov

See International Building Code (IBC) 2024 for detailed information on seismic building requirements.

In general, observe the following considerations when designing to accommodate seismic risks of Modified Mercalli (MM) intensity 3.0 or greater:

- A qualified architect **shall** be contracted to determine seismic structural needs for a specific location. The site seismic design helps ensure safety of personnel at the site should an earthquake occur.
- Shelters **shall** incorporate a steel door frame and a steel door for security and seismic integrity. In an earthquake a structure may deform, preventing doors from being opened from the inside. As most communication sites do not have windows, this becomes a serious issue for trapped occupants. Some concrete prefabricated shelter manufacturers also cross-brace the door frame area to prevent deformation during an earthquake.
- Only specifically designed seismic support hardware **shall** be used for seismic bracing.
- Seismic battery racks, seismic bracing and support, and seismic facility and antenna structure construction practices **shall** be employed in seismically active locations.
- Storage cabinets **shall** be closable and secured to walls.

3.3 Foundation Considerations

- All foundation designs **shall** comply with the guidelines set forth in “Foundation Design and Installation” on page 2-9.
- The foundation **shall** be appropriate for the structure

IMPORTANT: If a site requires concrete-encased grounding electrodes within the foundation or other concrete structures, appropriate measures **shall** be taken to accommodate the grounding system within a concrete structure before the concrete is poured. See “Concrete-Encased Electrodes” on page 4-23.

- The foundation for a prefabricated shelter **shall** be in accordance with manufacturer's specifications. Prefabricated building manufacturers usually provide typical foundation specifications for their building models.
- A foundation for a cabinet **shall** be level and sealed.
- Foundation design **shall** consider any special precipitation conditions unique to the installation locality. These considerations include, but are not limited to, elevated (pier type) platforms used in low-lying areas prone to regular flooding and elevated foundations to prevent burial of site due to snowfall. Special foundation designs include:
  - Footings
  - Piers
  - Columns



Figure 3-5. Typical Shelter Mounted on Elevated Piers

3.4 Floor Loading

When determining equipment placement in an existing structure or when developing building specifications for an equipment shelter, attention **shall** be given to the Structural Live Load capacity of the building. Usually, standard commercial construction specifications will provide substantial floor loading capacity. However, stacking and/or back-to-back placement of some equipment may exceed structural load limits. The weight and footprint dimensions of each piece of equipment to be installed **shall** be used to calculate floor loading.

The shelter **shall** be capable of supporting a minimum uniformly distributed load of 9.6 kPa (200 lb/ft^2 (psf)), and concentrated loads as required to support the proposed equipment.

Battery configurations can sometimes be specified with feet, rails, or specialized load-spreading devices that can facilitate deployments in high-rise structures. It is often necessary to specify a battery's location within a prefabricated shelter so that if the building is staged (fully equipped and optimized) before shipment, it has enough structural strength to be lifted and transported fully loaded.

If the battery configuration's weight exceeds 9.6 kPa (200 lb/ft2), the battery rack must be equipped with a specialized load-spreading device. Include potential expansion when calculating floor loading.

The design and/or construction team (civil engineering firm, contractor, or architect) will require data related to anticipated floor loads for the site.Typically, the following initial information is required:

- The total weight of the equipment. This is to be determined by adding the individual weights of all electronic equipment, racks, and other ancillary support equipment to be installed.
- A diagram showing the amount, weight, and proposed location of the equipment planned for installation.

An engineering firm must determine if the floor of an existing site is adequate to safely support the weight of the equipment, and if not, how to reinforce it. The distributed weight **shall not** exceed the rating of the existing floor and **shall** conform to jurisdictional building codes.

Some of the practices used to distribute a structural live load can prove to be counterproductive in an earthquake. For example, steel I-beams are sometimes used to support a modular shelter between parapet walls of a high-rise building, where the roof itself could not handle the weight without costly retrofit. In an earthquake, the I-beams will flex to their limits at the moment of the shelter movement. Rooftop isolators attached between the roof surface and the I-beam supports can dampen the movement of the shelter, absorbing the energy of an earthquake.

3.5 Ceilings and Floors

For tenant improvements in existing high-rise buildings, the contractor must determine if post-tensioning is employed in floor, roof, or wall construction. If so, industrial X-ray mapping **shall** be employed to avoid structural damage caused by accidental penetration of a tensioning cable.

3.5.1 Ceilings

The following general considerations must be observed when designing a site building, selecting a prefabricated shelter, or installing equipment in an existing structure or room:

- Ceiling height **shall** conform to applicable jurisdictional building codes.
- The minimum acceptable ceiling height for communications sites utilizing 2.2 m racks (standard 7.5 ft rack) is recommended to be 2.75 m (9 ft).
- Before adding equipment to existing sites, ensure that the ceiling is high enough to accommodate the planned additional equipment, including stacked cabinets.
- Determine the height of the tallest rack that could be deployed at a site, and then provide additional height to accommodate cabling, working space, and ventilation.
- Consider the size of the cable that might be attached to the top of the rack and that cable's bending radius. The cable tray will typically be at least 152.4 mm (6 in.) above the tallest rack or cabinet.
- The cable tray **shall** be installed with a minimum clearance of 200 mm (8 in.) between the cable tray and the ceiling; a clearance of 305 mm (12 in.) is recommended (TIA-569-E, 2019).
- In a site where the existing ceiling is too low to accommodate the specified clearances, the location of the cable tray may be moved above the aisle behind the equipment row. Good site engineering practices must be considered, including the accommodation of any electrical and working spaces.

3.5.2 Floors

Observe the following general considerations when designing a site building or selecting a prefabricated shelter:

- Floor construction **shall** conform to applicable jurisdictional building codes.
- Except for access flooring, floors should be constructed of concrete or wood. Normally if the building shelter floor is at ground level, the floor is concrete. If the building shelter is elevated from ground level, the floor is normally constructed of heavy-duty floor joists and plywood or a cement/wood composition board (commonly known as Viroc®).
- Concrete used as communications site flooring **shall** be mixed to ensure adequate tensile strength under load.
- Concrete **shall** be poured and reinforced in accordance with applicable jurisdictional requirements. Where an earthquake-resistant structure is specified, additional considerations may apply.
- Floors **shall** be level before equipment is installed.
- When using wooden floors, the contractor's floor loading calculations must take into account the type of equipment that will be installed, as well as any potential future equipment. (See “Floor Loading” on page 3-7).

CAUTION: Ensure equipment racks installed on wooden floors are anchored using lag screws that penetrate into the floor beams or a similar sturdy structure. Lag screws SHALL NOT be fastened into the plywood only.

- Floors **shall** be sealed to minimize the generation of airborne particulates (TIA-569-E, 2019). This is extremely important for a long equipment service life. Concrete and wooden floors may be finished using vinyl flooring. Concrete floors may also be sealed with an epoxy coating or equivalent.
- Anti-static vinyl flooring is available for installations where equipment is vulnerable to electrostatic discharge (ESD). Care **shall** be taken when installing this type of flooring to ensure the integrity of the anti-static properties. Consult a contractor experienced with this type of flooring. See Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”, for more information.

3.6 Weatherproofing/Sealing

3.6.1 Transmission Line Entry

To route transmission lines and other cables into a building or shelter, use these appropriate entry methods:

- An entry port specifically designed for cabling.
- Non-metallic conduit, typically 102 mm or 127 mm (4 to 5 in.) diameter, allowing 50.8 mm (2 in.) protrusion at ends. If a non-metallic conduit is used, it **shall** be sealed using an appropriate all-weather silicone sealant between the conduit and the wall. The free space between the cables and the inside of the conduit should be packed with appropriate fiberglass or foam insulation.
- Roof/wall feed-through.

Observe the following for building or shelter transmission line and cable penetrations. See Figure 3-8 for an example of cable penetrations.

- Where a cable entry panel/plate assembly is used, it must be commercially manufactured and specifically designed for the purpose. These assemblies typically consist of a transmission line entry plate and boot assembly.
- The cable entry panel/plate assembly **shall** be installed per the manufacturer's instructions.
- Cable entry plates should have 102 mm or 127 mm (4 or 5 in.) diameter openings. The plate is usually made of painted aluminum, with one to twelve ports per plate. An example is shown in Figure 3-6.
- Densely populated buildings or shelters may require multiple cable entry panels.
- Cable entry panels **shall** be sized to meet current requirements and should be sized to accommodate future site expansion. See Figure 3-6 and 3-7.
- Cable boots corresponding to the cable diameter(s) **shall** be used. The openings of cable boots may be round, oval, or rectangular. Some cable boots allow multiple smaller cables to enter through a single boot. The boot usually comprises a two-piece cushion jacket, cushion (sized to cable diameter), and clamp set.
- To minimize heat loss from the building, two entry plates should be installed (one on the inside and one on the outside), with rigid foam insulation placed between them. (Two sets of boots are then required.)
- The building/shelter and the port attachment to the building/shelter **shall** be designed to prevent animals or birds from nesting in and around the entry ports. This is accomplished using the appropriate cable boots and caps for unused ports.
- Boots **shall** be made of a material unaffected by ozone, sunlight, extreme heat, and cold.
- All unused ports in the entry plate **shall** be sealed with blank caps supplied by the port manufacturer.
- If a metallic port is used, it **shall** be bonded to the grounding electrode system. An integrated cable entry panel **shall** be bonded to the external grounding electrode system.
- Tower lighting, tower control and signaling, and building grounding conductors **shall not** be routed through transmission line entry ports. Separate wall penetrations must be used for these cables and conductors. (See Figure 3-8.)

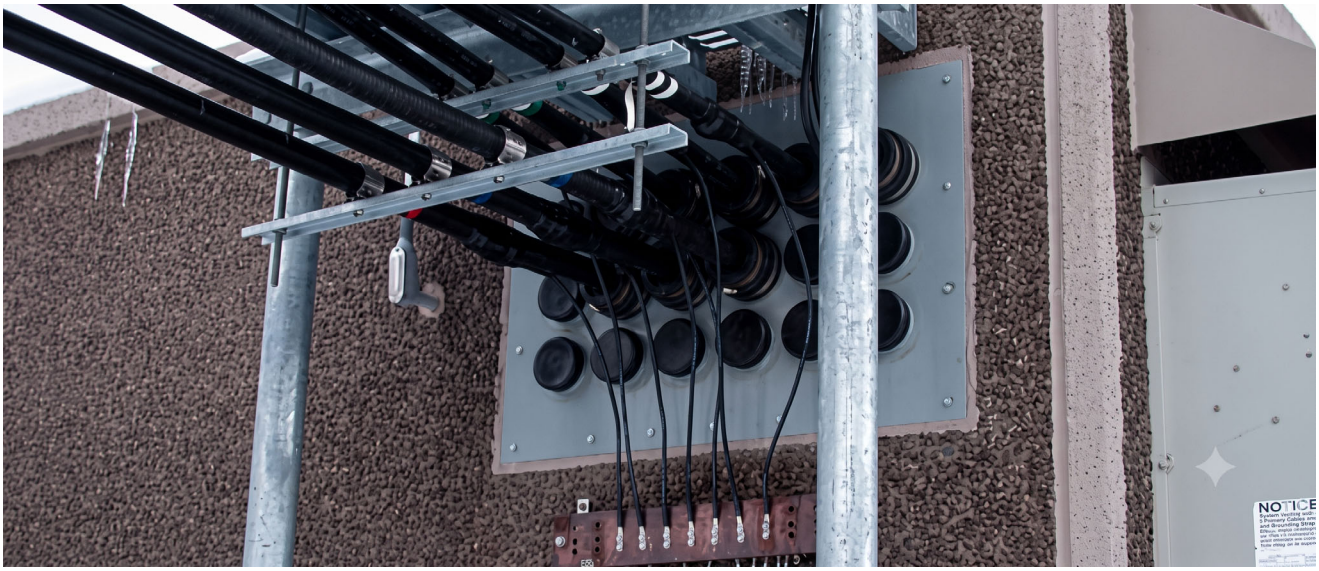


Figure 3-6. Typical Cable Entry Plate

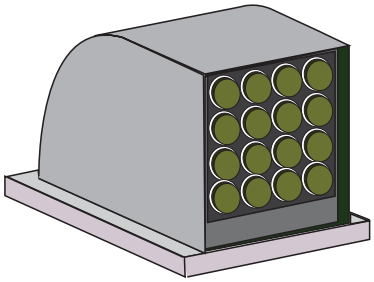


Figure 3-7. Typical Rooftop Cable Entry Assembly

NOTE: Roof penetrations should be completed by a qualified roofing contractor.

3.6.2 Conduit Entry

Some cables and conductors are routed through wall penetrations using a conduit. These penetrations should utilize a boot specifically designed for this purpose (see Figure 3-8, left image). The conduit boots seal the building penetration and protect against weather and insects. A correctly sized cable boot **shall** be used to seal the conduit to the cable (see Figure 3-8, right image).



Figure 3-8. Examples of Conduit Wall Penetration Boot (left) and Cable Boot (right)

3.6.3 Sealing of Buildings and Shelters

IMPORTANT: Keep the site area clear of debris and rubbish to prevent rodents from nesting.

All site buildings **shall** be weather-tight and **shall** deter entry by animals, birds, and insects.

3.6.3.1 Hantavirus Precautions

WARNING: The site may be contaminated with hantavirus if rodents are present or suspected. The site must first be cleaned and sanitized by a hazmat remediation company before any other work can begin.

Rodents and insects can pose health risks to personnel and damage equipment. Rodent droppings and urine can spread hantavirus, a deadly airborne virus. This risk is higher at remote sites (non-urban). Hantavirus infections can be fatal within days without emergency medical care. Sealing all exterior openings is the best way to prevent hantavirus at the site. Frequent hand washing and refraining from touching one's mouth and nose are good practices to follow when working at any site.

If rodents are present or suspected, the affected area **shall** be cleaned in a safe and sanitary manner before other activities begin in the site. Rodent waste removal and decontamination of sites should be carried out by professional companies that specialize in this area. These companies have the necessary equipment, such as HEPA vacuums, and utilize hospital-grade disinfectants to safely eliminate rodent droppings, urine, and nests.

For additional information on controlling the spread of hantavirus, see the Centers for Disease Control website:

http://www.cdc.gov/hantavirus

3.7 Heating, Ventilation, and Air Conditioning

A key consideration of site development is effective environmental control, achieved through the site's Heating, Ventilation, and Air Conditioning (HVAC) system, to allow for efficient equipment operation. The ambient temperature and humidity within the building or equipment room must be maintained within the range specified by the manufacturer for each piece of equipment. All Motorola Solutions products, and outsourced items, list temperature, humidity, and cleanliness requirements in their respective manuals.

Equipment manuals may specify either operating or ambient temperature. Operating temperature refers to the temperature within the equipment case, with the equipment operating at a given capacity or load. Ambient temperature refers to the environmental temperature typically measured 1.5 m (5 ft) above the floor in the center of an adjacent aisle.

In lieu of manufacturer environmental standards, the site HVAC system **shall** be capable of maintaining interior conditions of 18° to 27°C (64° to 81°F) (American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommendation) and 40% to 55% relative humidity (RH) (ATIS-0600321.2020, Section 4.1).

See APCO ANS 2.106.1-2019, section 3.12 for more information.

The variables involved in maintaining ambient temperatures include, but are not limited to, the following:

- Building construction
- Building size
- Type and amount of equipment installed at the site
- Ambient outside temperature
- Room size
- Number of entry ports (windows, doors, transmission line entry ports)

- Insulation
- Roof type (slope and construction material)
- Surrounding structures
- Use of a forced fresh air system
- Geographical location of the site

The facility backup generator **shall** be sized to accommodate the HVAC system. To prevent damage to the HVAC compressors from power fluctuations during site AC power cycling or standby generator cutover, it is recommended that a start-up delay kit be installed on the HVAC system.

An HVAC engineering firm or the equipment shelter manufacturer's engineer must determine the type and number of HVAC units required. Due to the many variables involved, a single HVAC specification is not applicable to all situations.

3.7.1 HVAC Design Considerations

Each site's HVAC requirements should be evaluated individually. Planning calculations should include an expansion factor of at least 25%, with consideration for future growth potential. For prefabricated buildings, the wall structure can sometimes be designed to allow for additional units to be added later to accommodate growth.

Consider the following when working with the HVAC contractor to design the HVAC system:

- Obtain thermal loading for each piece of equipment from the appropriate engineering personnel and provide it to the building manufacturer, HVAC engineering, or HVAC contractor. Motorola Solutions System Planners typically provide heat generation information in BTU and Watts.
- Obtain site specifications for construction materials, insulation type and R values, size, existing conditions, and predicted growth.
- In areas with a history of Seismic Design Category D or higher, the HVAC engineering firm or contractor **shall** address seismic considerations for the HVAC system. Additional flexible bracing can be provided to prevent HVAC equipment from tipping or shifting position. Flex hoses or semi-rigid hoses with strain relief should be provided to prevent mechanical stress failure.
- Only HVAC equipment that uses chlorofluorocarbon-free (CFC-free) coolant **shall** be used for new installations.
- The HVAC system should be alarmed. If the site has an alarm system, each HVAC unit installed at a site **shall** be connected to the building alarm system so that the total shutdown of any HVAC unit will result in an alarm.
- To ensure a clean environment and prevent dust and contaminants from entering electronic equipment, HVAC filters **shall** be used and maintained on a regular schedule.

3.7.1.1 Wall-Mounted HVAC Units

Observe the following general considerations for wall-mounted HVAC units. See Figure 3-9.



Figure 3-9. Typical Commercial Wall-Mounted Air Conditioning Unit

- Self-contained wall-mounted HVAC units are acceptable in most applications. Care should be taken when selecting the correct unit size for the projected BTU heat load.
- Only commercial-grade HVAC units **shall** be used. Consumer-grade household units or window-mounted units **shall not** be used.
- To reduce operating costs and prevent the compressors from freezing during cold weather, all units should be equipped with heating elements and an economizer that allows the site to be cooled by outside air if the outside temperature falls below a predetermined value.
- HVAC systems using outside air circulation features may not be suitable for environments having unusually high dust, high humidity, or particulate emissions.
- Redundant HVAC units **shall** be installed and available as a backup in case one unit fails, or a single unit may be used if it is alarmed to a remote terminal. All redundant HVAC units should be designed in a lead-lag configuration to cycle with the primary unit so that all units experience equal wear.
- If two HVAC units are required to provide sufficient cooling, one additional unit should suffice for redundancy.
- The HVAC units may need to have an automatic shutdown circuit installed in order to comply with local fire codes. This circuit would be triggered by the activation of the smoke or heat alarm.

3.7.1.2 Exhaust Fans

- A thermostatically-controlled exhaust fan may be recommended at some sites, to remove excessive heat buildup if air conditioning units are disabled or fail.
- Locate the exhaust fan as high as practicable in the structure to remove the maximum amount of heat.
- A corresponding filtered exterior cold air inlet vent with motorized louvers should be installed low on an opposing wall to allow unobstructed air flow through the site.
- The inlet of the fan **shall** be protected with a screen barrier to prevent the entry of insects, birds or animals.
- To prevent excessive dirt and/or humidity from entering the building, the exhaust fan is intended to be used only as an emergency backup.
- Battery and generator rooms require special attention regarding exhaust requirements. See “Battery Systems” on page 6-37 for additional information.

- Louvered entries into buildings or shelters may present a security risk due to ease of unauthorized entry through the louver assembly. This concern should be considered in the site's overall security plan.
- The design of motorized louver systems **shall** comply with NFPA shutdown requirements. Exhaust fans and HVAC systems **shall** automatically shut down and the exterior wall vents automatically close during fire alarm activation and fire suppressant release. See NFPA 12-2025 for additional information.

3.7.1.3 Heat Pumps

For facilities experiencing thermal loads exceeding wall-mounted unit capacities, the contracted HVAC engineering firm may specify commercial-grade heat pumps. The appropriateness of a heat pump system **shall** be determined by the contracted HVAC engineering firm or contractor. Heat pumps are also used in shared sites or where an exterior wall is not available for installation of a stand-alone HVAC unit. The compressor is separate from the control units and **shall** be mounted on either a pad on the roof of the structure or on a concrete pad outside the building.

Per NFPA 70-2026, Article 210.63, a 15- or 20- ampere receptacle outlet is required for heat pump maintenance. A ground fault circuit interrupter (GFCI) receptacle is also required within 7.5 m (25 ft) for maintenance. All units should be equipped with a start control option to avoid compressor damage during short power outages.

3.7.1.4 Thermostats

The placement and number of thermostats should be determined by the contracted HVAC engineering firm. Thermostats must be installed in locations that allow for optimal and uniform control of the room's ambient temperature.

3.7.1.5 Temperature Alarm

To prevent equipment damage and downtime, all sites must have high and low-temperature alarms integrated with the security and monitoring systems.

3.7.1.6 HVAC Hot and Cold Aisle Considerations

The hot aisle/cold aisle data center layout, a method for improving energy efficiency introduced by IBM in 1992, arranges equipment racks in alternating rows to manage airflow. Cool air is drawn into the front of the equipment, facing the cold aisle, while hot air is exhausted from the rear, facing the hot aisle. This design, commonly used with raised floors, enables efficient cooling. Computer Room Air Conditioner (CRAC) units deliver conditioned air into the subflooring and the air rises through floor tile perforations into the cold aisle(s), cooling the equipment. The hot exhaust air then rises in the hot aisles and returns to the CRAC unit intakes along the ceiling. See Figure 3-10.

The hot aisle/cold aisle layout can also be used in equipment rooms without raised floors and equipment shelters (or equivalent). Equipment racks can be organized so that the front faces a cold aisle and the back faces a hot aisle. This creates distinct hot and cold aisles, as hot air is exhausted toward the hot aisle. Return registers and ducts should be placed above the hot aisle.

Equipment rooms and shelters without raised floors can still utilize a hot aisle/cold aisle layout. By arranging equipment racks so that their fronts face a cold aisle and their backs face a hot aisle, distinct hot and cold aisles are created, as hot air is expelled towards the hot aisle. Return registers and ducts should be positioned above the hot aisle where practicable. This arrangement is not applicable to shelters and buildings with wall-mounted HVAC units.

See ATIS-0600336.2020, Telcordia GR-63-CORE, TIA-569-E, and TIA-942-C for more information.

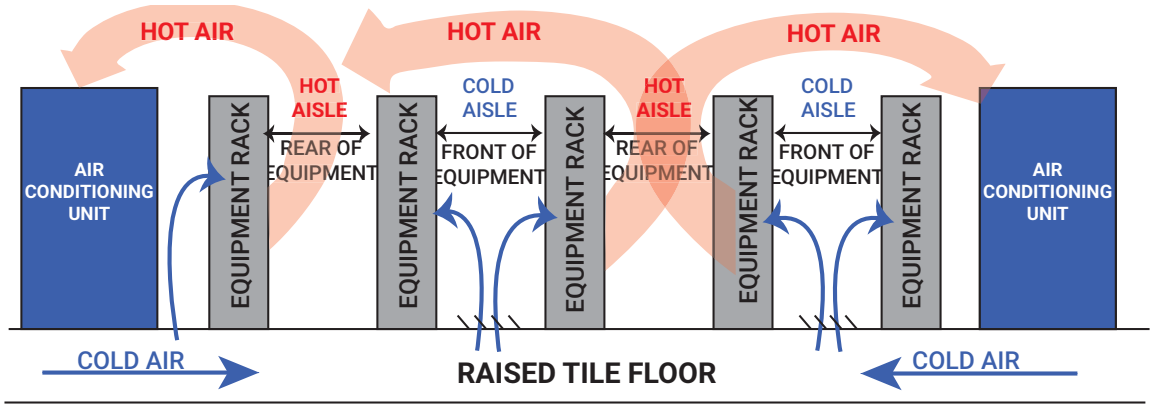


Figure 3-10. Hot and Cold Aisle HVAC Configuration Example

3.7.2 HVAC Maintenance

To ensure optimal performance, Motorola Solutions advises its customers to arrange routine maintenance with a local HVAC service provider. This maintenance should include regular cleaning and filter replacement. Additionally, for backup HVAC units that are not set to an equal-sharing duty cycle, the maintenance program should also include periodic exercise of the unit.

3.8 Cable Trays

This section details the requirements and installation guidelines for cable trays, which are used to support communications cabling within buildings and shelters.

Cable trays support cables between cabinets, relay racks and bays of equipment and help maintain adequate separation between the cable groups. The orderly separation and support of cable also simplifies maintenance. Cable management over relay racks and equipment cabinets can be accomplished by utilizing cable tray systems. These tray systems are designed to provide support, routing, parallel separation and securing of wires and cables as defined in “Cable Installation Within Cable Trays or Ladders” on page 9-34. As defined in NFPA 70-2026, Article 100, a cable tray or tray system is a unit or assembly of units or sections and associated fittings forming a rigid structural system used to securely fasten or support cables and raceways. See Figure 3-11.

3.8.1 Cable Tray Selection

Cable support can be provided by two types of overhead cable tray systems:

- Steel stringer-style ladder
- Aluminum or steel ladder-style cable tray

Steel stringer-style ladders come in various designs and styles. Typically, they are available in C-channel, tubular, and solid bar in painted or yellow zinc dichromate finishes. Stringers are typically 38.1 mm (1.5 in.) to 51 mm (2 in.) in depth and vary in length. Rungs should be spaced at least 229 mm (9 in.) apart. Simple hardware is used to make “T” and cross connections.

“J-bolts” (threaded, formed metal rods bent into a “J” shape) **shall not** be used as fasteners for cable trays. These rods typically deform when stressed, possibly allowing cable trays to drop. Captive hardware, such as threaded bolts, washers, and nuts, is recommended.

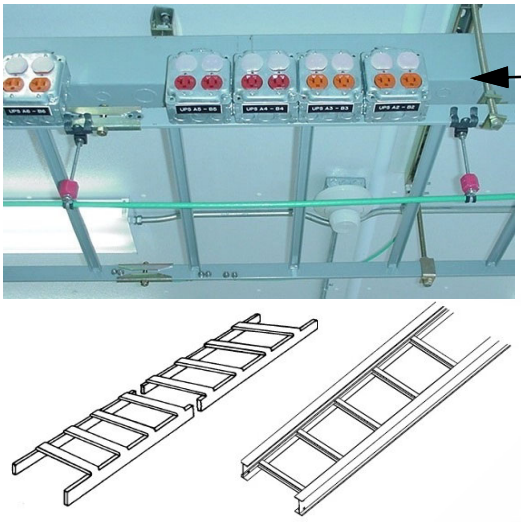
Aluminum or steel cable tray systems also come in various designs and styles such as ventilated trough, solid trough, and ladder type with “I” beam or C-channel side rails. The most practical is the ladder type. The major difference between the stringer style ladders and tray systems is that a tray has a side rail or wall height from 102 mm (4 in.) to 178 mm (7 in.). This load depth may be desirable for large bundles of cables or transmission line routing. The side rail height affects overall rack to cable tray to ceiling dimension restrictions as outlined in this chapter. A rung spacing of 229 mm (9 in.) is also recommended for this tray type. This type of tray system requires prefabricated Ts, bends, crosses and reducers, which must be factored into the system design.

Both types of trays are available in widths ranging from 102 mm (4 in.) to 1.06 m (42 in.). Typically, widths of 457 mm (18 in.) and 610 mm (24 in.) are used. Stacking of trays is allowed, but a minimum clearance or headroom of 200 mm (8 in.) **shall** be maintained above each tray, with a recommended clearance of 300 mm (12 in.) (TIA-569-E, section 9.7.3.1).

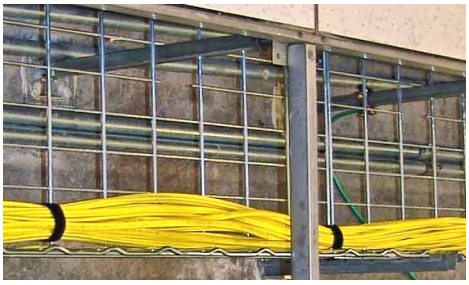
The overall sizes of cables, number of cables, and number of cable groups required in a run **shall** be considered when specifying tray width. Account for a minimum of 152.4 mm (6 in.) loss of width for cable group spacing.

If connecting aluminum and steel cable tray systems together, use appropriate connection and bonding devices to prevent corrosion.

NOTE: In all cases the width of the cable tray **shall not** be less than 457 mm (18 in.) and is recommended to be 610 mm (24 in.) wide.



Solid Steel Painted Type
AC receptacles are supported by the raceway, not the cable tray



Flexible Steel Wire Type

Extruded Aluminum Types

Figure 3-11. Typical Cable Tray Types

3.8.2 Cable Management Under Raised Floors

A welded wire mesh cable tray system is recommended for cable management under raised computer room floors. This type of tray system can be mounted to, or suspended from, raised floor pedestals or sub flooring. This tray system typically consists of high strength steel wire in a 50 x 100 mm (2 x 4 in.) mesh. The finishes can be electro-plated zinc galvanized or stainless steel, both suitable for all environments. Bends can be fashioned by cutting the mesh with a bolt cutting tool and simple hardware connections to the wire mesh. Manufacturers can supply bonding terminations and outboard ground cable supports for tray system grounding and bonding. See Figure 3-12 for an example.

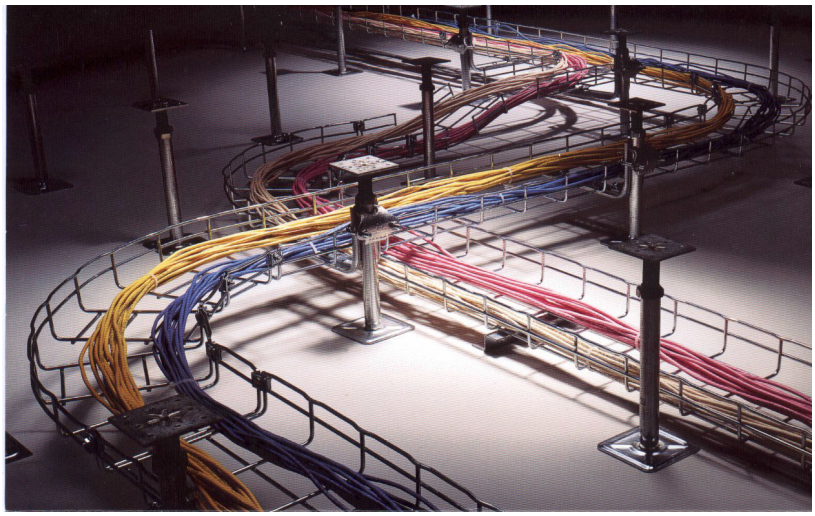


Figure 3-12. Typical Wire-Mesh Cable Runway

3.8.3 Wire-Mesh Cable Trays

In general, observe the following when selecting and installing wire-mesh cable trays:

- The cable tray **shall** be listed.
- The cable tray **shall** be installed per the manufacturer's instructions.
- The cable tray **shall** be supported at the required intervals, as per the manufacturer instructions.
- The wire mesh tray should be listed for use as an equipment grounding conductor. (This eliminates the need to install a bonding jumper at each junction.)
- The wire mesh tray sections **shall** be joined using manufacturer-approved fastening hardware.
- The wire-mesh tray **shall** be bonded to the Internal Bonding and Grounding system (see Chapter 5, "Internal Bonding and Grounding (Earthing)", for more information.

3.8.4 Cable Tray Layout and Design

The following requirements and considerations must be observed when preparing the layout of cable trays:

- Noting the number of cables to be supported by each run, cable tray width **shall** be selected to provide 50.8 mm (2 in.) minimum separation between cable groups. Cable tray systems may need to be stacked in some installations to provide space for the anticipated cables.
- The size, weight and projected expansion of the system **shall** be considered.
- The number and function of conductors to be placed within a cable tray **shall** be considered.
- Cable trays designed specifically for communications are recommended rather than standard electrical cable trays.
- The cable tray system **shall** use the sections as designed by the manufacturer. Straight sections, elbows, tees, dropouts and expansion connectors **shall** be used as required within the system.
- The cable tray system **shall** be designed with suitable strength and rigidity to provide adequate support for all cabling contained within.
- Due to thermal contraction and expansion, cable tray systems may require expansion connectors.
- If the building has a sprinkler system, ensure the cable trays do not block the sprinklers.
- Cable trays **shall not** be placed under smoke or heat detectors.

- The cable tray system **must** be designed to accommodate cable distribution across the equipment area. It is essential to maintain the continuity of the cable tray system and to support the cables.
- Cable trays and troughs may extend through walls or floors, provided that the installation is designed to prevent any potential increase in the spread of fire or combustion products.
- Openings through fire-rated partitions, floors, or ceilings **shall** be firestopped using an approved method to maintain the fire resistance rating (TIA-569-E, section 9.7.3.1).
- Factors such as ceiling height, light fixture locations, cable entry panels, equipment location, and minimum cable bending radius must be considered during design and layout.
- Cable trays should not be placed under lights or electrical fixtures or boxes.
- A minimum of 152.4 mm (6 in.) between the top of an equipment rack/cabinet and the bottom of the cable tray **shall** be maintained where practicable.
- The minimum distance between the top of the cable tray and the ceiling **shall** be 200 mm (8 in.), however, 305 mm (12 in.) is recommended (ANSI/TIA-569-E, section 9.7.3). If at an existing site with a lower ceiling, good engineering practices are required.
- Where AC power distribution is to be combined with the cable tray system, the AC power raceway **shall not** be supported by the cable tray system unless the cable tray system is manufactured and approved for this purpose. The AC power raceway may be supported by a trapeze arrangement with the cable tray attached to the top of the trapeze and the AC power raceway attached to the bottom of the trapeze. The trapeze arrangement is supported from the ceiling and/or sidewalls. See NFPA 70-2026, Articles 110.3(B) and 392.18(G) for more information.
- Steel stringer and steel tray systems may utilize an extended post for attaching grounding conductors outside the tray. This post should extend 102 mm (4 in.) to 152.4 mm (6 in.) either horizontally or vertically from the side rail of the tray, with no less than 457 mm (18 in.) of spacing between posts.

3.8.5 Cable Tray Installation

Observe the following general requirements and considerations when installing cable trays:

- The entire system **shall** be rigid, immovable, and secured in place.
- The cable tray system **shall** be installed per the manufacturer's specifications, NFPA 70-2026, Article 392, and local codes.
- Cable trays **shall** be securely supported to the ceiling or wall such that they are immovable. These supports **shall** provide a strength and working load capacity sufficient to meet the load requirement of the cable tray system.

NOTE: Cable trays **shall not** be supported by equipment racks.

- Cable tray installation may have additional requirements for active seismic areas (Seismic Design Category D or higher), such as wooden headers at wall connections. It is recommended in these cases that cable tray ends be attached to walls using a 50.8 mm x 102 mm (2 x 4 in.) wooden header. The header may be nailed along the wall approximately 305 mm (12 in.) below the ceiling. This provides a blunt attachment point which will prevent the sharp ends of cable trays from penetrating the walls. Seams between multiple cable tray sections run across a room should be staggered so that, if a seam fails, the entire cable ladder system will not fail.
- Unless otherwise specified by the manufacturer, cable tray supports **shall** be placed within 2 feet of the ends and joints between two sections, with additional supports placed every 1.5 m (5 ft) (BICSI N1-2019, section 6.2.2.2 and TIA-569-E, sections 9.7.2 and 9.8).
- Cable tray systems **shall not** be used as incidental support for other raceways or equipment.

- Cable trays **shall** be positioned such that they are easily accessible with sufficient space provided above and around the cable tray to permit adequate access for installation and maintenance of cables.
- Cable trays **shall not** have any sharp edges, burrs or projections that may damage cables (TIA-569-E, section 9.7.3.1).
- All cable tray sections **shall** be electrically bonded together by an approved method and connected to the building ground system. See Figure 3-13 and Chapter 5, "Internal Bonding and Grounding (Earthing)", for additional information.

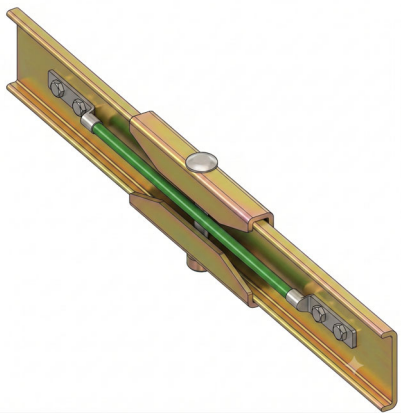


Figure 3-13. Cable Tray Bonding Conductor

3.8.6 Cable Tray Safety Considerations

The following cable tray safety considerations **shall** be observed:

- The cable tray system **shall** be installed per the manufacturer's specifications, NFPA 70-2026, Article 392, and local codes.
- Cable tray systems **shall not** be installed at heights or in positions that pose a hazard to service personnel working within the site.
- Cable trays and cable runways **shall not** be used as walkways or ladders (TIA-569-E, section 9.7.3.1).
- Threaded support rods **shall not** extend below the tray bottom further than the required fittings and **shall** include appropriate protective end caps.

3.9 Lighting

All lighting **shall** follow the applicable requirements of NFPA 70-2026, Article 410, and any other applicable local code requirements. Interior lighting requirements are based upon several considerations, including:

- Adequate lighting for a safe and efficient work environment. Placement should ensure illumination behind tall rack cabinets.
- Energy efficient design
- Low heat generation characteristics
- Exterior lighting requirements are concerned with lighting for points of entry and exit from the building and for perimeter security.
- Remote site lighting can be visible for miles and may lead to complaints from neighbors. To prevent this, use on-demand lighting systems, like infrared proximity sensors or twist-knob timers. Bright lights, including those used on photocell controllers, may also cause complaints from neighbors and environmentalists.
- Incandescent, fluorescent or Light Emitting Diode (LED) lighting may be used.

3.9.1 General Interior Lighting Specifications

In locations considered hazardous because the atmosphere does or may contain gas, vapor or dust in explosive quantities, special application fixtures **shall** be used. These fixtures **shall** be rated for use in areas classified as Class I, II and III and Division 1 and 2, as applicable. These fixtures **shall** comply with NFPA 70-2026, Articles 500 through 506.

In applications where fixtures are susceptible to being dislodged or where tube breakage may represent a hazard to personnel or equipment, shatterproof fluorescent tubes or shielded safety lamps **shall** be used. Seismic and industrial practices require that fluorescent lamp protectors be installed over lighting to prevent falling glass or accidental damage to lamps.

If incandescent lighting is used, industrial-grade protective covers **shall** be used.

3.9.2 Interior Lighting Quality

Interior lighting **shall** produce a minimum of 500 Lux (50 foot-candles) measured 1 m (39.4 in.) above the finished floor in the middle of all aisles between cabinets or racks. See TIA-569-E, section 6.3.6.1.5 for additional information.

3.9.3 Emergency Interior Lighting

- All emergency lights **shall** be UL approved and meet all OSHA, NFPA 101, and any other applicable code requirements.
- All equipment shelters and tenant improvement equipment rooms within a building **shall** have emergency backup lighting units installed that will activate immediately upon loss of AC power.
  - Each unit **shall** be equipped with a self-test button or switch.
  - Each unit **shall** have a minimum of two lamps.
  - Batteries **shall** be sealed and maintenance-free, and **shall** provide a minimum of 90 minutes of emergency power.
- Emergency lights installed in harsh environments must have the appropriate NEMA rating and meet the requirements of the authority having jurisdiction.
- The lights **shall** illuminate all doorways and exits.
- Exits **shall** be labeled with illuminated signs reading EXIT. Pathways to exits **shall** be marked.
- Emergency lighting in high-rise buildings may need to be connected to the building's master alarm system and powered by the building's main power supply.

3.9.4 Exterior Lighting

- One exterior light **shall** be installed near the door to provide lighting for personnel entering and exiting an equipment shelter. The fixture **shall** be type NEMA 3, weather resistant and suitable for general outdoor application.
- If floodlights are installed to provide yard/perimeter security lighting, the following requirements **shall** be met:
  - UL approved Quartz, High Pressure Sodium or Light Emitting Diode (LED) lighting elements **shall** be used.
  - Mercury Vapor and Metal Halide lamps **shall not** be used. These lamps can cause serious skin burns and eye inflammation from short-wave ultraviolet radiation if the outer envelope of the lamp is broken or punctured.
  - An automatic photo-control switch, with a manual override, can be used to turn the lights on at dusk and off at dawn if desired.
  - Fixtures **shall** be NEMA-rated and UL (or equivalent) listed for use in wet locations.

3.10 Fire Protection and Safety

WARNING: The first priority when suppressing a fire at a communication site is to protect human life; equipment protection is secondary. If a manual fire extinguisher can completely put out the fire, then it can be used. However, attempting to suppress a fire to save equipment should never be done at the risk of personnel safety. In all cases of fire in occupied shared buildings, the fire department and tenants must be notified immediately.

Fire extinguishers can represent an important segment of any overall fire protection program. An effective fire suppression program depends upon the following general requirements:

- Extinguishers must be of the correct type and size for a fire that may occur.
- Extinguishers must be correctly located and clearly identified.
- Extinguishers must be in working order and properly maintained.
- Employees must understand how to operate the extinguishers.
- Safety awareness training has been made available.

3.10.1 Reference Publications

The following are suggested reference publications regarding fire suppression systems:

- NFPA 1: Fire Code
- NFPA 10: Standard for Portable Fire Extinguishers
- NFPA 12: Standard on Carbon Dioxide Extinguishing Systems
- NFPA 13: Standard for the Installation of Sprinkler Systems
- NFPA 17: Standard for Dry Chemical Extinguishing System
- NFPA 2001: Standard on Clean Agent Fire Extinguishing Systems
- CAN-ULC-S503-2025: Standard for Carbon Dioxide Hand and Wheeled Fire Extinguishers
- CAN-ULC-S504-2025 Standard for Dry Chemical Fire Extinguishers
- UL 154: Carbon Dioxide Fire Extinguishers
- UL 299: Dry Chemical Fire Extinguishers
- UL 711: Rating and Fire Testing of Fire Extinguishers

3.10.2 Training and Usage of Fire Protection Equipment

Site personnel **shall** be familiar with the use of all fire protection equipment provided at the site, and documentation for that equipment **shall** be available to all personnel. Responsible personnel **shall** fully understand the content of the equipment documentation.

More complicated systems, such as an installed automatic system, should be supported with training supplied by the vendor.

3.10.3 Fire Classifications

The National Fire Protection Association standard 10 (NFPA 10) contains information on the following fire classifications and portable fire extinguishers. Refer to NFPA 10 for additional information.

In general, fires are classified according to the type of combustible material that is consumed. Table 3-2 lists the classifications:

Table 3-2. Fire Classifications

Class	Symbols		Description
Class A Fire	A		Fires in ordinary combustible materials, such as wood, cloth, paper, rubber and many plastics.
Class B Fire	B		Fires in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols and flammable gases.
Class C Fire	C		Fires that involve energized electrical equipment where the electrical non-conductivity of the extinguishing medium is required.
Class D Fire	D	**N/A**	Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.

Portable fire extinguishers are classified by a letter indicating the class of fire on which they are effective. This is sometimes followed by a rating number that shows the relative extinguishing effectiveness on Class A and Class B fires. Class C and Class D extinguishers typically do not require a rating number.

Modern portable fire extinguishers typically use a picture labeling system to designate the type of fire for which the extinguisher is suitable. Examples are shown in Figure 3-14.



Figure 3-14. Fire Classification Labeling Examples

Instructions are typically provided on the fire extinguisher label or with permanently installed fire suppression systems. It is important that site personnel be familiar with the location and type of extinguishers available at the site.

The example in Figure 3-15 uses the acronym “PASS” to describe the following actions typically performed with a handheld fire extinguisher.

1. Pull the pin. Hold the extinguisher with the nozzle pointing away from you and release the locking mechanism.
2. Aim low. Point the extinguisher at the base of the fire.
3. Squeeze the lever slowly and evenly.
4. Sweep the nozzle from side-to-side.

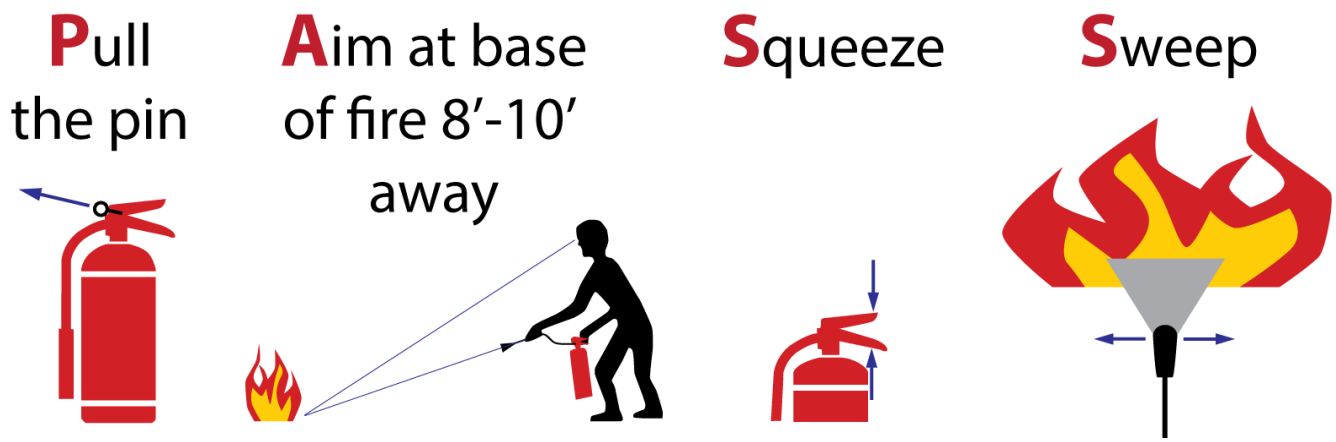


Figure 3-15. Example of PASS Instructions for Fire Extinguisher Use

3.10.4 Portable Extinguishers

WARNING: The Fire Department SHALL be notified as soon as a fire is discovered.

CAUTION: Fixed or portable fire suppression systems using water SHALL NOT be used in communication sites.

IMPORTANT: Portable fire extinguishers **shall** be inspected as required by the manufacturer and the authority having jurisdiction.

3.10.4.1 Minimum Required Fire Extinguishers

IMPORTANT: Local codes **shall** determine minimum required fire extinguishers, in addition to the requirements listed in this section.

IMPORTANT: The presence of an Automatic Suppression System does not negate the need for portable fire extinguishers.

All communications facilities **shall** have a correctly installed portable fire extinguisher on the premises before equipment is installed at the site. At a minimum, building code typically requires a Class ABC portable fire extinguisher with a UL/ULC rating of 2-A:10-B:C for general fire fighting purposes.

An FE-36™ or CO_2 (or equivalent agent) Class BC fire extinguisher with a minimum UL/ULC rating of 10-B:C **shall** be correctly installed in electronic equipment rooms/areas for equipment firefighting purposes. These extinguisher types minimize secondary damage caused by dry chemical agents used in most Class ABC rated extinguishers.

CAUTION: The fine, alkaline-based powders in dry chemical agents can cause severe corrosion, potentially damaging not only the involved equipment but also any other electronic devices at the site.

IMPORTANT: Dry chemical extinguishers can obscure visibility in a closed room, making egress difficult. A dry chemical type extinguisher should only be considered as a second line of defense if the fire cannot be extinguished with an equipment-friendly Class BC type portable fire extinguisher.

NOTE: If an FE-36™ or equivalent clean-agent type portable fire extinguisher is sized to meet Class ABC requirements, a second Class BC portable fire extinguisher is not required.

The following minimum size, classification and UL/ULC rating of portable fire extinguishers **shall** be available at the facility or within the room/area where communications equipment is installed:

- 9 kg (20 lb), Class ABC, UL/ULC rating 2-A:10-B:C
- 3.2 kg (7 lb), Class BC, UL/ULC rating 5-B:C

NOTE: Review the requirements of NFPA 10 or applicable jurisdictional/ local regulations to determine the need for additional extinguishers based on site size and special considerations. Depending on the size of the site building, additional extinguishers may be required.

3.10.4.2 Required Standards for Portable Fire Extinguishers

Portable fire extinguishers **shall** be listed and labeled, **shall** meet or exceed all requirements of the fire test standards, and **shall** meet the appropriate performance standards listed in this section.

- Fire Test Standards: UL 711 Edition 8 (2023 revision), CAN/ULC-S508-2023
- Performance Standards:
  - Carbon Dioxide Types: UL 154 Edition 10 (2025), CAN-ULC-503-2025A
  - Dry Chemical Types: UL 299 Edition 12 (2025), CAN-ULC-504-2025
  - Halocarbon Clean Agent Types: UL 2129 Edition 3 (2025), CAN-ULC-566-2025A

3.10.4.3 Fire Extinguisher Comparisons

Extinguishers commonly used at communication sites are listed in Table 3-3, with advantages and disadvantages.

Table 3-3. Portable Fire Extinguisher Comparisons

Type	Advantages	Disadvantages
Dry Chemical Extinguishers		
Dry Chemical	• Fast flame knockdown characteristics enable the dry chemical to reach and surround nearly everything in the vicinity of the discharge. • Typically have an ABC rating and are safe for use on structural, fuel, and energized electronic equipment fires. • No adverse environmental impact.	• Dry chemical agents have corrosive properties that can be harmful to electronic equipment and other equipment in the general area. • A dry chemical fire extinguisher containing ammonium compounds **shall not** be used on oxidizers that contain chlorine. The reaction between the oxidizer and the ammonium salts can produce an explosive compound. • When discharged in an enclosed or confined space, dry chemical extinguishers limit visibility, cause breathing problems and clog air filtration systems. • Cleanup can be time consuming and costly.
Clean Agent Extinguishers		
FE-36™ (HFC-236fa)	• Environmentally friendly replacement for Halon™ 1211 portable extinguishers • Depending on size, the extinguishing unit can be rated for an ABC classification and discharged from up to 4.9 m (16 ft) away from fire. • The agent is dispersed as a stream of gas and liquid droplets, physically removing heat and chemically stopping combustion. • Electrically nonconductive, residue-free, will not cause thermal shock damage to equipment. • Zero potential for ozone depletion and moderate ratings for potential climate change impact and atmospheric lifetime.	• May not be readily attainable or easily refilled in certain areas. • Typically much more costly to purchase and maintain than dry chemical extinguishers. • When released under fire conditions, hydrofluoric acid (HF) can be produced.
Carbon Dioxide (CO_2)	• Uses a clean gaseous extinguishing agent, with proven reliability. • Normally available in BC classification. Can safely be used on electronic equipment without leaving any residue. • No special environmental impact. • Normally easy to obtain. Inexpensive recharge.	• Limited effective range, typically between 0.92 to 2.4 m (3 to 8 ft), and is affected by draft and wind. Initial application must start reasonably close to the fire. • Usage displaces oxygen, posing a suffocation hazard in confined areas. • Carbon dioxide can form carbonic acid if it comes in contact with moisture.

3.10.4.4 Fire Extinguisher Installation

Fire extinguisher installation and maintenance **shall** meet the following requirements (see NFPA 10 for more information):

- Portable fire extinguishers **shall** be maintained in a fully charged and operable condition and **shall** be stored in their designated places at all times when they are not being used.
- Fire extinguishers **shall** be conspicuously located, readily accessible, and immediately available in the event of a fire. Preferably, extinguishers **shall** be located along normal paths of travel, including exits from areas.
- Fire extinguisher locations **shall** be clearly marked. Acceptable means of identifying the fire extinguisher locations include arrows, lights, signs or coding of the wall or column.
- If more than one fire extinguisher is in the same location and they are intended for different classes of fires, the intended use of each extinguisher **shall** be marked conspicuously to aid in choosing the correct extinguisher in the event of a fire.
- Cabinets housing fire extinguishers **shall not** be locked.
- Fire extinguishers **shall not** be obstructed from view.
- Portable fire extinguishers (other than wheeled types) **shall** be securely installed in the hanger or the bracket supplied, or placed in cabinets or wall recesses. The hanger or bracket **shall** be securely anchored to the mounting surface in accordance with the manufacturer's instructions.
- Fire extinguishers installed in areas where they are subject to dislodgment **shall** be installed in brackets specifically designed to retain the extinguisher.
- Fire extinguishers having a gross weight not exceeding 18.1 kg (40 lb) **shall** be installed so the top of the fire extinguisher is not more than 1.52 m (5 ft) above the floor.
- Fire extinguishers having a gross weight greater than 18.1 kg (40 lb) (excluding wheeled types) **shall** be so installed that the top of the fire extinguisher is not more than 1.07 m (3.5 ft) above the floor.
- In no case **shall** the clearance between the bottom of the fire extinguisher and the floor be less than 102 mm (4 in.).
- Extinguisher operating instructions **shall** be located on the front of the extinguisher and be clearly visible. Hazardous materials identification systems (HMIS) labels, six-year maintenance labels, hydrotest labels, or other labels **shall not** be located or placed on the front of the extinguisher.
- Fire extinguishers mounted in cabinets or wall recesses **shall** be placed so that the fire extinguisher operating instructions face outward. The location of such extinguishers **shall** be conspicuously marked.

IMPORTANT: Portable Fire Extinguishers **shall** be installed according to the authority having jurisdiction.

3.10.5 Fixed Fire Detection, Alarm, and Suppression Systems

CAUTION: Fixed or portable fire suppression systems using water SHALL NOT be used in communication sites.

This section specifies minimum requirements for fixed fire detection, alarm, and suppression (FFDAS) systems. For additional requirements, see NFPA 12, NFPA 13, NFPA 75, and NFPA 2001 as applicable, and any local code requirements that may apply. Specifically, fixed systems comprise the following:

- Detection systems
- Alarm systems
- Automatic suppression systems

Installation of these systems **shall** be performed by certified personnel with specialized skills in this work, typically a contractor specializing in these systems. This information is provided to assist personnel responsible for purchasing, inspecting, testing, approving, operating, and maintaining this equipment when consulting with a fire protection engineering firm.

Some communications sites feature detectors and alarms that relay information to a centralized control center. High-rise buildings often utilize a second dedicated facility alarm and can be included as part of a central alarm system connected to the local fire department.

3.10.5.1 Automatic Fire Detection

Automatic fire detection **shall** be accomplished by any listed or approved method or device capable of detecting and indicating heat, flame, smoke, combustible vapors, or an abnormal condition in the controlled area that is likely to produce fire. On large installations, the fire detection system **shall** have a combination of ionization smoke detector and a rate-compensated fixed temperature thermal detector. This type of two-loop detection system will provide a positive verification of a fire condition and the earliest possible pre-alarm notification. The detector units **shall** conform to UL 268 standards (or equivalent). If the fire detection system shuts off power to the installation, battery-operated emergency light sources **shall** be provided in the affected areas.

3.10.5.2 Automatic Alarms

Automatic audible or visual alarms (or both) indicate the operation of the FFDAS system, hazards to occupants, or failure of any supervised device. The number, type (audible or visual), and location of the indicators **shall** be such that all occupying personnel will be alerted. At a minimum, the FFDAS system **shall** provide an initial warning signal for occupants to evacuate and confirm a fire condition. A secondary alarm system **shall** sound, indicating the automatic discharge of an extinguishing agent. The system **shall** allow a time delay between the two warning signals, adjustable to provide adequate time for evacuation or abort procedures.

3.10.5.3 Site Alarm Switch Form

Site alarms are defined as any action, reaction or determination related to diagnostics, security, or emergencies. All equipment that provides alarms will send alarms from the equipment utilizing dry-contact closures. The dry contact closures will conform to Form-C configuration, providing Common, Normally-Open and Normally-Closed contacts. The outputs will not be referenced to either ground or any voltage potential.

3.10.5.4 Automatic Suppression Systems

Automatic suppression systems automatically discharge fire-extinguishing agents when a fire condition is detected. With the use of control panels, directional valves, and flow control equipment, these systems can be used to protect against one or more hazards or groups of hazards. For multiple close-proximity hazards (for example, an
A-class fire or B-class fire) simultaneously involved in a fire, separate individual suppression systems **shall** be used and configured to discharge at the same time. Another option is to protect them with a single system that is sized and arranged to simultaneously discharge on all potentially involved hazards that have indicated an alarm condition. A qualified fire protection engineer **shall** be consulted when designing automatic extinguishing systems.

If an overhead water sprinkler system is used, it **shall** be the “dry pipe” type. Upon detecting a fire condition, a “dry pipe” system removes power to the room and then opens a master valve to fill the overhead sprinklers. These systems sometimes use a primary suppressor, such as CO_2, that is released before the sprinkler system is activated. Dry pipe systems can have enough delay so that a manual reset can be provided, if allowed. This system is preferable to a “wet” type system, which has the risk of water leakage and resulting equipment damage, and can potentially use contaminated water that has been stored in overhead pipes for extended periods.

Sites with water sprinkler systems that have power connections beneath raised floors **shall** use waterproof electrical receptacles and connections below the raised floor.

IMPORTANT: The presence of an automatic fire suppression system does not negate the need for portable fire extinguishers.

An example of an automatic fire suppression system is shown in Figure 3-16.

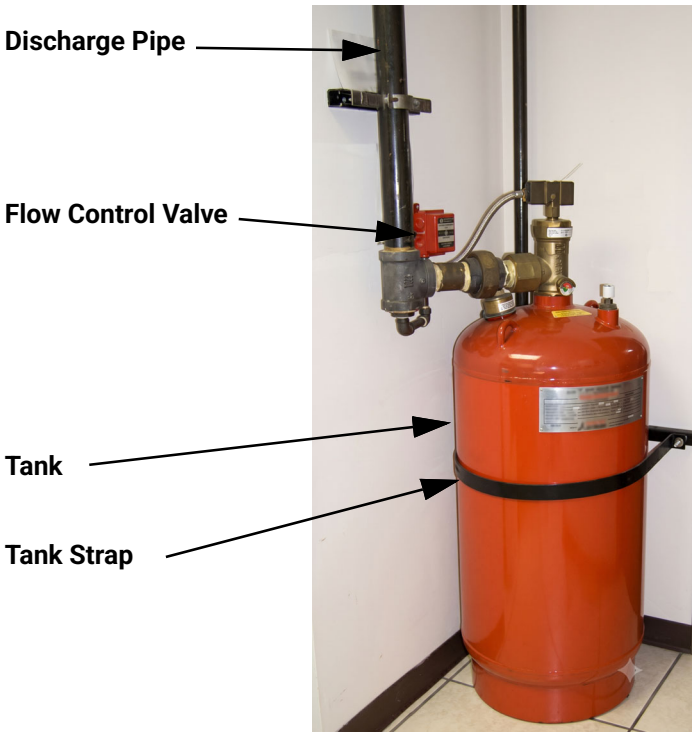


Figure 3-16. Example of Automatic Suppression System

3.10.6 Warning Signs

Appropriate warning signs **shall** be affixed outside of areas where concentrations of extinguishing gases can accumulate. This should not be limited to just protected spaces but also in the adjacent areas where the gases could migrate or leak (such as the storage room for the gas containers, adjacent rooms and hallways). There **shall** be a warning sign posted at the entrance to the protected area and inside the protected space. An example is provided in Figure 3-17.



Figure 3-17. Example of Warning Signs

3.10.7 Power Sources

The primary power source for the fire extinguishing system's operation and control **shall** have the capacity for intended service and **shall** be reliable. Where failure of the primary power source would jeopardize the protection provided, a secondary (standby) power source **shall** supply energy to operate the system for a period of 24 hours and be capable of operating the extinguishing system continuously for the full designed discharge period. The secondary (standby) power **shall** automatically transfer to operate the system within 30 seconds of the loss of primary power.

3.10.8 Fixed Systems Comparison

If a new system is being installed or an existing fixed fire-extinguishing system is being replaced, check with local fire protection authorities and a competent fire protection engineer first. Have available details on the building's material composition, occupancy, surrounding environment, and any equipment requiring protection. Request their suggestions for suitable extinguishing systems, including the pros and cons of each system.

Some of the more common fixed systems currently used at communication sites are listed in Table 3-4. The advantages and disadvantages of each type are also described.

Table 3-4. Fire Suppression Systems

Type	Advantages	Disadvantages
Water Extinguishing (Water Sprinkler)	• Upon detecting a fire condition, a “dry pipe” type of system removes power to the room and then opens a master valve to fill the overhead sprinklers. (The “dry pipe” system is preferable to a “wet pipe” system, which has the chance of water leakage and resultant equipment damage and possible electrical shock.)· • No adverse environmental impact.	• If power connections are made beneath raised floors, waterproof electrical receptacles and connections are required. • Either type of water sprinkler system can cause damage to electronic equipment and will require an extensive cleanup effort. • Upon discharge, system downtime can be lengthy.
Clean Agent Extinguishing System		
FE-13™ (HFC-23)	• Environmentally friendly replacement of Halon™ 1301-based systems. • Advantage over CO_2 systems, due to FE-13 lack of oxygen displacement characteristic. • Electrically nonconductive and residue-free. No cleanup is required after discharge. System downtime can be minimized. • The storage cylinder(s) may be stored away from the protected area. • Storage cylinders can be stored in a wide range of temperatures; containers do not need to be stored in a protected place at room temperature. • System recharge is less expensive than alternative fluorocarbon agents.	• May not be readily attainable or easily refilled in certain areas. • Typically much more costly to purchase and maintain than water systems. • When released under fire conditions, hydrofluoric acid (HF) can be produced.
FM-200™ (HFC-227ea)	• Environmentally friendly replacement of Halon 1301-based systems. • Less toxic than Halon 1301. • Electrically nonconductive and residue-free; no cleanup is required after discharge. System downtime can be kept to a minimum. • When compared to Halon 1301, FM200 systems require minimal additional storage space on the floor.	• System recharge can be more expensive than other types of extinguishing agents. • When released under fire conditions, hydrofluoric acid (HF) can be produced.
INERGEN™ (IG-541)	• Environmentally friendly replacement of Halon 1301-based systems. It has no Ozone Depleting Potential, Global Warming Potential or Atmospheric Lifetime. • No toxic or corrosive decomposition products. • Electrically nonconductive and residue-free; no cleanup is required after discharge. System downtime can be minimized. • Because INERGEN is stored as a gas, it can be stored at a substantial distance from the risk area, where more space is available.	When compared with Halon 1301 and FM200 systems, INERGEN systems require more cylinders and additional storage space on the floor.

3.11 Safety Equipment

The safety equipment described in the following subsections **shall** be permanently located inside all equipment shelters and in or within close proximity to tenant improvement equipment rooms.

NOTE: It is recommended that all employees obtain formal training and certification in First Aid and cardiopulmonary resuscitation (CPR).

3.11.1 First Aid Kit

Because many communications facilities are located in areas far from medical help, a first aid kit **shall** be present at every site.

- All first aid kits, case, and contents **shall** meet or exceed the specifications of ANSI / ISEA Z308.1.
- All first aid kits **shall** be mounted in a conspicuous, easily-accessible location.
- The first aid kit case **shall** be durable and rustproof and **shall** allow for wall mounting.

3.11.2 Typical Battery Safety Kit

Depending on the type of batteries used, a safety kit may be required within the battery area (check with the battery manufacturer). An example is shown in Figure 3-18.

Where required by OSHA or applicable local codes, the following equipment **shall** be supplied:

- A lightweight, acid resistant bib-type apron. The bib-type apron **shall** be permanently stored onsite near the battery plant. The fabric **shall** be acid, caustic, puncture resistant and flame resistant.
- An acid resistant, full face shield. The face shield **shall** be permanently stored onsite near the battery plant. The shield **shall** meet all requirements of ANSI Z87.1-2025. Protective eyewear that does not provide full face protection **shall not** be allowed.
- One pair of acid resistant gloves. The gloves **shall** be permanently stored onsite near the battery plant. These gloves **shall** be of sufficient length to cover the hand, wrist and forearm for protection from chemical splash.
- One 0.5 kg (1 lb) box of baking soda or equivalent acid neutralizing compound and water. The compound and water **shall** be permanently stored onsite near the battery plant.
- An OSHA-approved emergency eyewash station. The eyewash station **shall** be permanently mounted near the battery plant. The eyewash station **shall** use an isotonic saline wash capable of neutralizing acids or caustics and **shall** be able to flush the eye for 15 minutes. A plumbed eyewash station and a shower should be provided in battery areas if practicable.
- Any other items required by OSHA or the authority having jurisdiction.



Figure 3-18. Examples of Battery Safety Kit

IMPORTANT: Discard and replace bottled eyewash solution according to the expiration date on the bottle. Only appropriate eyewash solution **shall** be used.

3.12 Onsite Communications

Some form of two-way communications **shall** be available at each facility for safety reasons and for performing maintenance and troubleshooting. Many outages occur after hours, and normally, only one technician is dispatched to perform repairs. Cellular phones may only be used if there is known coverage at the location.

- Important numbers **shall** be posted inside, on or near the entrance door. Phone numbers include, but are not limited to:
  - Police, ambulance, and fire personnel
  - Site owner
- For maintenance and troubleshooting, a telephone or microwave orderwire is invaluable, if monitored. In most cases, the technician must contact a central support group and/or a computer to obtain help.
- Onsite communication between personnel on the ground and any personnel working on a tower **shall** be maintained at all times.

3.13 Signage

An equipment room entrance door, roof entrance door, shelter, enclosure, tower or site compound **shall** be posted with signs identifying the site and providing notices and warnings. The types of site signage **shall** be in accordance with national, state and jurisdictional/local regulations.

Signs containing general required notices, along with spaces for custom information, are commercially available and should be used. Warning signs containing the appropriate information and symbols are also commercially available and should be used.

NOTE: Additional signage may be required during construction, especially if dust or fumes may be present. Check with the authority having jurisdiction for local regulations that may apply, such as Proposition 65 warnings required in the state of California.

3.13.1 Minimum Required Signage

Signage **shall** be posted as required by the authority having jurisdiction. Signage should be installed five feet above the ground (APCO ANS 2.106.1-2019, section 3.2.2.4). Appropriate signage **shall** be posted during all phases of site planning, construction, and operation. Warning signs **shall** meet or exceed industry standards, such as ANSI, OSHA, and ISO 7010 (see APCO ANS 2.106.1-2019, section 3.2.2.4).

At a minimum, sites which are not continuously supervised **shall** post the following:

- **Authorized Personnel Only - No Trespassing**

  Mandatory legal requirements exist in which signage must be conspicuously posted to warn against unauthorized access to the site. This is to not only deter crime but to help in showing criminal intent. The maximum distance between signs should be 50 feet (APCO ANS 2.106.1-2019, section 3.2.2.4).
  See Figure 3-19.



Figure 3-19. Example of "No Trespassing" Sign

- **Emergency Contact Identification**
  - The site **shall** have conspicuous signage containing the site identification and emergency contact information. The signage should not indicate site ownership or operational purpose; the intent is to avoid governmental targeting (APCO ANS 2.106.1-2019, section 3.2.2.4). For an example, see Figure 3-20.
  - Permit or licensing information (as assigned by the Federal Communications Commission or other equivalent) **shall** also be included.



Figure 3-20. Typical Entity Identification Sign

- **Battery Area Signage**

WARNING: NFPA-compliant signs warning of battery electrolyte reactivity with water SHALL be posted.

  - Appropriate hazard diamond signage compliant with NFPA 704-2027 section 4.1.5 and Figure 9.1(a) **shall** be present on doors leading to battery rooms and within the room itself, notifying personnel of explosion, chemical and electrical hazards within the area, as well as battery electrolyte reactivity with water. For an example, see Figure 3-21.
  - NO SMOKING" signs **shall** be prominently displayed in the battery room and on the exterior of the battery room entry door. Smoking and any other spark-producing materials or activities **shall** be strictly prohibited in this area.

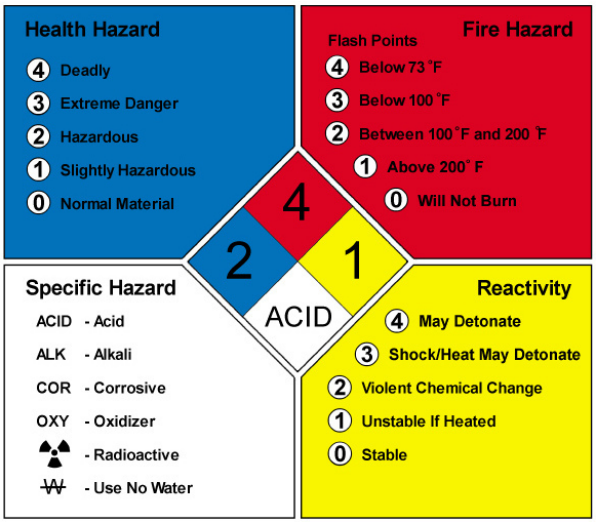


Figure 3-21. Example of Warning Signage for Specific Hazards

3.13.2 Additional Signage

- Depending on the site's function, additional signage may be required. These signs typically notify of potential hazards associated with authorized or unauthorized site entry.
- Site design engineers **shall** evaluate the facility for high-voltage and RF energy emission hazards to determine necessary warning signage.
- See Appendix A, "Electromagnetic Energy Information", for additional information regarding EME signage.



Figure 3-22. Typical RF Warning Sign

3.14 Site Security

The physical security of mission-critical and public safety sites is crucial for protecting both emergency responders and the community. This helps ensure that these vital resources operate and function at their highest level during the greatest times of need. See APCO ANS 2.106.1-2019, section 3.2 for more information.

Buildings and shelters **shall** be enclosed by a locked chain-link fence to deter unauthorized access and enhance security. This fence **shall** encompass the entire site, including the building, tower, and fuel storage. Fencing is particularly crucial in publicly accessible areas and for any site components located outside restricted zones.

NOTE: Fencing is not required in restricted areas or within an existing fenced area. It is only necessary around site components that are accessible to the public and located outside of restricted areas.

The fence acts as a clear boundary, warning and deterring potential intruders. It also delays access and helps establish criminal intent in the case of intrusion. Clear zones on both sides of the fence improve visibility and hinder potential concealment for intruders.

The fencing system **shall** be constructed from commercial-grade materials and meet the following requirements (see APCO ANS 2.106.1-2019, section 3.2.2 for more information):

- 9-gauge galvanized fabric, 1,290 lbf breaking strength.
- 1-inch mesh (max 2-inch) with anti-cut, anti-climb material.
- Bottom buried to prevent penetration.
- Minimum 8 feet height (7 feet fabric, 1 foot barbed wire angled out).
- Top with razor wire or 1 foot of 3-strand, 4-barbed wire (12 gauge) angled out at 45 degrees.
- Schedule 40 welded pipe frame, minimum 2.875 inches diameter.
- Frame posts and bracing on secure side of fencing.
- Top rail secured to fabric.
- Design considers weather and wind load.
- If chain link is not possible, install an 8-foot high non-scalable wall.

Furthermore, the site should have remote cameras monitoring both the exterior and interior, including access points and vulnerable areas. The camera feeds should be accessible from the NOC/SOC and/or local law enforcement. A remote video recording system, triggered by motion or events, should also be implemented. Lastly, a local audible alarm, controllable from the NOC/SOC, should be installed for additional security.

It is also recommended to implement a video surveillance system covering the perimeter of the fenced area and key access points. This will enhance security monitoring and provide a record of activities at the site. See APCO ANS 2.106.1-2019 for more information.

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CHAPTER

4

External Grounding (Earthing) and Bonding

This chapter provides requirements and guidelines for designing and installing the external grounding (earthing) and bonding system at a communications site. The requirements and guidelines in this chapter are provided to enhance personnel safety and equipment reliability.

This chapter provides information on the following topics:

- "Introduction to External Grounding (Earthing) and Bonding" on page 4-1
- "Grounding System Types" on page 4-3
- "Lightning Activity and Exposure" on page 4-4
- "Site Type Classification Definitions" on page 4-6
- "Common Grounding" on page 4-7
- "Grounding System Component and Installation Requirements" on page 4-9
- "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38
- "Dissimilar Metals and Corrosion Control" on page 4-55
- "Bonding to the External Grounding and Bonding System" on page 4-61
- "Minimum Site Grounding (Earthing) Requirements" on page 4-79
- "Bonding of RF Preamplifiers and Other Active Devices on Towers" on page 4-102
- "Grounding and Bonding of RF Transmission Lines and Communications Cables" on page 4-104
- "Metallic Objects Requiring Bonding" on page 4-108
- "Grounding Roof-Mounted Antenna Masts and Metal Support Structures" on page 4-124
- "Grounding Side-Mounted Antennas" on page 4-129
- "Grounding (Earthing) Rooftop-Mounted Tower Structures" on page 4-131
- "Special Grounding (Earthing) and Bonding Applications" on page 4-135
- "Special Situations" on page 4-149

NOTE: Throughout this chapter the terms "grounding" and "earthing" are used interchangeably.

NOTE: NFPA 70 is also known as the *National Electrical Code*® or *NEC*®. NFPA 780 is the *Standard for the Installation of Lightning Protection Systems*.

4.1 Introduction to External Grounding (Earthing) and Bonding

Grounding, as defined by NFPA 70-2026, Article 100, involves connecting to the earth or a conductive extension of it. Bonding, also defined in the same source, refers to creating electrical continuity and conductivity through connections.

At communication sites, safeguarding personnel and protecting delicate electronic devices from ground faults, lightning, ground potential rise, electrical surges, and power quality issues is paramount. While electrical occurrences, such as lightning strikes and power surges, are unavoidable, this chapter provides guidance on the design and installation of grounding and bonding systems for these sites, aiming to minimize potential damage.

This chapter outlines the external grounding and bonding requirements and guidelines derived from local and national codes, broadly recognized industry standards, and established engineering principles. These codes and standards are sourced from organizations including, but not limited to, the following:

- Alliance for Telecommunications Industry Solutions (ATIS)
- American National Standards Institute (ANSI)
- APCO International
- Australian Standards® (AS)
- British Standards Institution (BSi)
- Canadian Standards Association (CSA)
- International Association of Electrical Inspectors (IAEI)
- International Electrotechnical Commission (IEC)
- International Telecommunication Union (ITU)
- Institute of Electrical and Electronics Engineers (IEEE)
- National Fire Protection Association (NFPA)
- Telcordia
- Telecommunications Industry Association (TIA)
- Underwriters Laboratories (UL)
- United States Department of Defense (DoD)
- United States Federal Aviation Administration (FAA)
- United States National Weather Service (NWS)

References to specific industry codes and standards are provided throughout the chapter.

WARNING: The AC power system ground SHALL be sized appropriately for the electrical service and SHALL be approved by the authority having jurisdiction (AHJ).

CAUTION: Grounding and bonding alone are insufficient to adequately protect a communications site. Surge Protective Devices (SPD) must be included at a communications site to ensure sufficient protection. See Chapter 7, "Surge Protective Devices," for details and requirements.

IMPORTANT: Local codes and other codes enforced by the AHJ **shall** take precedence over the requirements of this manual. The more stringent requirement **shall** be followed.

NOTE: The phrases "neat and workmanlike" and "professional and skillful" are used interchangeably.

A grounding electrode system must maintain a low electrical impedance with conductors that are sufficiently large to handle high fault currents. The lower the impedance of the grounding electrode system, the more effectively it can dissipate high-energy impulses into the earth.

All site development and equipment installation work **shall** comply with all applicable codes established by the authority having jurisdiction (AHJ). Grounding systems **shall** be installed in a professional and skillful manner (ATIS-0600313.2019(R2024), section 11.1; ATIS-0600334.2019(R2024), section 13.1; IEC 60364-1:2005, section 134; NFPA 70-2026, Article 110.12; and NFPA 780-2026, section 1.5.1). In the event of a conflict, the more stringent requirement **shall** be followed.

Unusual site conditions may require additional effort to achieve an effectively bonded and grounded site. See "Special Situations" on page 4-149 for these instances. Consultation with Motorola Solutions Engineering or an engineering firm specializing in grounding electrode system design is recommended.

Some benefits of a properly designed and installed low-impedance grounding electrode system are outlined as follows (see ATIS-0600333.2013(S2023), section 4; ATIS-0600334.2019(R2024), section 5.1; BS 7430:2026; IEC 60364-1:2005; IEEE 142-2007, section 1.3; IEEE 1100-2005, section 3.3.1; IEEE 3003.1-2019, section 1.3; ITU Earthing and Bonding Handbook, section 2.1.2; and NFPA 70-2026, Article 250.4, for additional information):

- To help limit the voltages caused by lightning.
- To provide a path to earth for the discharge of lightning strikes in a manner that protects the structure, its occupants, and the equipment inside.
- To help limit the voltage caused by accidental contact of the site AC supply conductors with conductors of higher voltage.
- To help dissipate electrical surges and faults, and to minimize the chances of injury from grounding system potential differences.
- To help maintain a low potential difference between exposed metallic objects.
- To stabilize the AC voltage relative to the earth under normal conditions.
- To contribute to reliable equipment operation.
- To decrease noise in signal and control circuits by minimizing the voltage differentials between different signal reference subsystems.
- To provide a common signal reference ground.

A recommended best practice is to design the grounding electrode system with test wells at specific locations to easily monitor components or portions of the grounding electrode system using a clamp-on ohmmeter. Such locations could be test wells at the base of radials (see Figure D-1), test wells at the connection before a ground rod array (see Figure D-16), test wells over electrolytic ground rod connecting conductors, etc.

IMPORTANT: Local codes and other regulations enforced by the authority having jurisdiction (AHJ) **shall** take precedence over the requirements of this manual. The more stringent requirements **shall** be followed.

4.2 Grounding System Types

IEC 60364 recognizes five grounding (earthing) system types:

- Terra Neutral-Separate (TN-S)
- Terra Neutral-Combined-Separate (TN-C-S)
- Terra Terra (TT)
- Terra Neutral-Combined (TN-C)
- Isolated Terra (IT)

The focus of this chapter is TN-C-S and TN-S, for low-voltage AC distribution systems less than or equal to 1000 V. Figure 4-1 shows an example of TN-C-S Protective Multiple Earth Neutral (PME) or Multiple Earth Neutral (MEN). Figure 4-2 shows an example of TN-S separated earthing.

NOTE: France, Denmark and Japan use TT systems. Older T-N-S (two-wire) distribution remains in some parts of Europe, Africa and the Middle East. Two-wire distribution should not be used to facilitate power to Motorola Solutions network equipment without the use of an onsite isolation transformer in order to create the Protective Earth (PE).

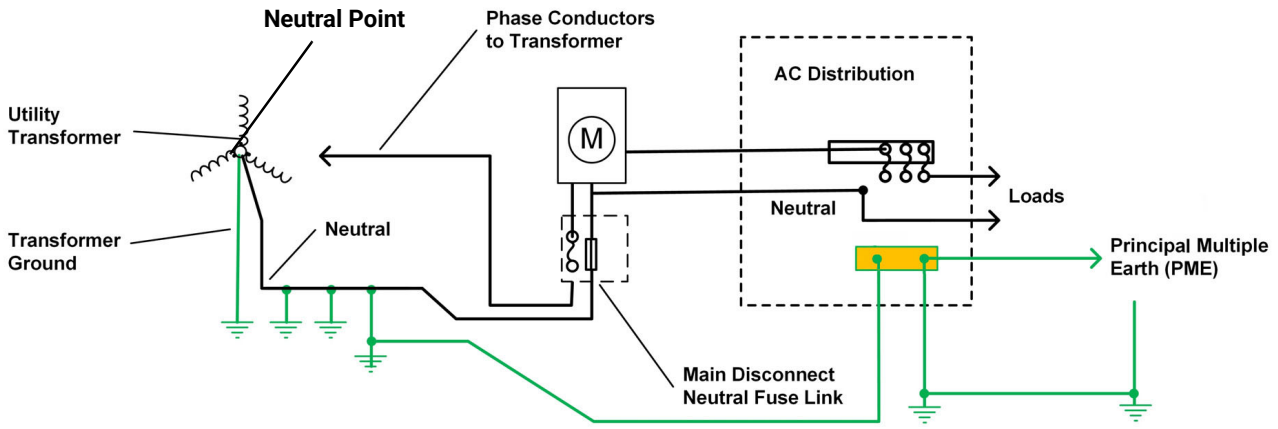


Figure 4-1. TN-C-S Protective Multiple Earth or Multiple Earth Neutral

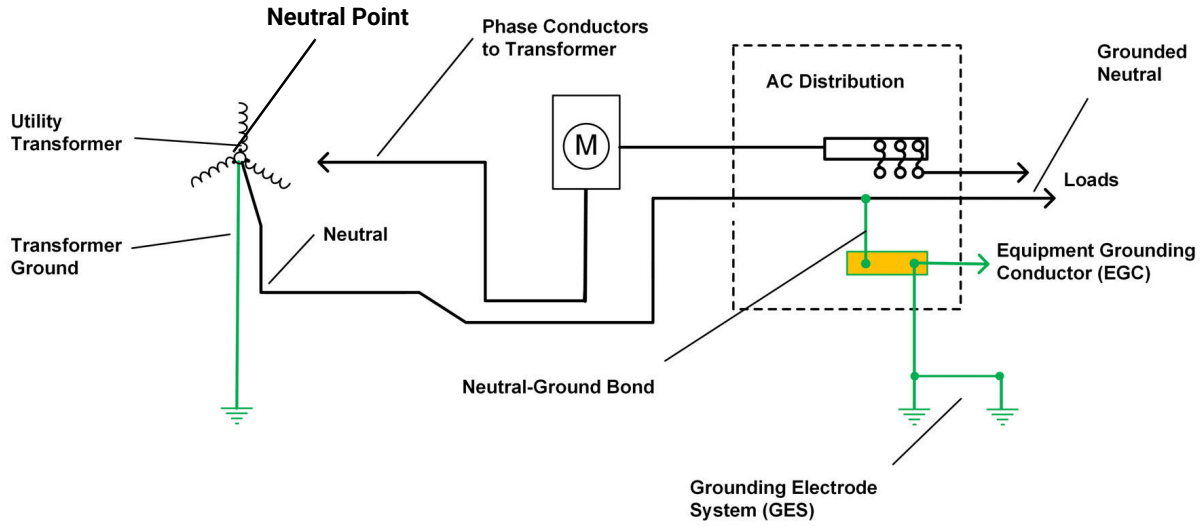


Figure 4-2. TN-S Separated Earth Neutral North America

4.3 Lightning Activity and Exposure

Communication facilities are considered exposed to lightning unless both of the following conditions are met: the ground flash density averages 0.3 flashes/km²/year or fewer, and the earth resistivity at the site is less than 100 ohm-meters (Ω-m). Soil resistivity must be measured according to IEEE 81-2025 (ATIS-0600313.2019(R2024), section 5.1.1). Refer to Appendix B, “Soil Resistivity Measurements” for detailed measurement methods.

Figure 4-3 is a map representing typical lightning activity worldwide. This figure is for general informational and educational purposes only and does not indicate current or future lightning activity. The average number of lightning occurrences in any given area varies significantly from year to year. For the most accurate and current maps, see the Vaisala Interactive Global Lightning Density Map: https://interactive-lightning-map.vaisala.com/

WARNING: Personnel SHALL NOT work on a tower or in the equipment building during an electrical storm (IEEE 1692-2023, section 12).

NOTE: In this manual, high-lightning areas are areas with lightning flash density greater than two (2) flashes/km^2/year.

NOTE: Refer to NFPA 780-2026, Annex M, for information on personal safety from lightning.

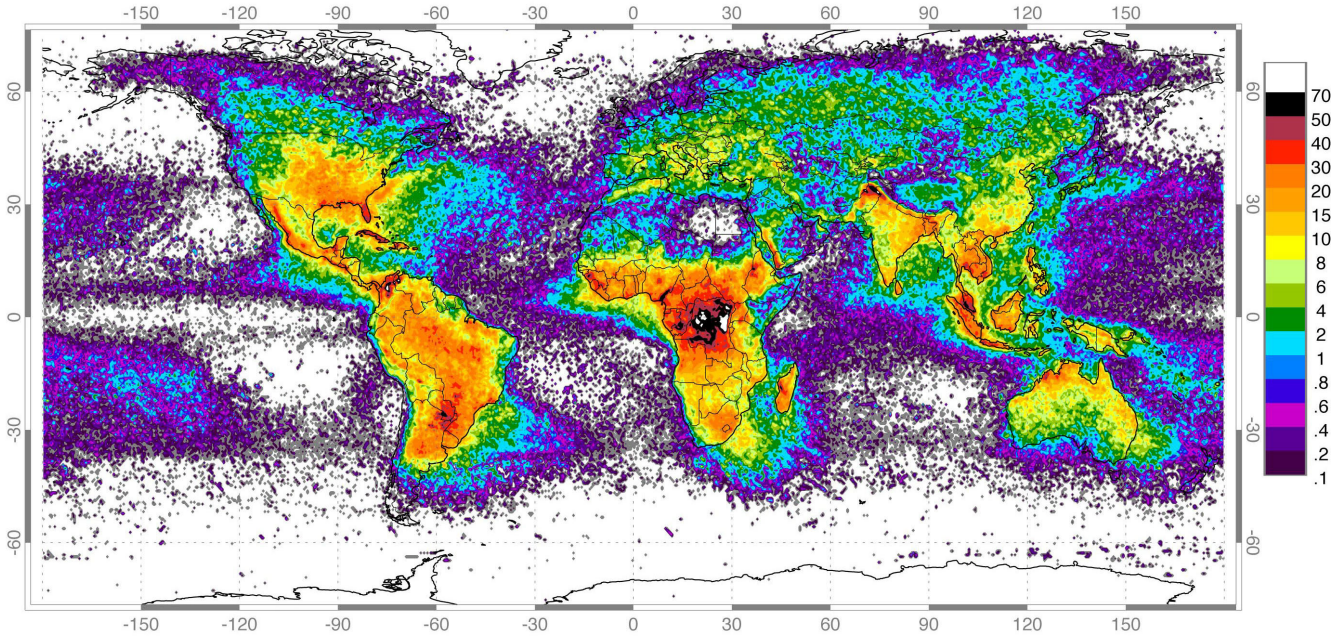


Figure 4-3. Lightning Activity, Flash Density (Flashes per Square Kilometer per Year)

Table 4-1 presents the relationship between the number of thunderstorm days per year and the number of lightning flashes per square kilometer per year.

Table 4-1. Relationship Between Thunderstorm Days per Year and Lightning Flashes per Square Kilometer per Year

Thunderstorm days per year	Flashes per square kilometer per year		Flashes per square mile per year	
	Mean	Limits	Mean	Limits
5	0.2	0.1 to 0.5	0.5	0.25 to 1.35
10	0.5	0.15 to 1	1.29	0.38 to 2.59
20	1.1	0.3 to 3	2.84	0.77 to 7.77
30	1.9	0.6 to 5	4.92	1.55 to 13
40	2.8	0.8 to 8	7.25	2 to 20.7
Source: BS 6651:1999, Table 6				

Table 4-1. Relationship Between Thunderstorm Days per Year and Lightning Flashes per Square Kilometer per Year (continued)

Thunderstorm days per year	Flashes per square kilometer per year		Flashes per square mile per year	
	Mean	Limits	Mean	Limits
50	3.7	1.2 to 10	9.58	3.1 to 25.9
60	4.7	1.8 to 12	12.17	4.66 to 31
80	6.9	3 to 17	17.87	7.8 to 44
100	9.2	4 to 20	23.82	10.36 to 51.8
Source: BS 6651:1999, Table 6				

Communications facilities situated at elevations significantly higher than the average height of the surrounding terrain (such as hilltops, fire towers, airport control towers, and high-rise buildings) **shall** be deemed exposed to lightning, irrespective of thunderstorm activity and earth resistivity (ATIS-0600313.2019(R2024), section 5.1.1).

Communications facilities with a tower **shall** be considered exposed, irrespective of thunderstorm activity and soil resistivity. Due to their very construction, radio antennas and towers are regarded as exposed to the potentially damaging effects of lightning. Tall structures such as towers, buildings, and antenna masts serve as favorable discharge points for lightning strikes. (ATIS-0600313.2019(R2024), section 5.2.3)

Some communications facilities may be classified as unexposed if the building and tower are within the zone of protection of a taller structure. Only a qualified engineer should determine if the communications facility is unexposed. Standards that the engineer can use to help assess communications facility lightning exposure include CSA B72:20, IEC 62305-3, and NFPA 780.

4.3.1 High Lightning Geographic Region Defined

Geographic regions with a lightning flash density exceeding two (2) flashes/km²/year are defined as high-lightning areas in this manual.

4.3.2 High Soil Resistivity Defined

High soil resistivity is defined as exceeding 25,000 ohm-cm (see TIA-607-E, section C.3).

4.4 Site Type Classification Definitions

Communications sites vary and may serve different purposes; therefore, the required protection level also varies. Communications sites are classified into three general categories based on their function and required protection levels: Light Duty (Type A), Standard Duty (Type B), and Extra Duty (Type B2). Light Duty sites do not require the extensive grounding electrode system mandated for Standard Duty or Extra Duty sites, nor do they mandate as low a value of grounding electrode system resistance as Standard Duty or Extra Duty sites. Refer to TIA-607-E, section D.2.3, for more information.

The general site characteristics are listed in the following sections.

4.4.1 Light Duty (Type A)

Light Duty sites have the following general characteristics:

- The site is not considered exposed to lightning. See “Grounding System Types” on page 4-3.
- No tower is associated with the site
- Single control station or remote control

- Single voting receiver site
- Point-to-Point/Multi-point radio
- Wireless Access Points
- Electronic equipment installed at the site does not require an extensive grounding electrode system

See 4.10.3.1 “Type “A” Sites: Light Duty,” on page 4-81 for more information.

4.4.2 Standard Duty (Type B)

If any of the following apply, the site should be considered a ***Standard Duty*** site:

- The site is considered exposed to lightning. See “Grounding System Types” on page 4-3.
- A tower is associated with the site
- The site houses public safety or *mission critical* installations
- The site is a 911 or other communications dispatch center (without a co-located tower)
- The site is part of a large system installation

See 4.10.3.2 “Type “B” Sites: Standard Duty,” on page 4-82 for more information.

4.4.3 Extra Duty (Type B2)

Extra Duty sites typically fall into two general categories:

- Sites that are normally occupied and have a co-located tower.
  Examples: communications dispatch centers or 911 emergency dispatch centers.
- Sites with a co-located tower that contain electronic equipment necessary for operating other wide-area communications sites. A failure at this site typically results in performance degradation or loss of communications at other sites. This type of site may be referred to as a *Master*, *Core,* or *Prime* site.

Extra Duty sites have the following general characteristics:

- Communications dispatch center with a co-located tower
- 911 emergency dispatch center with a co-located tower
- Master or Core site with a co-located tower
- Prime site with a co-located tower

See 4.10.3.3 “Type “B2” Sites: Extra Duty,” on page 4-82 for more information.

4.5 Common Grounding



WARNING: Failing to interconnect all grounding electrode systems at a communications site can create hazardous potential differences, potentially causing injury to personnel and/or equipment failure.

At a communication site, all grounding electrodes **shall** be bonded together to create a single grounding electrode system. This includes grounding electrodes for power, communications, and lightning protection, which **shall** be effectively and permanently bonded together (IEEE 1100-2005, section 8.5).

Specifically, the following **shall** be bonded together, if present:

- The AC power system ground
- The communications tower ground
- The lightning protection system ground

- The telephone system ground
- Exposed structural building steel (metal framework)
- Underground metallic piping entering the facility
- Any other existing grounding electrode system present.

This requirement is detailed in multiple standards (ATIS-0600313.2019)R2024), section 7; ATIS-0600333.2013(S2023), section 5.1; ATIS-0600334.2019(R2024), section 5.3; IEC 62305-3:2024, section 6.2; ITU Earthing and Bonding Handbook, section 3.1; IEEE 1100-2005; IEEE 1692-2023; NFPA 70-2026, Articles 250.58, 250.104, 250.106, and 750; NFPA 780-2026, section 4.13; and Telcordia GR-3171-CORE.i02).

Various underground metallic piping systems, such as water service, well casings (within 7.6 m or 25 ft of the building), gas piping, underground conduits, and liquefied petroleum gas systems, are common. Gas line interconnections **shall** occur on the customer's side of the meter (IEC 60364-5-54:2011, section 542.2.6 and Annex B; and NFPA 780-2026, section 4.13.6.1).

See Figure 4-4 for a common grounding example.

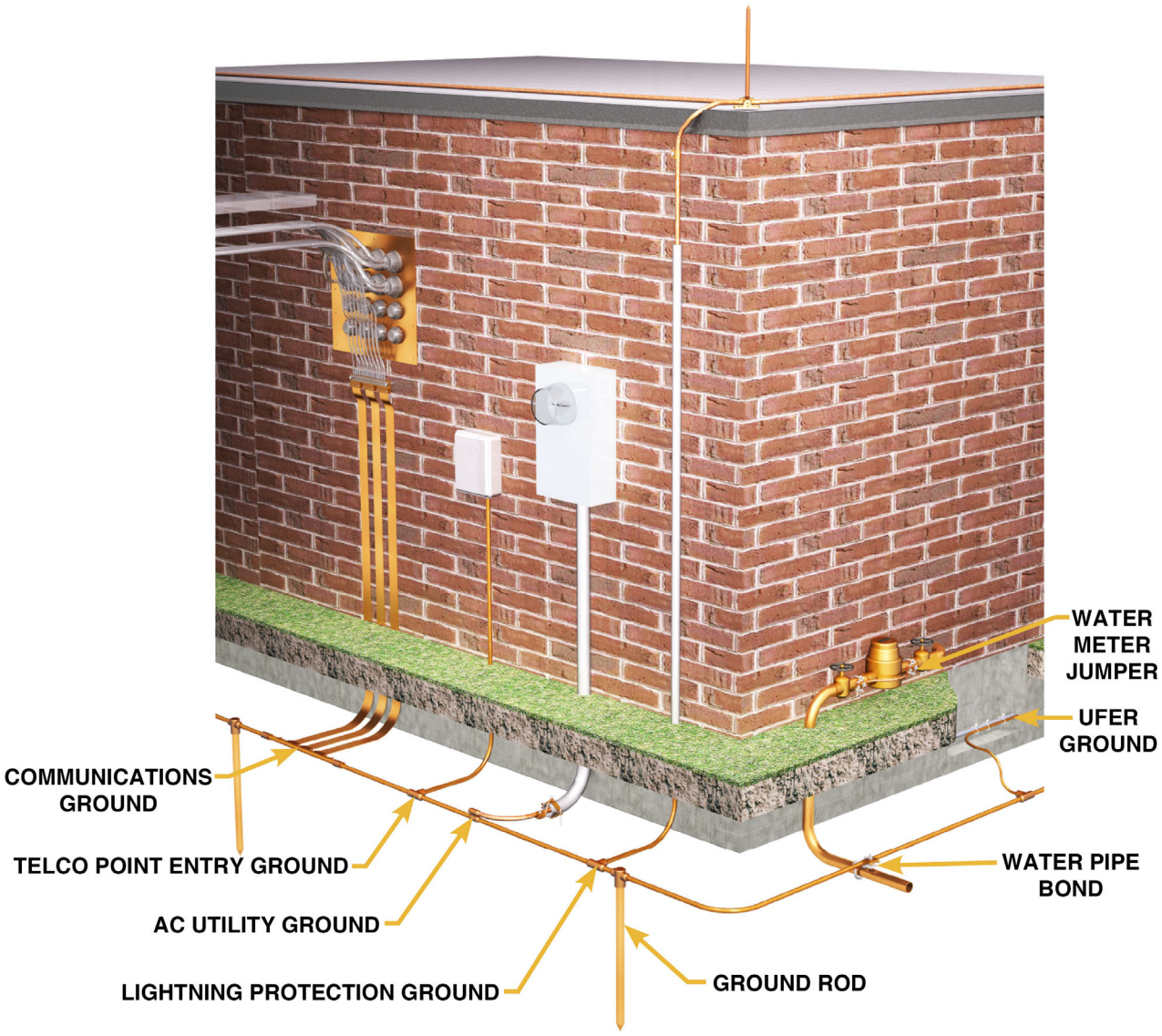
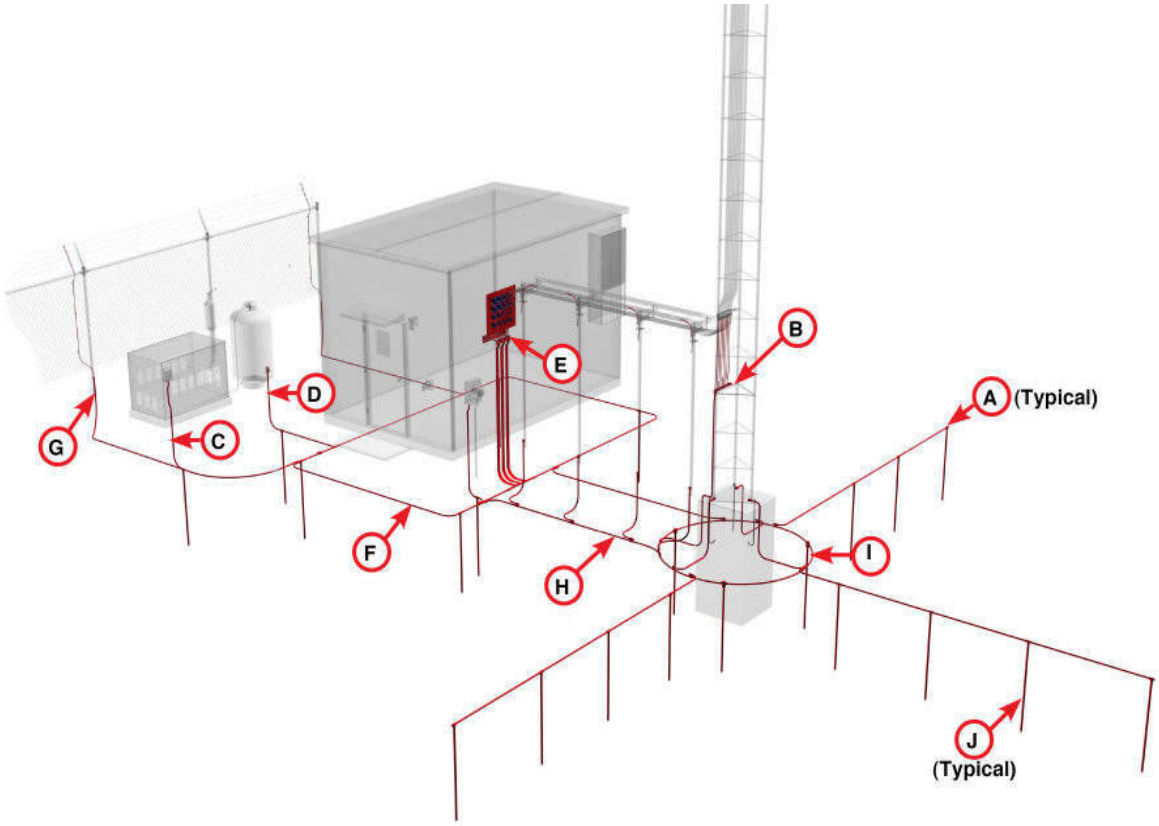


Figure 4-4. Common Grounding Example – All Grounding Electrodes Bonded Together

4.6 Grounding System Component and Installation Requirements

The external grounding and bonding system may include, but is not limited to, components shown in Figure 4-5.



A:	Grounding Radials
B:	Tower Ground Busbar and Down Conductors
C:	Generator Grounding Conductor
D:	Fuel Tank Grounding Conductor
E:	External Ground Busbar
F:	Shelter Ground Ring
G:	Fence Grounding Conductor
H:	Ground Ring Bonding Conductor (2 minimum)
I:	Tower Ground Ring
J:	Earthing Electrodes (Ground Rods)

Figure 4-5. Typical External Grounding Electrode System

WARNING: Failing to locate buried utilities can endanger personnel and result in penalties for noncompliance with regulations.

NOTE: A buried utility locator service **shall** be contacted before digging or excavating. In the USA, a "Call before you dig" service is available in all states by calling 811 or visiting www.811beforeyoudig.com. In Canada, visit https://www.clickbeforeyoudig.com. In other countries, the local utility **shall** be consulted to obtain buried utility location services.

4.6.1 Grounding (Earthing) Electrodes

Grounding electrodes are the conducting elements used to connect electrical systems and/or equipment to the earth. The grounding electrodes are placed into the earth to maintain electrical equipment at earth potential. Grounding electrodes may consist of ground rods, metal plates, concrete-encased electrodes, ground rings, electrolytic ground rods, wire mesh, the metal frame of a building or structure, metal underground water pipes, and other listed electrodes (NFPA 70-2026, Article 250 (III)).

IMPORTANT: Metallic underground gas piping **shall not serve** as a grounding electrode (IEC 60364-5-54:2011, section 542.2.6, and NFPA 70-2026, Article 250.52), but **shall** be bonded to the grounding electrode system upstream from the equipment shutoff valve (IEC 60364-5-54:2011, section 542.2.6 and Annex B; NFPA 70-2026, Article 250.104; and NFPA 780-2026, section 4.13).

IMPORTANT: Aluminum electrodes are not permitted (NFPA 70-2026, Article 250.52, and NFPA 780-2026, section 4.2.2.3.1). Also see IEC 62305-3:2024, section 5.5.1.

NOTE: Water pipes are not permitted for use as earth electrodes in several European countries. See IEC 60364-5-54:2011, section 542.2, for additional information.

4.6.1.1 Ground Rod Resistance Characteristics and Sphere of Influence

Around a grounding electrode, such as a driven ground rod, the resistance of the soil is the sum of the series resistances of virtual concentric shells of earth, located progressively outward from the rod. The shell nearest the ground rod has the smallest circumferential area or cross-section, so it has the highest resistance. Successive outward shells have progressively larger areas and lower resistances (see IEEE 142-2007, section 4.1.2, and MIL-HDBK-419A).

The effect of the concentric shells is that a finite amount of earth is required for a ground rod to fully realize its resistance value. This finite amount of earth is commonly known as the ground rod's sphere of influence. The sphere of influence for a ground rod is commonly thought to be a radius around the ground rod equal to its length. A ground rod achieves approximately 94% of its resistance value at this radius; 100% is achieved at a radius of approximately 2.5 times the rod length. See IEEE 142-2007, section 4.1, and Figure 4-6.

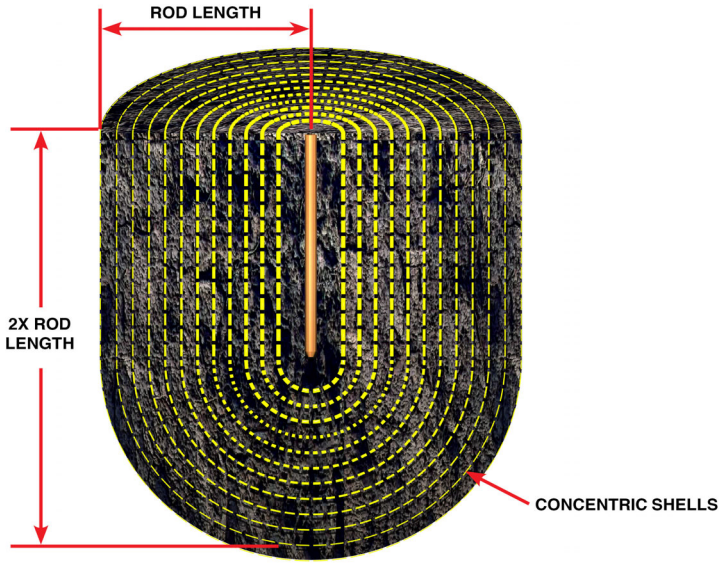


Figure 4-6. Ground Rod Sphere of Influence

As shown in Figure 4-7, maximum efficiency of parallel ground rods is achieved where the respective spheres of influence do not overlap.

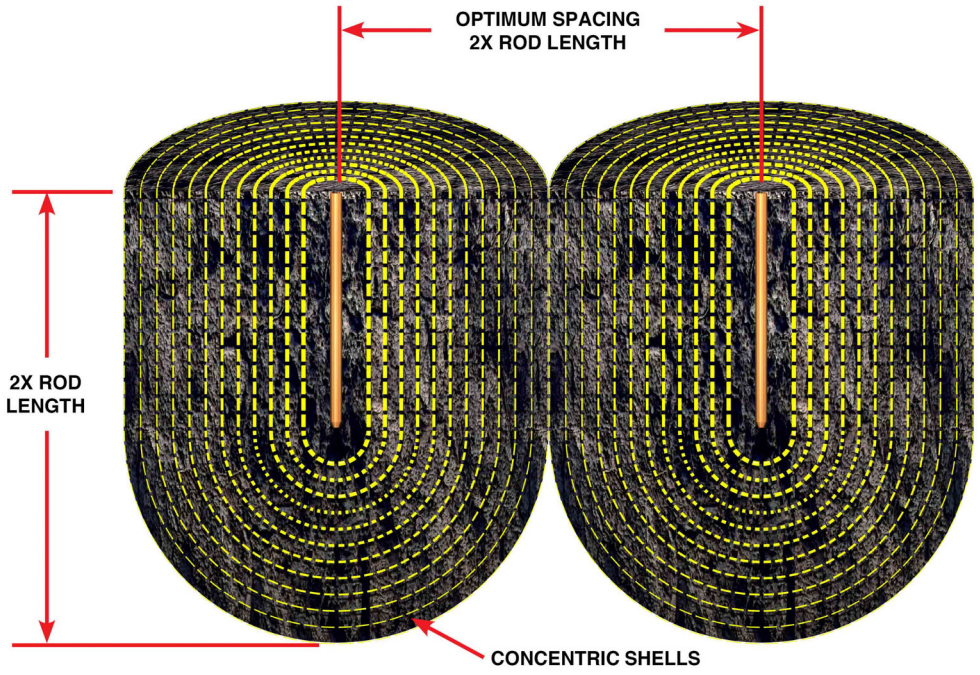


Figure 4-7. Ground Rod Spacing for Maximum Efficiency

Table 4-2 provides the relationship between percentage of total ground rod resistance and the radial distance from the ground rod (IEEE 142-2007, Table 4-1).

Table 4-2. Total Ground Rod Resistance Vs. Distance From 3 m (10 ft) Ground Rod

Distance from Electrode Surface (r)**		Approximate Percentage of Total Resistance
ft	Meters	
0.1	0.03	25%
0.2	0.06	38%
0.3	0.09	46%
0.5	0.15	52%
1.0	0.3	68%
5.0	1.5	86%
10.0*	3.0*	94%*
15.0	4.6	97%
20.0	6.1	99%
25.0	7.6	100%
*** 94% of the resistance to remote earth occurs within a radius equal to the length of the ground rod. This radius is commonly used as the ground rod's sphere of influence. ** Ground rod resistance at a radius (r) from a 3 m × 16 mm (10 ft × 0.625 in.) ground rod (from IEEE 142-2007, Table 4-1)**		

Table 4-2 indicates the following:

- Within the first 2.5 cm (1 in.) from the ground rod, 25% of the total resistance to earth is attained.
- Within the first 152 mm (6 in.) from the ground rod, 52% of the total resistance to earth is attained.
- The area immediately around a ground rod is the most important for reducing its resistance to earth. See "Grounding (Earthing) Electrode Encasement Materials" on page 4-36 for information on reducing resistance.
  - In high-resistivity soil areas, decreasing the soil resistance in this area helps improve the effectiveness of the grounding electrode system. This can be achieved using a ground rod or an electrolytic ground rod encased in a grounding electrode encasement material.
  - In porous soil areas, decreasing the contact resistance with the ground rod in this area helps improve the effectiveness of the grounding electrode system. This can be achieved using a ground rod or an electrolytic ground rod encased in a grounding electrode encasement material.

NOTE: In a given area, installing more ground rods closer together (such as one rod length apart) achieves a lower resistance to earth than installing fewer rods farther apart (such as twice the rod length apart). For example, five 3 m (10 ft) ground rods installed 6.1 m (20 ft) apart in a 24.4 m (80 ft) straight line achieve a resistance to earth of 7.8 Ω (assuming 10,000 ohm-cm soil). Nine 3 m (10 ft) ground rods installed 3 m (10 ft) apart in the same 24.4 m (80 ft) straight line achieve a resistance to earth of 5.7 Ω.

The resistance to earth of a ground rod can be calculated using the following formula (IEEE 142-2007, Table 4-5):

$$R = \frac{\rho}{2\pi L}\left[\ln\left(4\frac{L}{a}\right) - 1\right]$$

Where:

R: The resistance to earth of the ground rod in ohms (Ω)

ρ: The soil resistivity in ohm-centimeters (Ω-cm)

L: The length of the ground rod in centimeters (cm)

a: The ground rod radius in centimeters (cm)

4.6.1.2 General Ground Rod Requirements

This section provides general ground rod requirements. Typical ground rods are shown in Figure 4-8. Refer to IEEE 142-2007, section 4.3.1, and CSA C22.2 NO. 41:22/UL 467-2022 for further information. Ground rods are manufactured in various diameters and lengths.

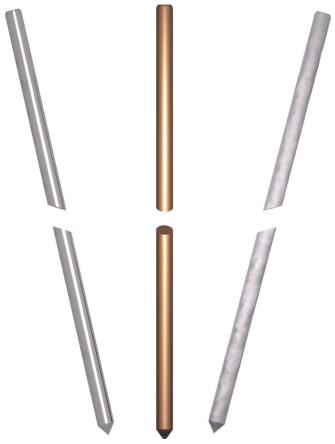


Figure 4-8. Typical Ground Rods

IMPORTANT: The type of ground rod installed **shall** be compatible with soil conditions at the site. Galvanized ground rods are unsuitable for acidic or aggressive soils and should only be used when engineered in the design. Motorola Solutions recommends against the use of galvanized ground rods. See Table 4-10 and Telcordia GR-3171-CORE.i02, section 10.2.6 for more information.

IMPORTANT: Stainless steel ground rods **shall** be formed of an austenitic stainless steel of the 18 percent chromium, 8 percent nickel type (CSA C22.2 NO. 41:22/UL 467-2022, section 6.10).

IMPORTANT: Due to potential corrosive effects, galvanized ground rods should not be installed near concrete-encased electrodes. Copper, copper-clad steel or stainless steel rods should be used to help prevent corrosion (IEC 62305-3:2024, section D.5.4.3.3).

- Ground rods **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- Ground rods **shall** be constructed of copper-clad steel, solid copper, hot-dipped galvanized steel, or stainless steel (ATIS-0600334.2019(R2024), section 5.3.2; IEEE 1692-2023, section 8.2; TIA-222-I, section 10.4.1; and TIA-607-E, section C.2). See NFPA 70-2026, Article 250.52; NFPA 780-2026, section 4.12.2.2; and CSA C22.2 NO. 41:22/UL 467-2022, section 6.10, for additional information. However, Motorola Solutions recommends against the use of galvanized ground rods, although many codes may permit them. In soil conditions unfavorable to copper or copper-clad rods (such as soils with organic acids), stainless steel rods are the Motorola Solutions-recommended alternative. See Table 4-11 on page 4-58 and Telcordia GR-3171-CORE.i02, section 10.2.6 for more information.
- Ground rods **shall** have a minimum length as required by local codes, and not less than 2.44 m (8 ft) (NFPA 70-2026, Article 250.52; NFPA 780-2026, section 4.12.2.1; ATIS-0600334.2019(R2024), section 5.3.2; IEEE 1692-2023, section 8.2; Telcordia GR-3171-CORE.i02, section 10.2.6; and UL 467-2022).

NOTE: The minimum ground rod length in Canada and Mexico is 3 m (10 ft) (CSA C22.2 NO. 41:22 and UL 467-2022).

- Ground rods installed around the tower should have a minimum length of 3 m (10 ft) (ATIS-0600313.2019(R2024), section 10.3.1 and TIA-222-I, section 10.4.1).
- Longer rods, such as 3 m (10 ft), should be considered for areas highly prone to lightning, sites with poor soil resistivity, and/or military installations (MIL-HDBK-419A and MIL-STD-188-124B).
- Ground rods **shall** have a minimum diameter of 15.9 mm (0.625 in.) (NFPA 70-2026, Article 250.52; ATIS-0600313.2019(R2024), section 10.3.1; ATIS-0600334.2019(R2024), section 5.3.2; IEEE 1692-2023, section 8.2; and TIA-222-I, section 10.4.1), unless otherwise allowed by the listing of the ground rod (see CSA C22.2 NO. 41:22/UL 467-2022).
- Ground rods **shall** be free of paint or other nonconductive coatings (NFPA 70-2026, Article 250.53 and NFPA 780-2026, section 4.12.2.3).

4.6.1.3 Ground Rod Installation Requirements

This section contains the general ground rod installation requirements:

- If practicable, ground rods **shall** be buried below permanent moisture level (NFPA 70-2026, Article 250.53 and MIL-HDBK-419A).
- Ground rods should penetrate below the frost line (MIL-HDBK-419A).

NOTE: Check with the authority having jurisdiction (AHJ) for frost line depth information.

- Ground rods longer than the minimum required 2.4 m (8 ft) may be required in order to maintain contact with permanently moist, unfrozen soil (MIL-HDBK-419A). See Figure 4-9.

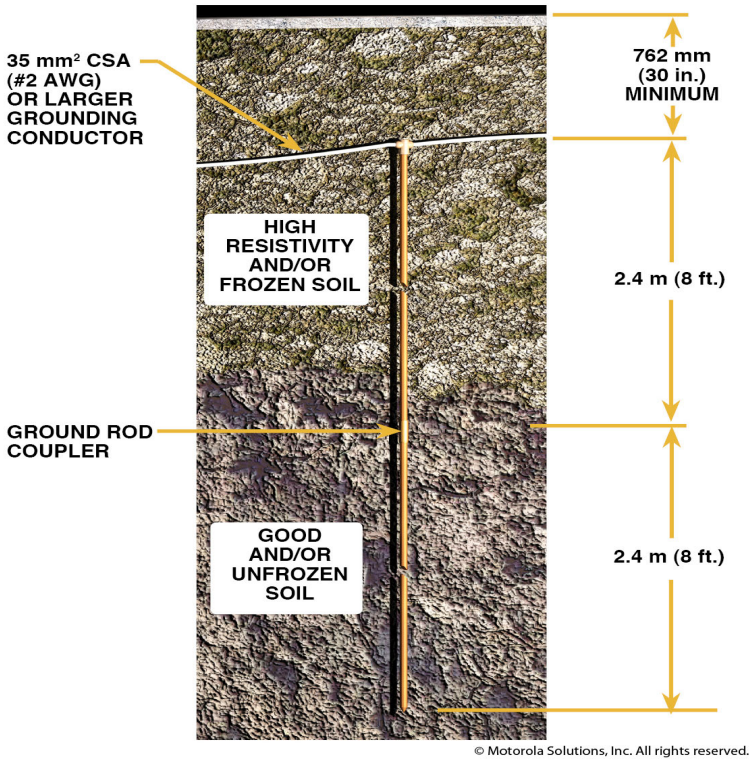


Figure 4-9. Ground Rods Coupled to Penetrate to Suitable Soil

- Ground rods that cannot be driven straight down due to contact with rock formations may be driven at an oblique angle of not greater than 45° from the vertical, or may be buried horizontally and perpendicular to the building, in a trench at least 762 mm (30 in.) deep, as shown in Figure 4-10 (NFPA 70-2026, Article 250.53). See Figure 4-20 on page 4-21 for an example of horizontal ground rods installed perpendicular to the building and tower.

IMPORTANT: The top of a ground rod **shall not** be cut off if contact with rocks prevents driving of the rod to the required depth. Alternative driving techniques, as described previously, **shall** be used in these cases.

- The method of bonding grounding conductors to ground rods **shall** be compatible with the types of metals being bonded. See “Dissimilar Metals and Corrosion Control” on page 4-55.

WARNING: When operating power tools, always wear appropriate safety glasses and other personal protective equipment to help prevent injury.

- Hammer drills or electric jackhammers may be used to drive ground rods. Precautions should be taken to prevent deforming (mushrooming) of the ground rod head (IEEE 142-2007, section 4.3.2).
- If rock formations prevent ground rods from being driven to the specified depth, an alternative method of achieving an acceptable grounding electrode system **shall** be implemented. See “Special Situations” on page 4-149 for additional information.

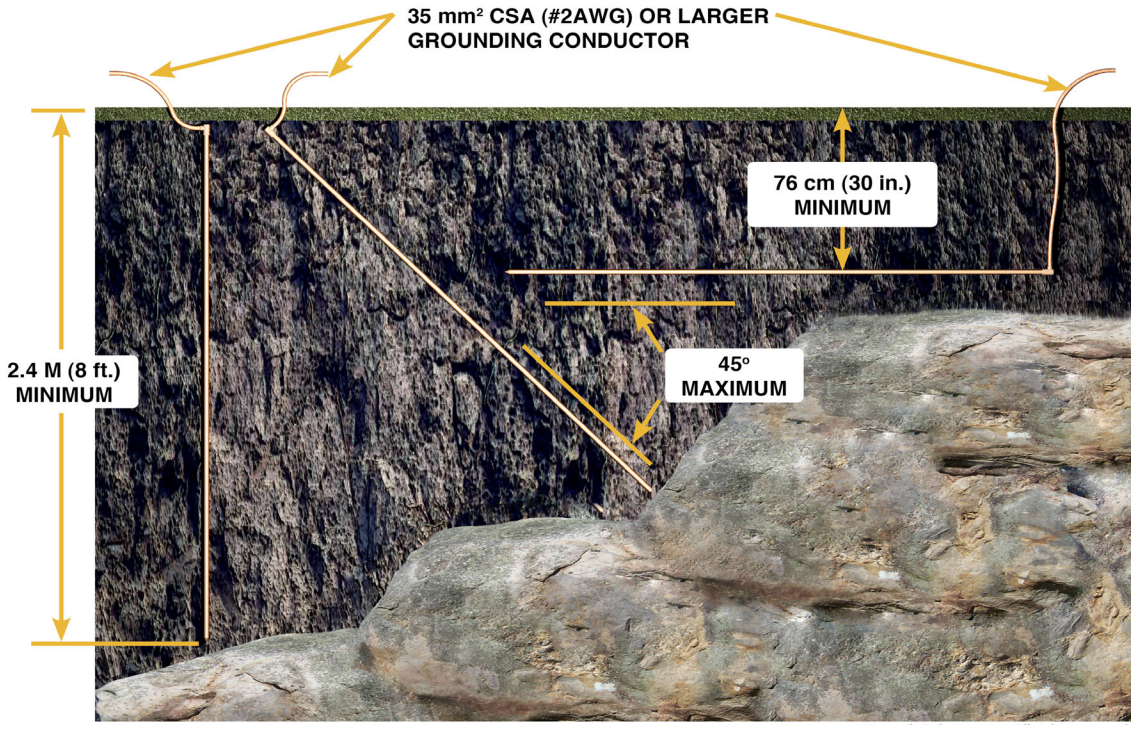


Figure 4-10. Angled Ground Rod Installation

- If the grounding electrode system design requires longer ground rods in order to lower the grounding electrode system resistance, reach the permanent moisture level, or penetrate below the frost line, two or more ground rods may be joined together using a coupling (threaded, compression sleeve or exothermic weld). Threaded rods or compression sleeves **shall** be listed (see IEEE 142-2007, section 4.3.1). See Figure 4-11.



Figure 4-11. Example of Sectional Ground Rod and Ground Rod Coupler

4.6.1.4 Ground Rod Requirements at Light Duty (Type A) Sites

NOTE: At a Light Duty (Type A) site, for better efficiency from each individual ground rod, the ground rods should be installed farther apart than the 1.8 m (6 ft) allowed by NFPA 70-2026, Article 250.53, such as the sum of their respective lengths (NFPA 780-2026, section 4.12.2.5). See Figure 4-7 on page 4-11 for more information.

- If not part of a ground ring system, such as at a Light Duty (Type A) site, the entire length of the rod **shall** be in contact with soil (NFPA 70-2026, Article 250.53). It is recommended to install the ground rods so the top of the rod is buried to a minimum depth of 610 mm (24 in.) below the surface of the earth (NFPA 780-2026, section 4.12.2.4.1). See Figure 4-12.

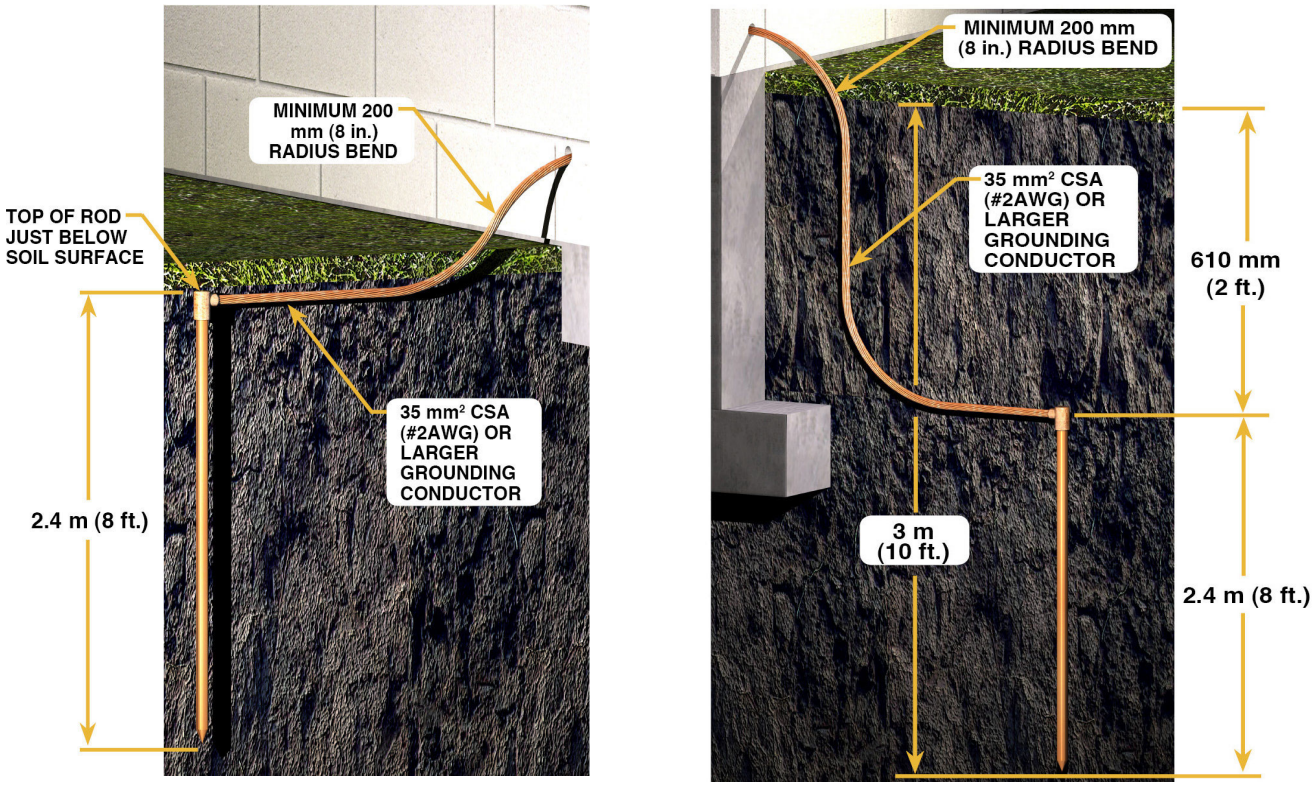


Figure 4-12. Typical Single Ground Rod Installations for Type A Sites

- Ground rods **shall not** be installed closer than 1.8 m (6 ft) to other ground rods and grounding electrodes (NFPA 70-2026, Article 250.53). See Figure 4-13 for an example.

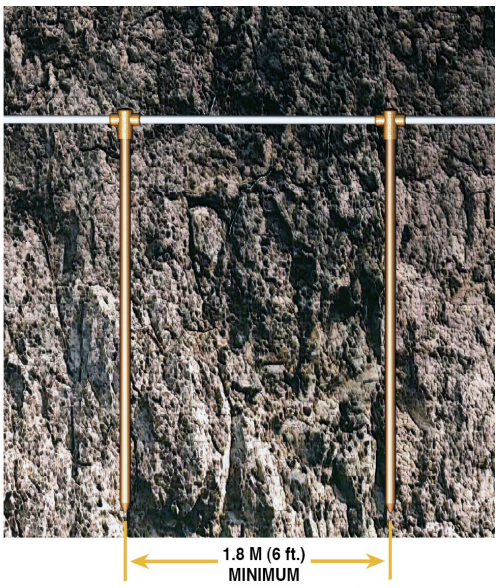


Figure 4-13. Parallel Ground Rod Installation

4.6.1.5 Ground Rods at Standard Duty (Type B) and Extra Duty (Type B2) Sites

- If part of a ground ring system, the top of the ground rods **shall** be buried to the depth of the ground ring, typically 762 mm (30 in.) minimum below finished grade. See “External Building and Tower Ground Ring” on page 4-25.
- Ground rods that are part of a ground ring system **shall** be installed at intervals of 3 m to 4.5 m (10 ft to 15 ft) (ATIS-0600334.2019(R2024), section 5.3.2).
- See “External Building and Tower Ground Ring” on page 4-25 for additional information.

4.6.1.6 Effect of Ground Rod Size on Resistance to Earth

Increasing the diameter of a ground rod does not significantly reduce its resistance to earth. Doubling the diameter of a ground rod reduces its resistance to earth by approximately 10% (see Figure 4-14).

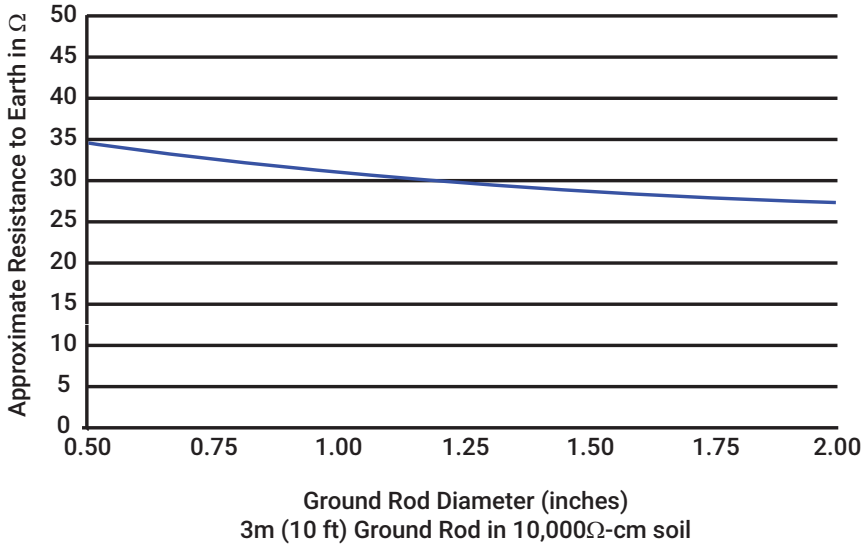


Figure 4-14. Resistance to Earth Due to Ground Rod Diameter

As the length of a ground rod is increased, its resistance to earth is substantially reduced. In general, doubling the length of a ground rod reduces its resistance to earth by approximately 45% (see Figure 4-15).

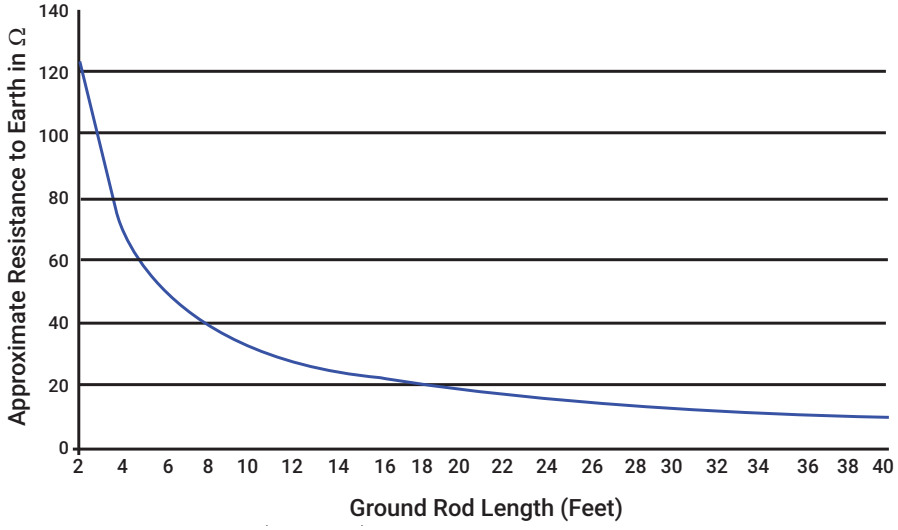


Figure 4-15. Resistance to Earth Due to Ground Rod Length

Figure 4-16 shows the resistance of different length ground rods versus earth resistivity.

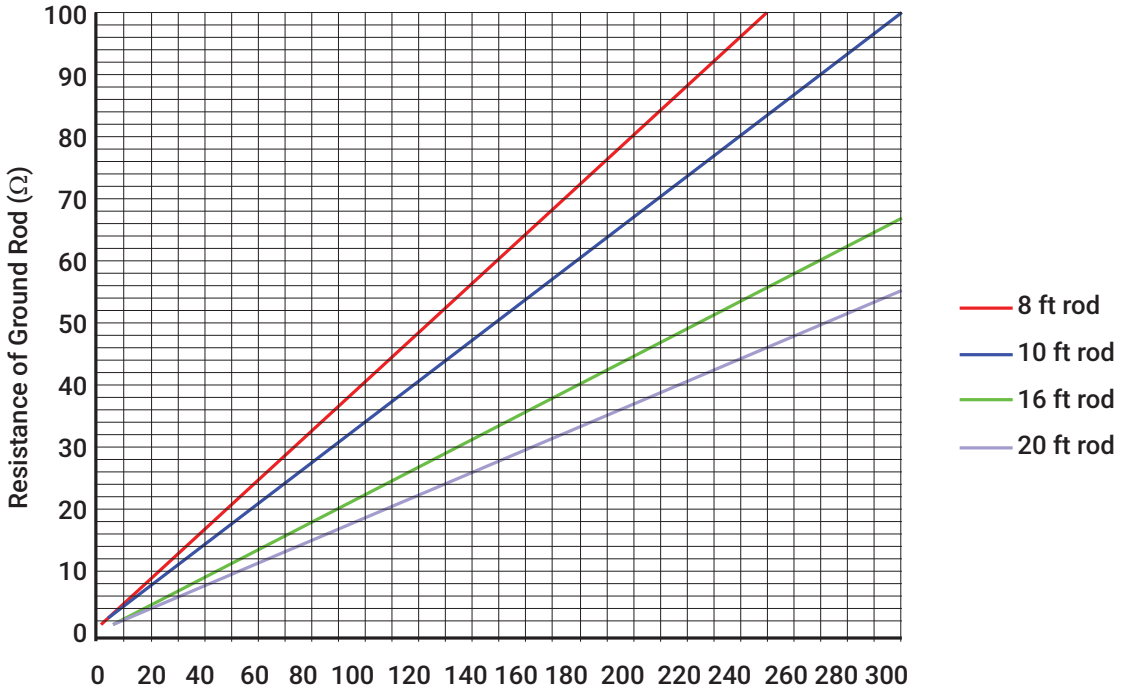


Figure 4-16. Resistance of Ground Rod versus Earth Resistivity

4.6.1.7 Effect of Parallel Ground Rods

Figure 4-17 shows the effects of adding additional ground rods (15.9 mm (0.625 in.) diameter by 3 m (10 ft) long) in parallel. As shown in the figure, the addition of one ground rod to the first ground rod (for a total of two rods) significantly reduces the resistance to earth of the ground rod system. Each subsequent ground rod added in parallel has less of an effect on the resistance to earth of the ground rod system.

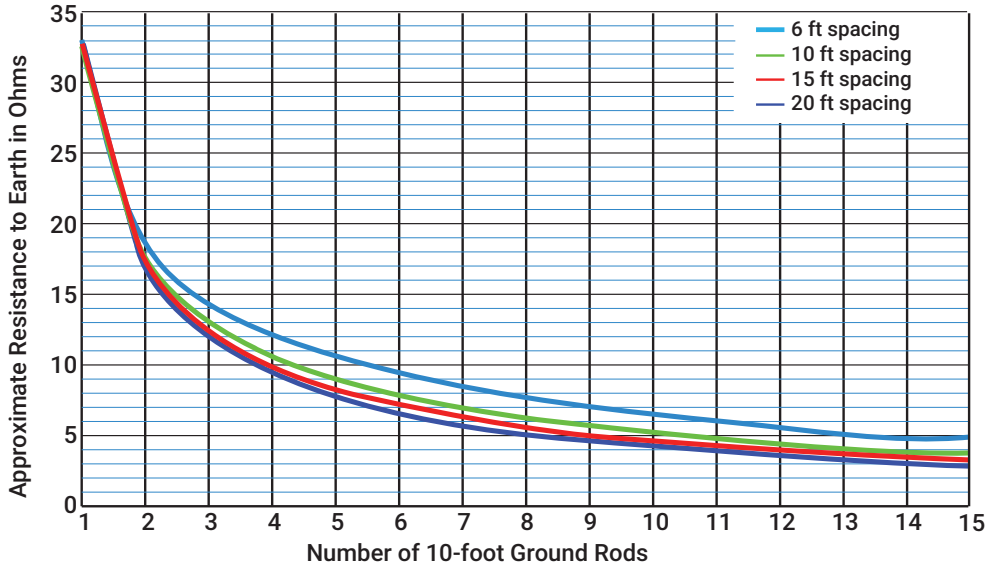


Figure 4-17. Resistance to Earth Due to Parallel Ground Rods

4.6.1.8 Electrolytic Ground Rods

At sites where poor soil conductivity (high resistivity) and/or limited space prevent achievement of acceptable grounding electrode system resistance using standard ground rods, commercially available electrolytic ground rods should be considered (TIA-607-E, section C.3). See MIL-HDBK-419A Volume I, section 2.9.5, and UL 467-2022, section 6.10.3, for additional information. Electrolytic ground rods (Figure 4-18, Figure 4-19, and Figure 4-20) are available in straight or L-shaped versions and in lengths from 3 m (10 ft) to 6.1 m (20 ft) or longer as a special order. Electrolytic ground rods are generally constructed of 54 mm (2.125 in.) diameter hollow copper or stainless steel pipe filled with a mixture of non-hazardous natural earth salts. Breather holes at the top of the pipe allow the salts to hygroscopically extract moisture from the air, forming conductive electrolytes. These electrolytes then leach out of the pipe into the soil, improving soil conductivity. Electrolytic ground rods are inserted into pre-drilled holes or trenches and then encased in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.

Electrolytic ground rods should also be considered for use in grounding electrode systems covered by concrete or pavement, such as parking lots (see “Grounding Electrode Systems Covered by Concrete or Asphalt” on page 4-147). By allowing moisture to enter, the design of the electrolytic ground rod improves the resistance of the grounding electrode system.

Electrolytic ground rods may provide significant improvement over standard ground rods of the same length. The resistance to earth of electrolytic ground rods is generally more stable in environments with variations in temperature and moisture.

IMPORTANT: Only grounding electrode encasement material **shall** be placed into pre-drilled holes when backfilling around electrolytic ground rods.

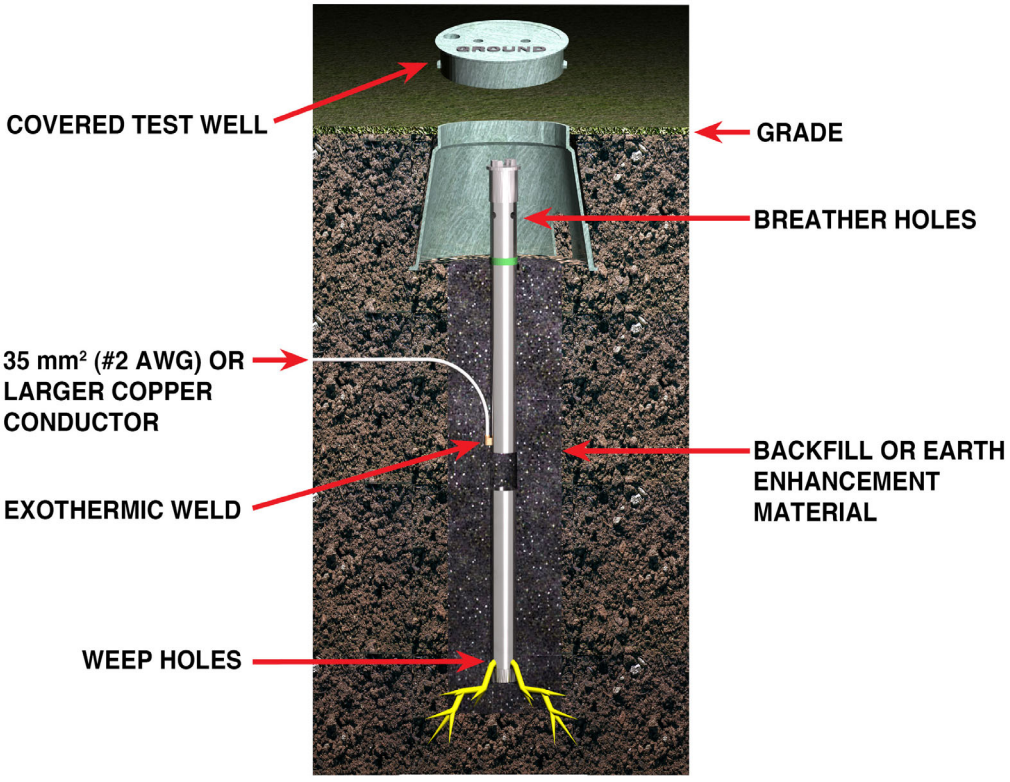


Figure 4-18. Electrolytic Ground Rod: Straight

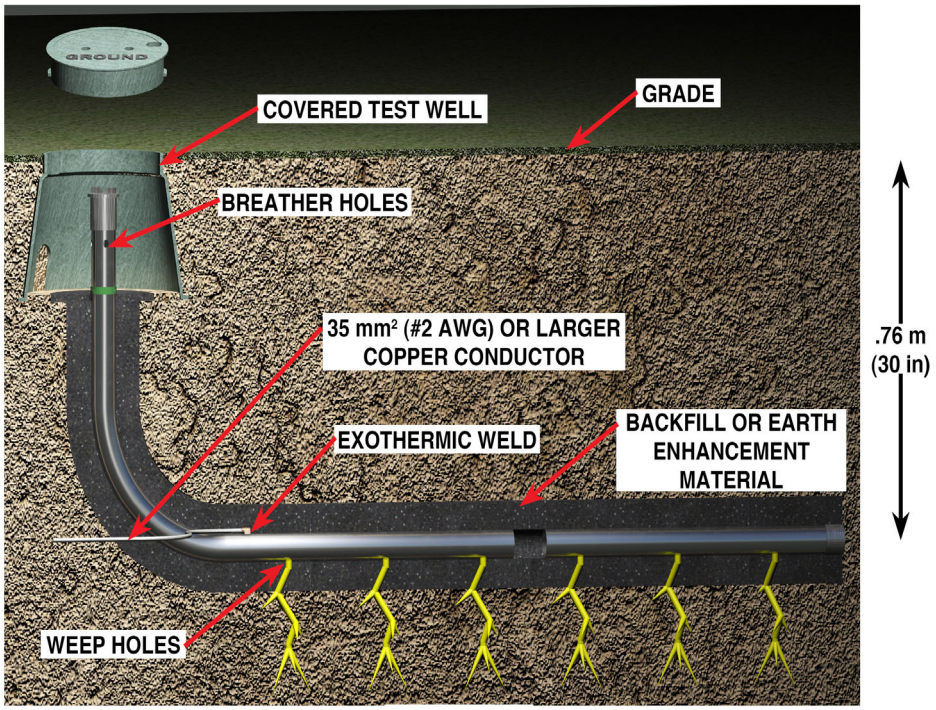


Figure 4-19. Electrolytic Ground Rod: L-Shaped

NOTE: Condensation from the HVAC system may be used to moisten the soil around the ground rod to improve soil conductivity, unless local environmental authorities prohibit this practice.

Requirements for the use of electrolytic ground rods are as follows:

- Electrolytic rods **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- Electrolytic rods **shall** be installed per the manufacturers' recommendation.
- Grounding electrode encasement materials (also known as backfill) **shall** be environmentally safe and approved by the authority having jurisdiction. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Grounding electrode encasement materials **shall** be approved by the ground rod manufacturer and **shall** be installed according to supplied instructions. Only grounding electrode encasement material **shall** be used as backfill.
- Electrolytic rods **shall** be free of paint or other nonconductive coatings (NFPA 70-2026, Article 250.53; and NFPA 780-2026, section 4.12.2.3).
- L-shaped electrolytic rods **shall** be installed perpendicular (or as near perpendicular as practicable) to the building, shelter, tower, and associated ground rings in order to maximize the grounding electrode system surface area. The rod **shall not** be installed in the same trench as the ground ring or grounding conductors. See Figure 4-20 for an example of a typical installation.

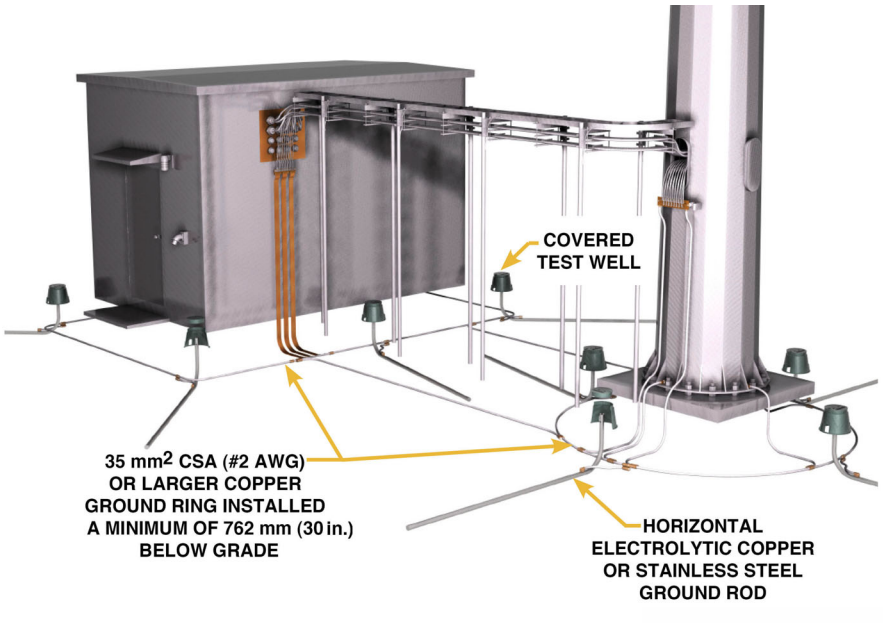


Figure 4-20. Example of Horizontal Electrolytic Ground Rod Installation

- L-shaped electrolytic rods (horizontal portion) **shall** be installed at least 762 mm (30 in.) below-grade, where practicable.
- Electrolytic rods should be considered in arctic regions. See “Arctic Environments” on page 4-158.

4.6.1.9 Ground Plate Electrodes

Ground plate electrodes (Figure 4-21) may be used in special cases or if specifically engineered into the design of the grounding electrode system (TIA-607-E, section C.4). Requirements for the use of ground plate electrodes are as follows:

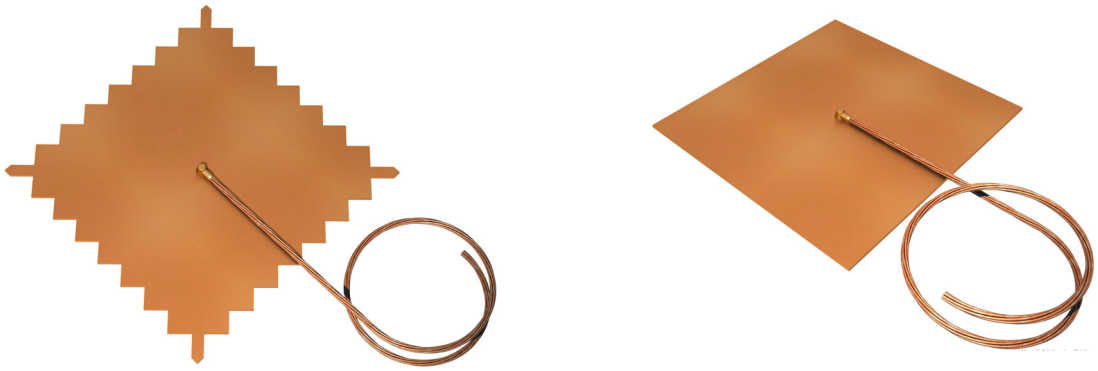


Figure 4-21. Typical Ground Plates

IMPORTANT: Ground plates **shall** only be used where specific soil conditions prohibit the use of ground rods and if specifically engineered into the grounding electrode system (TIA-607-E, section C.4).

- Ground plate electrodes **shall** be constructed of copper or copper-clad steel.
- Ground plates **shall** expose not less than 0.186 m^2 (2 ft^2) of surface to exterior soil (MIL-HDBK-419A, section 2.5.5; NFPA 70-2026, Article 250.52; and NFPA 780-2026, section 4.12.6.1).
- Ground plates with a minimum surface area of 0.744 m^2 (8 ft^2) are recommended (see FAA-STD-019G, section 4.4.4.3 for more information).
- Solid copper ground plates **shall** have a minimum thickness of 1.5 mm (0.06 in.) (MIL-HDBK-419A, section 2.5.5; and NFPA 70-2026, Article 250.52).
- Copper-clad steel ground plates **shall** have a minimum thickness of 6.4 mm (0.25 in.) (MIL-HDBK-419A, section 2.5.5; and NFPA 70-2026, Article 250.52).
- Ground plates **shall** be free of paint or other nonconductive coatings (NFPA 70-2026, Article 250.53).
- If practicable, ground plates **shall** be buried not less than 762 mm (30 in.) below the surface of the earth (NFPA 70-2026, Article 250.53 and TIA-607-E, section C.4). If soil conditions do not allow the ground plate to be buried at this depth, a burial depth of 460 mm (18 in.) may be considered acceptable (NFPA 780-2026, section 4.12.6.2). See “Shallow Topsoil Environments” on page 4-155 for additional information.
- If practicable, a ground plate **shall** be embedded below permanent moisture level (BS 7430:2026, section 8.5.2; NFPA 70-2026, Article 250.53; and TIA-607-E, section C.4).
- A grounding electrode encasement material **shall** be used to backfill around the ground plate to help ensure effective contact with the earth (BS 7430:2026, section 8.5.2; FAA-STD-019G; and NWSM 30-4106:2017, section 2.8.2.5). See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- If practicable, ground plates **shall** be installed vertically (Figure 4-22) to allow for minimum excavation and better contact with the soil when backfilling (BS 7430:2026, section 8.5.2; FAA-STD-019G, section 4.4.4.3; IEC 60364-5-54:2011, section D.3.2; and IEEE 142-2007, section 4.2.4).
- If part of a ground ring system, ground plates **shall** be installed at intervals not exceeding 3 m to 4.5 m (10 ft to 15 ft) and **shall not** be installed closer than 1.8 m (6 ft) to other ground plates and other grounding electrodes (see ATIS-0600334.2019(R2024), section 5.3.2; BS 7430:2026, section 8.5.2; and NFPA 70-2026, Article 250.53).

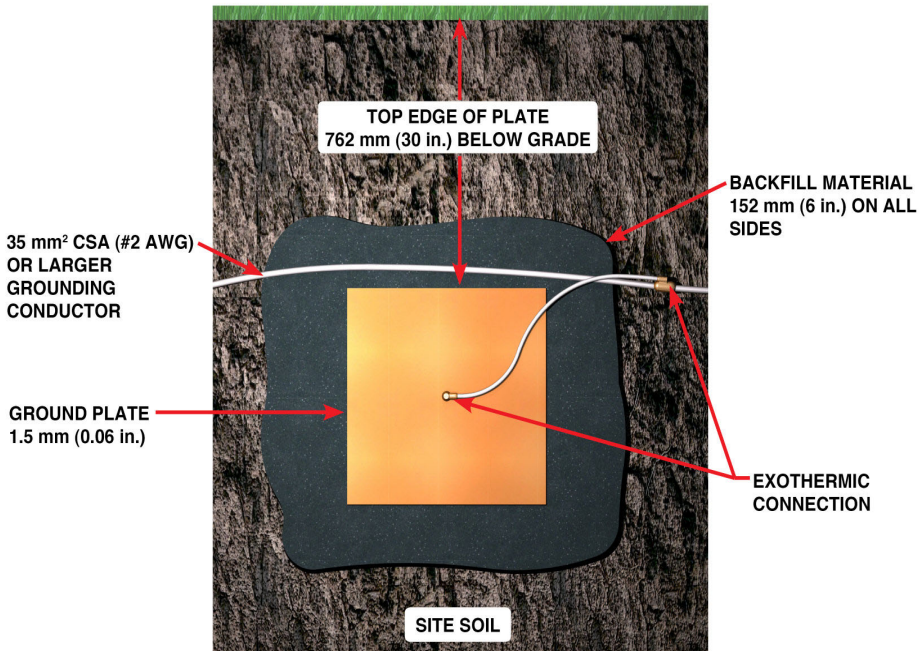


Figure 4-22. Typical Vertical Ground Plate Installation

4.6.1.10 Concrete-Encased Electrodes

Although not mandatory by this standard, concrete-encased electrodes (also known as foundation earth electrodes or Ufer electrodes, named after Herbert G. Ufer) should be incorporated into new construction to enhance the grounding electrode system and improve equal potential bonding. Their effectiveness is twofold: the concrete absorbs and retains moisture from the surrounding soil, and provides a larger surface area in direct contact with the soil. This is particularly beneficial in areas with high soil resistivity and/or limited space for the grounding electrode system. For further information, refer to BS 7430:2026, section 8.6; IEEE 142-2007 section 4.2.3; and the International Association of Electrical Inspectors publication, *Soares Book on Grounding and Bonding*, 12th Edition (ISBN 978-1890659653), Appendix A.

The use of concrete-encased electrodes must adhere to the following requirements (see IEC 60364-5-54:2011; NFPA 70-2026, Article 250.52; NFPA 780-2026, section 4.12.3; and TIA-607-E, section C.6.):

- Concrete-encased electrodes **shall** be encased by at least 51 mm (2 in.) of concrete, located horizontally near the bottom or vertically, and within that portion of a concrete footing or foundation in direct contact with the earth. Figure 4-23 shows examples of horizontal concrete-encased electrodes. Figure 4-24 on page 4-25 shows examples of vertical concrete-encased electrodes.
- Concrete-encased electrodes **shall** consist of at least 6.1 m (20 ft) of bare copper conductor not smaller than 25 mm² csa (#4 American Wire Gauge (AWG)), or at least 6.1 m (20 ft) of one or more bars of zinc galvanized or other electrically conductive coated steel reinforcing bars or rods at least 12.7 mm (0.5 in.) in diameter.
- Concrete-encased electrodes **shall** be bonded to any other grounding electrode system at the site. See “Common Grounding” on page 4-7.

IMPORTANT: At a communications site, concrete-encased electrodes **shall not** be used as the only grounding electrode. Concrete-encased electrodes **shall not** be used as the only means for tower grounding.

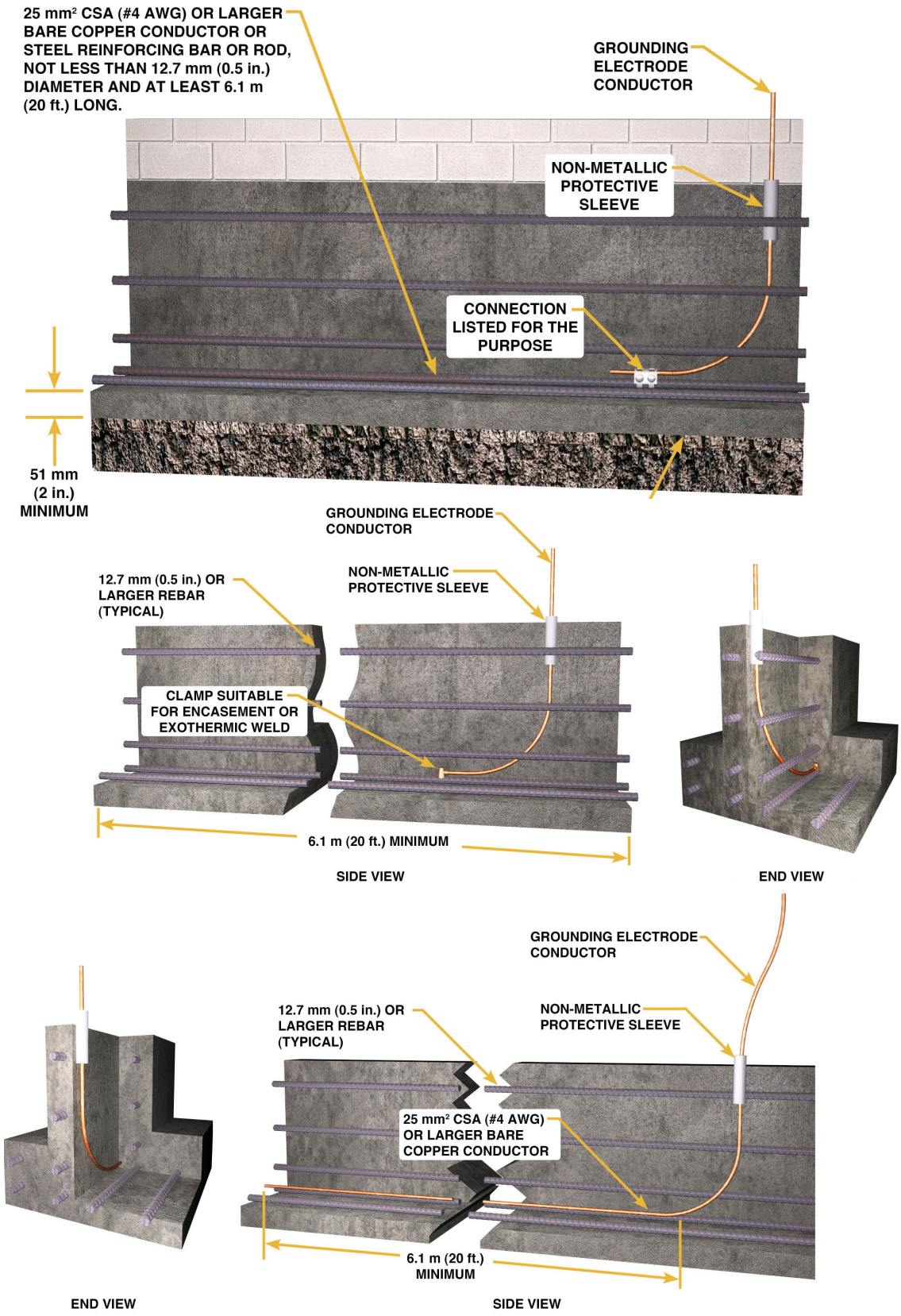


Figure 4-23. Typical Horizontal Concrete-Encased Electrodes

IMPORTANT: Due to potential corrosive effects, galvanized ground rods should not be installed near concrete-encased electrodes. Copper, copper-clad steel, or stainless steel rods should be used to help prevent corrosion (IEC 62305-3:2024, section D.5.6.2.2.2).

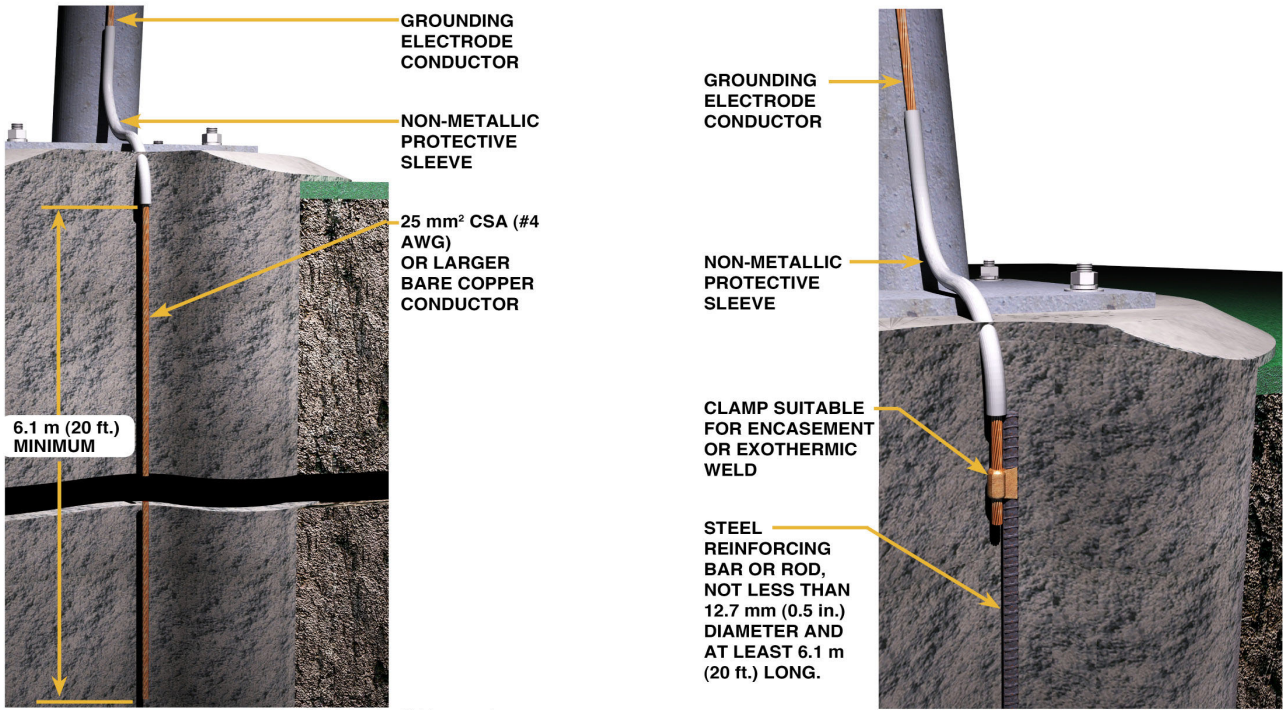


Figure 4-24. Typical Vertical Concrete-Encased Electrodes

4.6.1.11 External Building and Tower Ground Ring

A ground ring (also known as a ring earth electrode) is a buried bare copper or tinned-copper conductor encircling the building or structure and in direct contact with the earth. The buried external ground rings (building and tower) provide a means of bonding ground rods together and bonding other grounding electrode system components together, thereby improving the overall grounding electrode system. The ground rings also help equalize potential in the surrounding earth of the tower and building structures, regardless of earth resistivity, by ensuring that a low-impedance current path exists throughout the area (ATIS-0600334.2019(R2024), section 5.3).

Requirements for external ground rings are as follows. See Figure 4-25 and Figure 4-26 for examples.

- Building ground rings **shall** encircle the building or shelter where practicable (ATIS-0600313.2019(R2024), Figure 3(a); ATIS-0600334.2019(R2024), section 5.3; MIL-HDBK-419A; and MIL-STD-188-124B).
- Building ground rings **shall** be installed at least 914 mm (3 ft) from the building foundation (TIA-607-E, section D.2.5) and should be installed beyond the drip line of the roof. It is recommended that the building ground ring and ground rods be positioned 610 mm to 1.8 m (2 ft to 6 ft) outside the drip line of the building or structure to ensure that precipitation wets the earth around the ground ring and rods (MIL-HDBK-419A and MIL-STD-188-124B).
- Tower ground rings **shall** encircle the tower structure where practicable (ATIS-0600334.2019(R2024), section 5.3; and MIL-HDBK-419A).
- Tower ground rings **shall** be installed at least 610 mm (2 ft) from the tower foundation (ATIS-0600334.2019(R2024), section 5.3.1 and TIA-222-I, section 10.4.2.2).

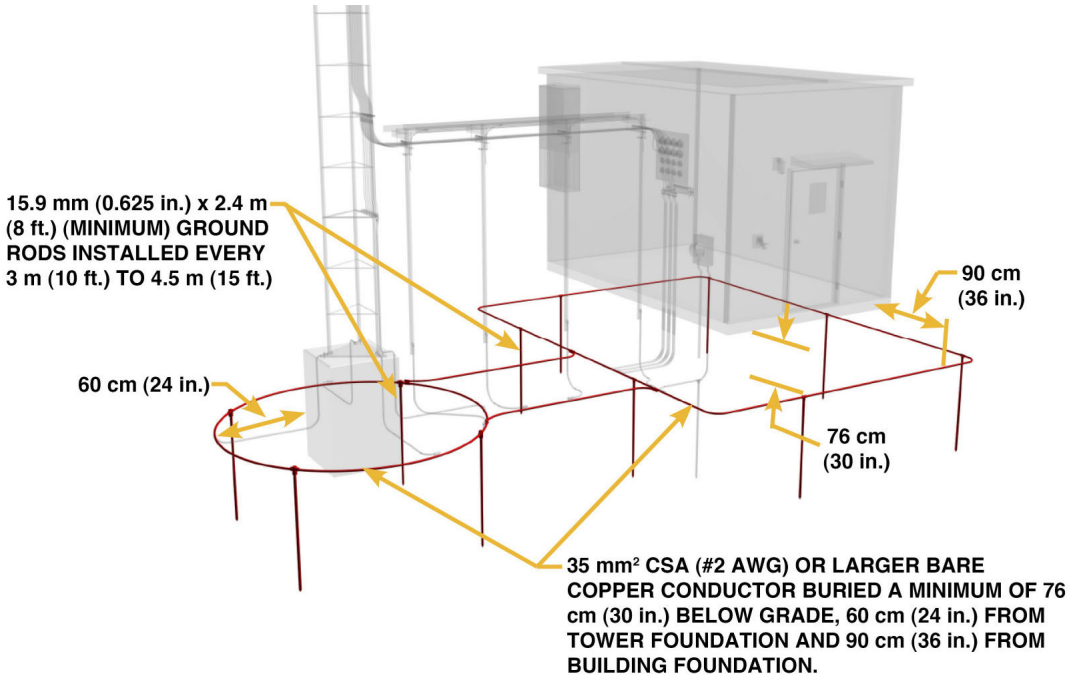


Figure 4-25. Example of Building and Tower Ground Ring

- Where the conductor completely encircles the building or tower, the ends of the conductor **shall** be joined together to form a continuous ring using an exothermic weld or a listed irreversible high-compression connector (ATIS-0600334.2019(R2024), section 5.3.1, and MIL-STD-188-124B). This may be easily completed at a ground rod.
- Ground rings **shall** be installed in direct contact with the earth at a minimum depth of 762 mm (30 in.) where practicable, or 0.2 m (6 in.) below the frost line, whichever is deeper (ATIS-0600334.2019(R2024), section 5.3.1; NFPA 70-2026, Article 250.53; TIA-607-E, section C.7; and Telcordia GR-3171-CORE.i02, section 10.2.5).
- The ground ring conductors **shall** be 35 mm² csa (#2 AWG) or larger, solid, bare, copper or tinned-copper (ATIS-0600313.2019(R2024); ATIS-0600334.2019(R2024), section 5.3.1; IEEE 1692-2023, section 8.2; NFPA 70-2026, Article 250.52; and Telcordia GR-3171-CORE.i02, section 10.2.5). Conductors larger than 35 mm² csa (#2 AWG) may be stranded, but should be tinned to help reduce corrosion. See “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38 for grounding conductor specifications.
- **Tinned**-copper conductors should be used to minimize galvanic corrosion between tower legs (and other galvanized items) and other parts of the grounding electrode system (ATIS-0600313.2019(R2024), section 10.7; and IEEE 1692-2023, section 8.2).
- For areas highly prone to lightning and/or military installations, larger conductors, such as 50 mm² csa (#1/0 AWG) or larger, should be considered (MIL-HDBK-419A, MIL-STD-188-124B, and TIA-607-E, section C.7); stranded conductors may be used in this application, but should be tinned to help reduce corrosion (see TIA-607-E, section C.7).
- Building and tower ground rings **shall** be bonded together in at least two points using two 35 mm² csa (#2 AWG) or larger, bare, solid, copper or tinned-copper conductors (ATIS-0600334.2019(R2024), Figure 1; MIL-STD-188-124B; TIA-607-E, section D.2.5, and Telcordia GR-3171-CORE.i02, section 10.6.1). The conductors **shall** be buried to the same depth as the ground rings (TIA-607-E, section D.2.4) and should be physically separated as much as practicable. See Figure 4-27.

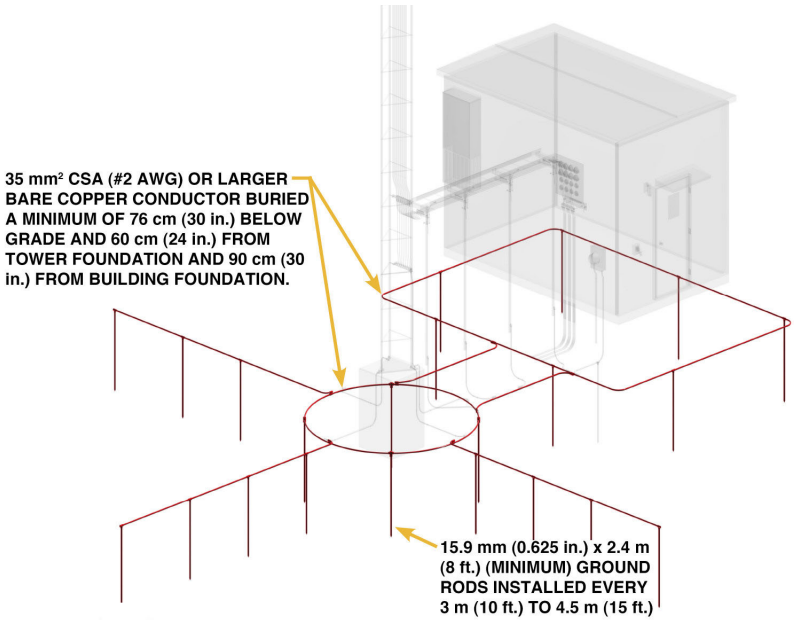


Figure 4-26. Example of Building and Tower Ground Ring With Radials

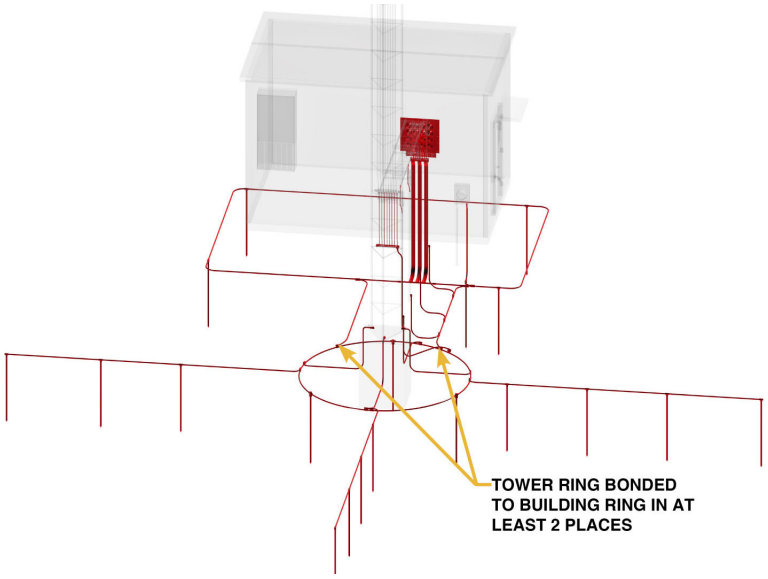


Figure 4-27. Bonding Building and Tower Ground Ring Systems Together

- Ground rods (conventional or electrolytic) **shall** be installed vertically and connected to the ground ring conductor at intervals not exceeding 3 m to 4.5 m (10 ft to 15 ft) (ATIS-0600334.2019(R2024), section 5.3.2).
- In situations where site-specific soil conditions prevent the installation of a vertical ground rod, the ground rods (conventional or electrolytic) may be installed horizontally, or ground plates may be used. The horizontal ground rods and ground plates **shall** be installed as described in this chapter.
- Horizontal ground rods and ground plates **shall** be installed at the same interval as required for vertical ground rods (intervals not exceeding 3 m to 4.5 m).
- If the building and tower are 1.5 m (5 ft) or less apart, a single ground ring should surround both structures (see Figure 4-28).
- A common ground ring conductor can be used between the building and tower if the distance between them is greater than 1.5 m (5 ft) but less than 2.4 m (8 ft) (See Figure 4-29).

NOTE: See Figure 4-112 on page 4-138 for an example of the ground ring for closely spaced structures.

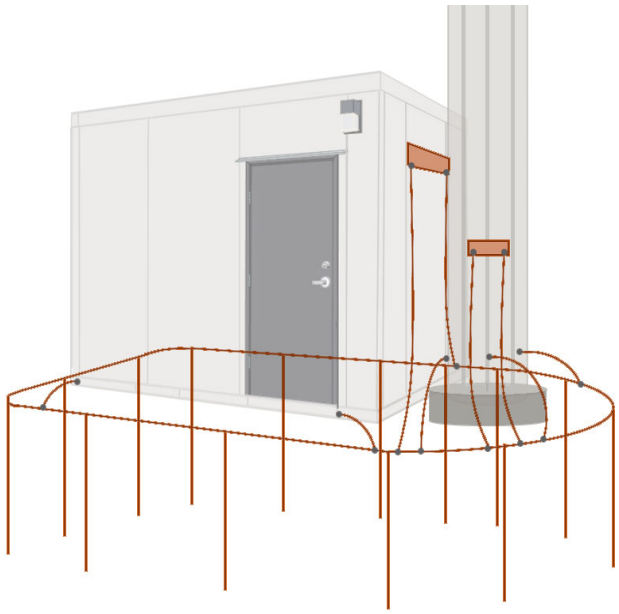


Figure 4-28. Example of Ground Ring for Closely Spaced Building and Tower

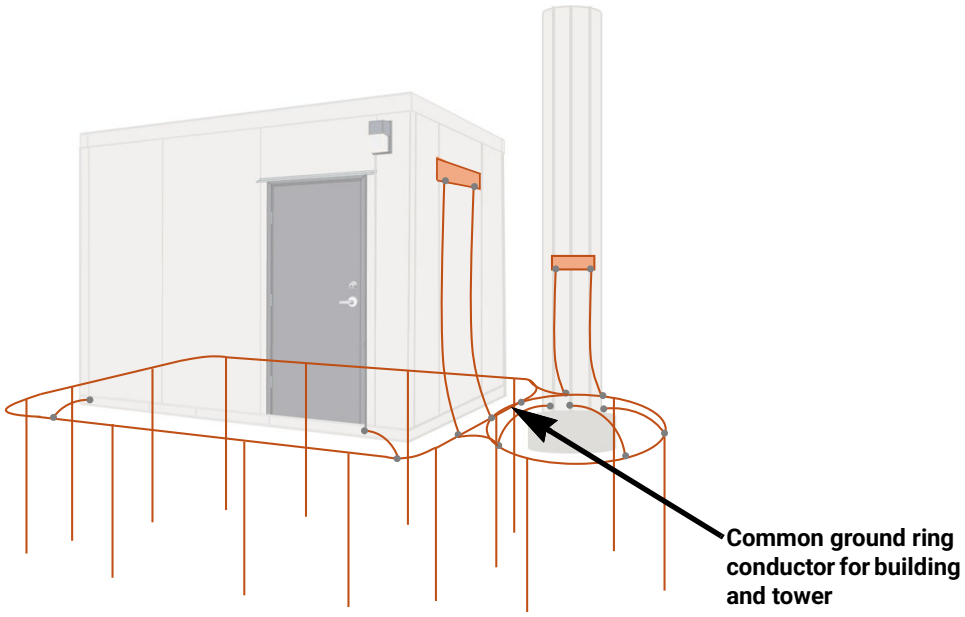


Figure 4-29. Example of Shared Ground Ring Segment

4.6.1.12 Radial Grounding Conductors

Radial grounding conductors are conductors installed horizontally in the earth, radiating away from the tower and building (see Figure 4-30). For high lightning-prone areas, normally occupied sites such as 911 dispatch centers, sites with high soil resistivity or situations where bedrock prohibits ground rods from being driven into the soil, radial grounding conductors should be used to improve equalization of the grounding electrode system (see ATIS-0600313.2019, section 10.3.2; and ATIS-0600334.2019(R2024), section 5.4), to reduce the impact of Ground Potential Rise (see IEEE 1692-2023) and to help meet the site's grounding electrode system resistance requirements (see “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-81).

NOTE: See “Ground Inspection Wells” on page 4-36, “Testing Prerequisites Not Met” on page D-4, and Figure D-16 for more information on test well locations for clamp-on ground resistance testing.

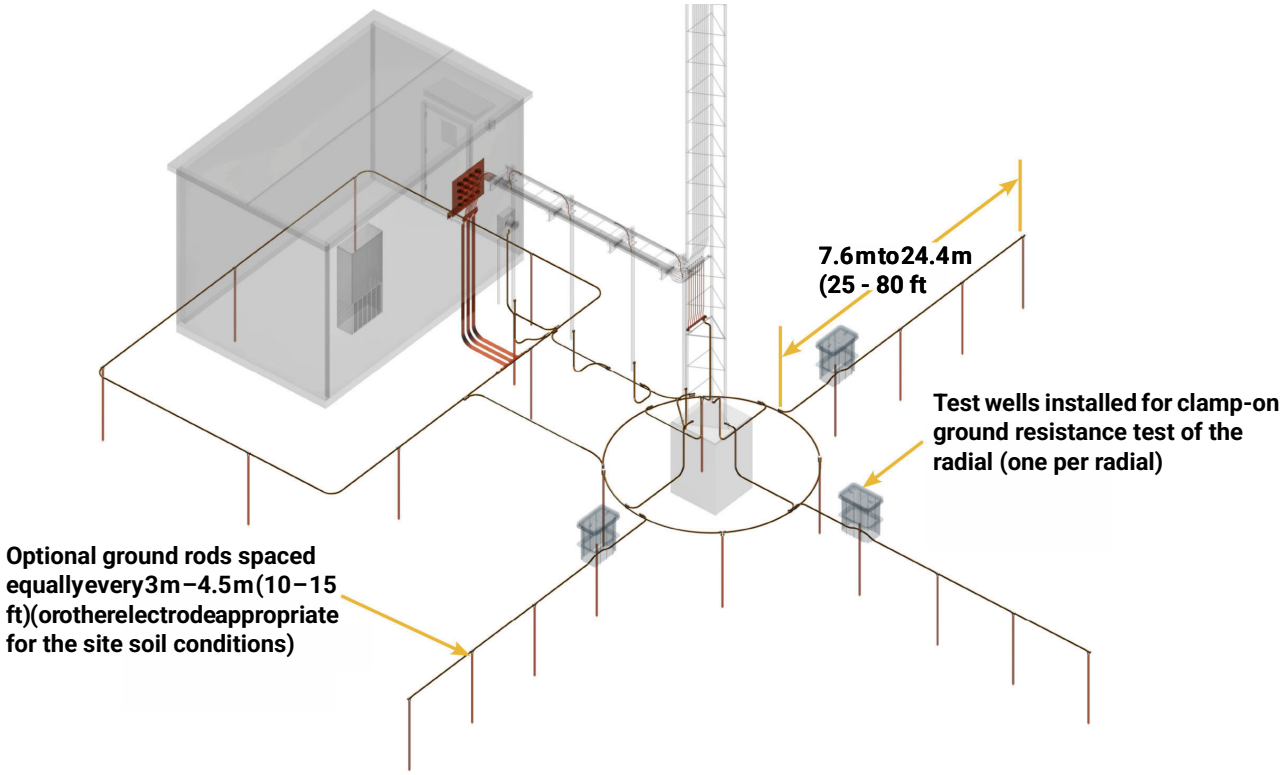


Figure 4-30. Example of Radial Conductors

NOTE: In typical soil resistivity conditions of 10,000 ohm-cm, the addition of five radial conductors 7.6 m (25 ft) in length may reduce the tower grounding electrode system resistance by a factor of two or three. More importantly, adding radial conductors divides lightning strike current into segments that allow for more effective dissipation of energy into the earth, away from the equipment building. See IEEE 1692-2023 for more information.

Where used, radial conductors **shall** meet the following specifications:

- The conductors **shall** radiate away from the building and tower (ATIS-0600334.2019(R2024), section 5.4; and TIA-607-E, section C.8.)
- The conductors **shall** be constructed of 35 mm² csa (#2 AWG) or larger bare, solid, copper or tinned-copper. Conductors larger than 35 mm² csa (#2 AWG) may be stranded, but should be tinned to help reduce corrosion. See “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38 for conductor specifications and installation requirements. (ATIS-0600334.2019(R2024), section 5.4)

- Where practicable, the conductors **shall** be buried at least 457 mm (18 in.) below-grade level or below the frost line, whichever is deeper (ATIS-0600334.2019(R2024), section 5.4). Where topsoil conditions allow, the recommended depth is at least 762 mm (30 in.) (TIA-607-E, section C.8). See “Stone Mountaintops” on page 4-152 and “Shallow Topsoil Environments” on page 4-155 for radial conductor installations at sites with limited or no topsoil.
- The minimum length of each conductor **shall** be 7.6 m (25 ft) (ATIS-0600334.2019(R2024), section 5.4; IEEE 1692-2023, section 8.3; TIA-222-I, section 10.4.2.1; and TIA-607-E, section C.8). If the desired resistance to earth is not achieved at 7.6 m (25 ft), the radial conductors may be extended to help obtain the desired resistance. The maximum effective length for a single radial conductor is generally considered to be approximately 24.4 m (80 ft) (IEEE 1692-2023, section 8.3; and TIA-607-E, section C.8). Adding additional conductors in separate trenches is generally more effective than extending the length of a single conductor.
- A minimum of three radial conductors should be used, where practicable (TIA-607-E, section C.8). The conductors should be of different lengths, such as ±5% (see TIA-607-E, section C.8).
- Where multiple radial conductors are installed, they **shall** be installed in separate trenches. The trenches **shall** be spaced as far apart from one another as practicable and in a manner that maximizes use of the available property area (see TIA-607-E, section C.8).
- The conductors **shall** terminate to the tower ground ring where practicable (see Figure 4-30), but may terminate to the building ground ring in special applications.
- Where the conductors are installed at the tower, the conductors **shall** be bonded directly to the tower and tower ground ring (ATIS-0600334.2019(R2024), section 5.4). If it is not practical to bond all radial conductors to the tower, the tower (or each leg on a self-supporting tower) **shall** have additional grounding conductors bonding it to the tower ground ring. See Figure 4-31 for an example of an additional grounding conductor on each tower leg. In this instance, the conductors should be 70 mm² csa (#2/0 AWG) or larger.
- Conductor bonding **shall** comply with “Bonding to the External Grounding and Bonding System” on page 4-61.

NOTE: Where soil conditions permit, the effectiveness of the radial grounding conductors may be enhanced by including a ground rod(s) on each radial (see TIA-607-E, section C.8). Due to the impedance of the radial conductor, ground rods located closer to the tower base dissipate a larger percentage of the lightning transient than those situated farther down the radial.

NOTE: Low resistance in radial grounding configurations is desirable, but not critical. Low resistance in the dissipating path of strike currents into the earth is of secondary importance when compared to the primary objective of controlling voltage gradients and voltage differences between structures and equipment close to the tower (ATIS-0600334.2019(R2024), section 5.4).

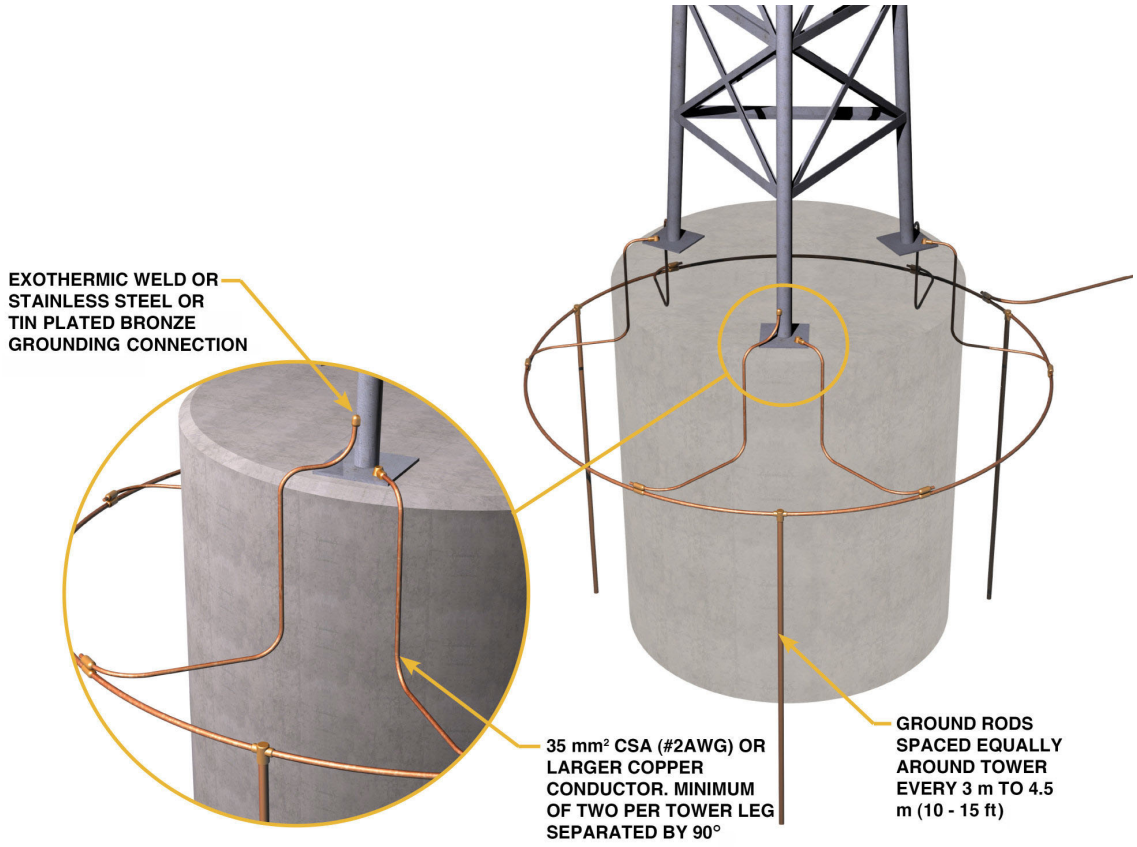


Figure 4-31. Example of an Additional Grounding Conductor Installed on Each Tower Leg (Radials Not Shown)

The resistance to earth of a straight horizontal electrode (radial grounding conductor) may be calculated as follows:

$$R = \frac{\rho}{\pi L}\left[\ln\left(2\frac{L}{\sqrt{2aD}}\right) - 1\right]$$

Where:

D<<L (D is much less than L)

R: The resistance of the electrode in ohms (Ω)

ρ: The soil resistivity in ohm-meters

L: The length of the conductor in meters

a: The conductor radius in meters

D: The conductor depth in meters

Figure 4-32 shows the resistance characteristics of a radial grounding conductor.

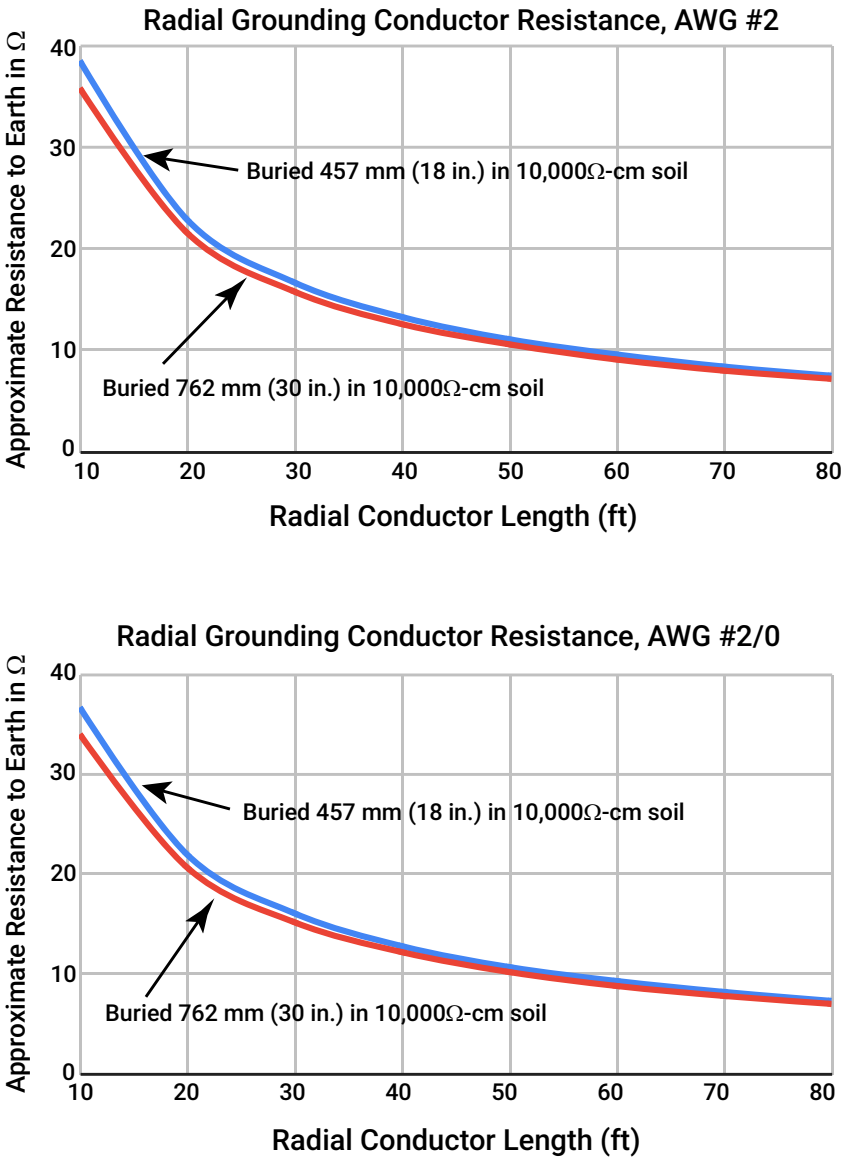


Figure 4-32. Resistance Characteristics of a Radial Grounding Conductor

IMPORTANT: Areas of high lightning exposure or high soil resistivity should utilize supplemental grounding, such as radial grounding conductors (see ATIS-0600313.2019(R2024), section 10.3.2).

IMPORTANT: Radial grounding conductors should be installed at dispatch center sites that have a co-located tower. See “Dispatch Centers Co-Located With Communications Towers” on page 4-135.

IMPORTANT: IEEE 1692-2023, section 8.2, recommends covering radial grounding conductors with 50 mm (2 in.) of a conductive cement where the soil resistivity exceeds 500 ohm-m. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.

4.6.1.13 Wire Mesh

Wire mesh is a prefabricated grounding conductor mesh specifically designed for grounding purposes. Wire mesh is installed horizontally in the earth or on the earth's surface if site-specific soil conditions do not permit burying. Metallic objects at the site that require grounding/bonding (such as external ground busbar, tower, fuel tank, fence, and so on) are bonded to the wire mesh.

The use of wire mesh is a simple method to obtain equal potential at sites where there is very little room for the grounding electrode system or at sites where the installation of other grounding electrodes is prohibited by soil conditions (such as shallow topsoil on stone mountaintops) (TIA-607-E, section C.5). See “Special Situations” on page 4-149 for wire mesh installation applications.

NOTE: If the wire mesh is constructed from 35 mm² csa (#2 AWG) conductors, and the building and tower are surrounded by the wire mesh, the building and tower do not require separate ground rings. If the wire mesh is constructed from 16 mm² csa (#6 AWG) conductors, the building and tower require ground rings as described in “External Building and Tower Ground Ring” on page 4-25. The wire mesh and ground rings **shall** then be bonded together at equally spaced intervals not exceeding 3 m (10 ft).

Requirements for using prefabricated wire mesh are as follows:

- The wire mesh **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL), such as CSA C22.2 NO. 41:22/UL 467-2022.
- The wire mesh **shall** be installed according to the manufacturer’s instructions.
- The wire mesh **shall** be constructed from copper, tinned-copper or stainless steel conductors (CSA C22.2 NO. 41:22/UL 467-2022, section 6.11).
- The wire mesh **shall** be constructed from 16 mm² csa (#6 AWG) or larger conductors. If the wire mesh is constructed from 35mm² csa (#2 AWG) conductors, separate building and tower ground rings are not required if the wire mesh surrounds the building and tower.
- The wire mesh conductors **shall** be brazed, welded, or exothermically bonded together at all intersection points (see ITU *Earthing and Bonding Handbook*, section 3.5).
- The wire mesh grid pattern **shall not** have any dimension less than 102 mm (4 in.) (CSA C22.2 NO. 41:22 and UL 467-2022, section 6.11). See Figure 4-33.
- The wire mesh grid pattern **shall not** have any dimension greater than 610 mm (24 in.) (CSA C22.2 NO. 41:22 and UL 467-2022, section 6.11). See Figure 4-33.
- The wire mesh **shall** be bonded to any other grounding electrodes at the site. See “Common Grounding” on page 4-7.
- If building and/or tower ground rings are used, they **shall** be bonded to the wire mesh at equally spaced intervals not exceeding 3 m (10 ft).

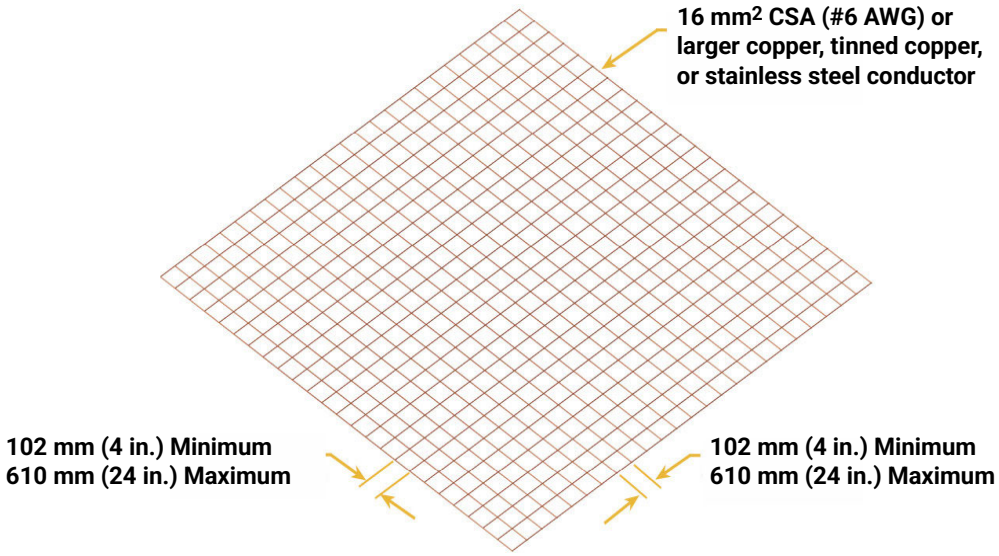


Figure 4-33. Example of Wire Mesh

4.6.1.13.1 Sites with Topsoil

- The wire mesh **shall** be buried to a minimum depth of 457 mm (18 in.) if practicable or as otherwise allowed by the site specific soil conditions. See Figure 4-34 and Figure 4-35.

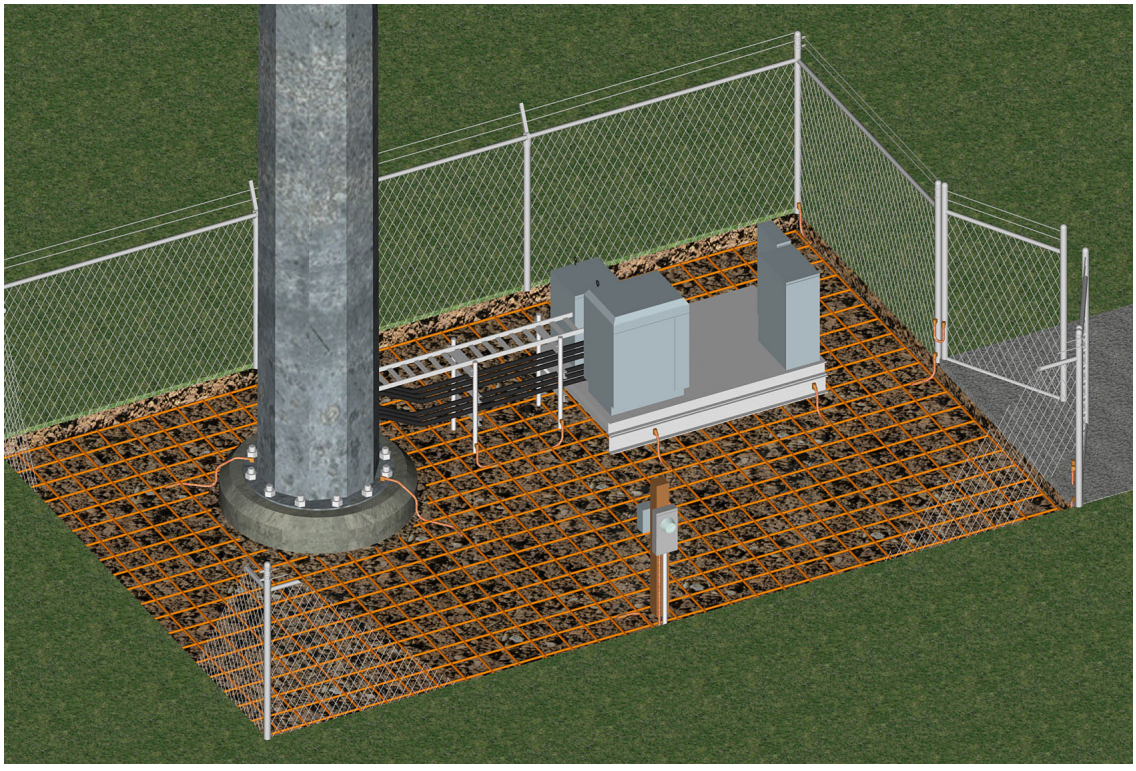


Figure 4-34. Typical Wire Mesh Installation at Site with Limited Space (Ground Cover Not Shown)

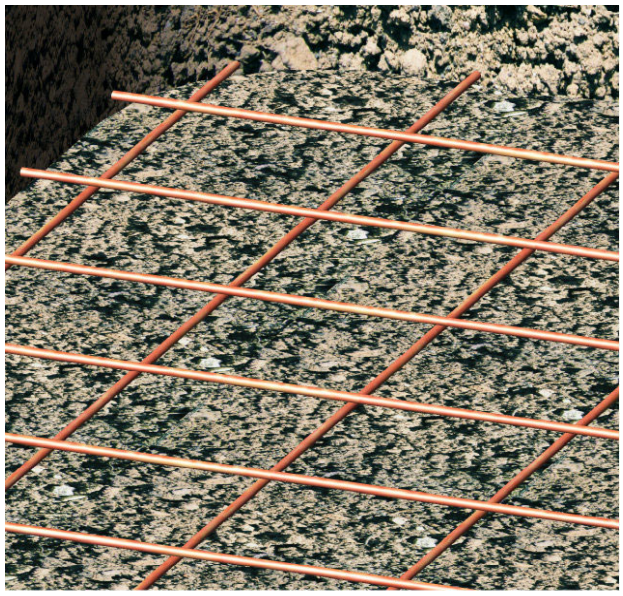


Figure 4-35. Wire Mesh Close-up View (Ground Cover Not Shown)

4.6.1.13.2 Sites Without Topsoil

The wire mesh **shall** be secured in place using one of the following techniques:

- Securing the mesh to the rock surface with appropriate hardware at least every 1 m (3 ft). See Figure 4-36.

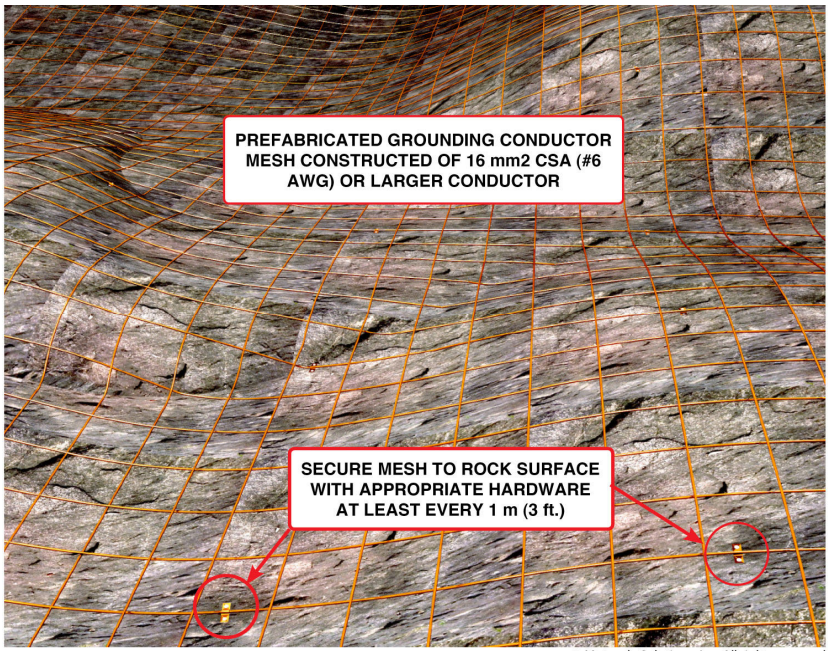


Figure 4-36. Wire Mesh Attached to Rock Surface at Sites Without Topsoil

- Covering the wire mesh with at least 15 cm (6 in.) of top soil (native or imported). Covering the mesh with topsoil improves the resistance to earth and may also help prevent theft. It is recommended to cover the top soil with landscaping fabric and then cover the fabric with approximately 5 cm (2 in.) of gravel.
- Protecting and securing the wire mesh with a conductive-type concrete.
- Other methods deemed practicable for the site-specific conditions.

4.6.1.14 Ground Inspection Wells

Ground inspection wells are not required, but may be desired for inspecting grounding electrode system components. Larger wells (hand-holes) may be installed at strategic locations to allow for easy clamp-on ground resistance meter (clamp-on ohmmeter) testing of portions or all of the grounding electrode system. See Figure D-16 for an example of using an inspection well for measurement.

Ground inspection wells are typically made of PVC tubing with a detachable cover to keep debris out. Wells may be rectangular, or circular with a minimum diameter of 203 mm (8 in.). A typical rectangular ground inspection well is shown in Figure 4-37.

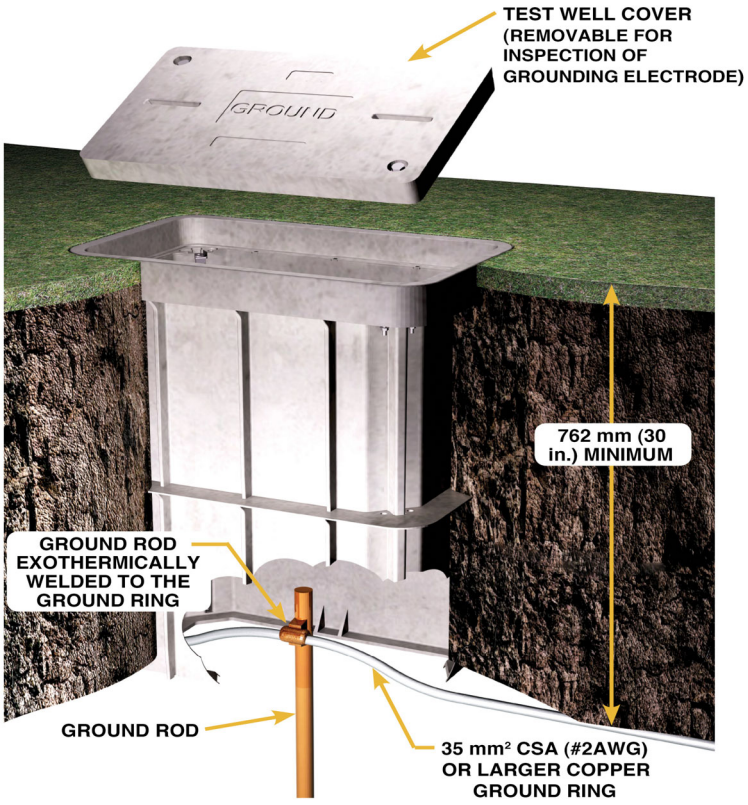


Figure 4-37. Example of Ground Inspection Well

4.6.1.15 Grounding (Earthing) Electrode Encasement Materials

The resistance to earth of a grounding electrode is directly proportional to soil resistivity and inversely proportional to the total area in contact with the soil. Grounding electrode encasement materials (also known as backfill, ground-enhancing material, or engineered soil) may consist of the following: bentonite-containing material, coke breeze or other carbon-based materials, concrete or conductive concrete, or cement made with graded granular carbonaceous aggregate in place of conventional sand or gravel. Grounding electrode encasement materials can absorb water from the surrounding soil and have hydration and water retention properties. When placed around grounding electrodes and their interconnecting cable, grounding electrode encasement materials greatly increase the effective area in contact with soil, which in turn reduces the resistance of the grounding electrode system. See IEEE 1692-2023, section 8.2; MIL-HDBK-419A Volume I, section 2.9; and BS 7430:2026, sections 8.2.2 and 8.11 for more details.

Grounding electrode encasement material may be used as needed to improve the grounding electrode system resistance and/or to protect grounding electrode system components from corrosive soil (see BS 7430:2026, sections 8.2.2 and 8.11). Grounding electrode encasement material is typically used with electrolytic ground rods but may also be applied to grounding conductors, conventional ground rods, and ground plates to enhance resistance to earth (see TIA-607-E, section C.9). See Figure 4-38 for examples.



Figure 4-38. Grounding Electrode Encasement Material Covering Grounding Electrode System Components

Requirements for the use of grounding electrode encasement material are as follows:

- Grounding electrode encasement material **shall** meet the requirements of IEC 62561-7:2024.
- Grounding electrode encasement material **shall** be packaged for the purpose of grounding electrode encasement.
- Grounding electrode encasement material **shall** be used according to the manufacturer's instructions.
- As outlined in IEC 62561-7:2024, the manufacturer **shall** supply instructions for preparation and installation, resistivity values, and a statement of conformity.
- Grounding electrode encasement material **shall** be environmentally safe and chemically inert to subsoil (IEC 62561-7:2024).
- Grounding electrode encasement material **shall not** contain more than 2% sulfur (IEC 62561-7:2024).

Coke breeze, a byproduct of coal in coke ovens, is generally an acceptable material for use. This is because the extremely high temperatures used in the coking process have removed the corrosive and volatile elements. Coke breeze is environmentally safe, stable, and conductive when completely dry or frozen, non-moisture-dependent, compactable, and very economical to install. Charcoal and/or petroleum-based coke breeze **shall not** be used. These materials typically contain high levels of sulfur, which can accelerate corrosion in the presence of moisture. See FAA-STD-019G, section 4.4.5.1 and NWSM 30-4106:2017, section 2.8.2.4 for more information.

IEEE 1692-2023, section 8.2, recommends a conductive cement. Conductive cement is further recommended to be used on radial grounding conductors when the soil resistivity exceeds 500 Ω-m.

According to MIL-HDBK-419A and the ITU *Earthing and Bonding Handbook*, the recommended grounding electrode encasement (backfill) material is a mixture of 75% gypsum, 20% bentonite clay, and 5% sodium sulfate. The gypsum, which is composed of calcium sulfate, absorbs and retains moisture, adding reactivity and conductivity to the mixture. Because it contracts very little when moisture is lost, it will not pull away from the ground rod or the surrounding earth. The bentonite ensures good contact between the ground rod and the earth through its expansion, while the sodium sulfate prevents polarization of the ground rod by removing the gases formed when current enters the earth through the ground rod. This mixture is readily available from cathodic protection distributors as standard galvanic anode backfill. The backfill mixture should be covered with 305 mm (12 in.) of excavated soil. See MIL-HDBK-419A Volume I, section 2.9, and the ITU *Earthing and Bonding Handbook*, section 3.9, for additional information.

IMPORTANT: Coke breeze or other carbon-based products that contain more than 1% sulfur by weight **shall not** be used because they accelerate corrosion when exposed to moisture. See FAA-STD-019G, section 4.4.5.1.

4.7 Grounding (Earthing), Bonding, and Down Conductors

Conductors are used to connect grounding electrodes together, form buried ground rings, or to connect objects to the grounding electrode system. See BS 7430:2026 and NFPA 70-2026, Article 100, for additional information.

4.7.1 General Specifications

General specifications for grounding conductors are as follows:

- Unless otherwise specified, all grounding and bonding conductors **shall** be copper or tinned-copper (ATIS-0600334.2019(R2024), section 5.1; IEEE 1692-2023, section 8.2; and TIA-607-E, section C.10). Tinned-copper conductors are generally preferred for external grounding (see IEEE 1692-2023, section 8.2).

NOTE: Where copper theft is a concern, alternative solid bare conductors may be used as described in “Theft-Deterrent Conductors” on page 4-39.

- Below-grade grounding conductors **shall** be bare (ATIS-0600334.2019(R2024), section 5.1).
- Unless otherwise specified, all below-grade grounding conductors **shall** be solid (ATIS-0600334.2019(R2024), section 5.1). Conductors larger than 35 mm² csa (#2 AWG) may be stranded, but should be tinned to help reduce corrosion.
- Tinned-copper conductors should be used to help minimize galvanic corrosion between tower legs (and other galvanized steel objects) and other parts of the grounding electrode system (ATIS-0600313.2019(R2024), section 10.7). See “Dissimilar Metals and Corrosion Control” on page 4-55.
- Tinned-copper conductors **shall** be used when bonding to tower legs and other galvanized steel items with mechanical clamps (IEC 62305-3:2024, section D.5.6.2.2.2).
- Below-grade or partially below-grade bonding conductors **shall** be 35 mm² csa (#2 AWG) or larger (ATIS-0600313.2019(R2024), Figure 3(a) and TIA-607-E, section C.10).
- Bonding conductors routed horizontally below-grade (such as the bonding jumper from a generator or fuel tank to the ground ring) **shall** be buried deep enough to provide conductor protection and not create a trip hazard. The recommended depth is no less than 46 cm (18 in.).
- For high lightning prone areas and/or military installations, larger conductors, such as 50 mm² csa (#1/0 AWG) or larger, should be considered for the ground ring (see MIL-HDBK-419A). Grounding conductors larger than 35 mm² csa (#2 AWG) may be stranded, but should be tinned to help reduce corrosion.
- Grounding electrode conductors **shall** be installed in one continuous length without a splice or joint, unless spliced using exothermic welding or listed irreversible high-compression connectors (NFPA 70-2026, Article 250.64). See “Bonding to the External Grounding and Bonding System” on page 4-61 for additional information.
- Above-grade bonding conductors should be jacketed if needed to help prevent unintentional contact between the copper conductor and metallic objects. Unintentional contact may create corrosion points.
- Above-grade bonding conductors used for bonding individual metallic objects **shall** be 16 mm² csa (#6 AWG) or larger (ATIS-0600334.2019(R2024), section 5.3.3). See “Metallic Objects Requiring Bonding” on page 4-108 for additional information.
- Above-grade bonding conductors used for bonding multiple metallic objects (used as a ground bus conductor) **shall** be 35 mm² csa (#2 AWG) or larger. See “Metallic Objects Requiring Bonding” on page 4-108.
- Above-grade jacketed bonding conductors exposed to direct sunlight **shall** have a UV resistant-rated jacket.
- Solid straps or bars may be used as long as the cross-sectional area equals or exceeds that of the specified grounding conductor.

IMPORTANT: Flat braided conductors **shall not** be used in the external grounding system. Flat braided conductors are prone to corrosion and can become a point for RF interference.

IMPORTANT: Unless otherwise allowed in this chapter, aluminum conductors **shall not** be used. See NFPA 70-2026, Article 250.64, and NFPA 780-2026 for more information.

NOTE: To help prevent corrosion, tinned-copper conductors should be used throughout the grounding electrode system. Tinned-copper conductors may be used anywhere copper conductors are specified in this chapter.

4.7.1.1 Theft-Deterrent Conductors

Where copper theft is a concern, alternative solid bare conductors may be used instead of copper or tinned-copper conductors (see Figure 4-39 for an example). Table 4-3 lists common theft deterrent conductors and their applications (ATIS-0600334.2019(R2024)).

- The conductors **shall** meet the conductivity requirements of ATIS-0600037-2016 (ATIS-0600334.2019(R2024), section 5.1 and 5.3).
- The conductors **shall** meet all other requirements of ATIS-0600037-2016 (ATIS-0600334.2019(R2024), section 5.1 and 5.3).
- See Table 4-3 for a list of common theft deterrent conductors and their applications (ATIS-0600334.2019(R2024)).



Figure 4-39. Theft Deterrent Conductor Example

Table 4-3. Commonly-Used Theft-Deterrent Conductor Applications

Theft-Deterrent Conductor	Application	Usage Precautions
Copper bonded steel, stranded cable	•Above-grade •Pigtails to below-grade solid copper grounding electrode •Coax grounding kits	Stranded conductors are not recommended for below-grade grounding electrode system, other than usage as pigtails to below-grade system.
Copper bonded steel, solid round	•Above-grade •Below-grade	Ensure conductor has adequate malleability when used around bends and corners.
Copper bonded steel, tape	•Above-grade •Below-grade	Ensure conductor has adequate malleability when used around bends and corners.
Composite cable with tinned-copper inner and galvanized steel outer	•Above-grade •Pigtail to below-grade solid copper grounding electrode •Coax grounding kits	Not suitable for below-grade electrode system. Where used as pigtails to connect to copper grounding electrode system below-grade, the buried section must be waterproofed with insulation, silicone or other material. Buried section is corrosion-prone.
Composite cable with tinned-copper inner and tinned-copper bonded steel outer	•Above-grade •Below-grade •Pigtail to below-grade solid copper grounding electrode •Coax grounding kits	Stranded conductors are not recommended for below-grade grounding electrode system, other than usage as pigtails to below-grade system.
Galvanized steel cable	•Above-grade •Pigtail to below-grade solid copper grounding electrode •Coax grounding kits	Not suitable for below-grade grounding electrode system. When used as pigtails to connect to copper below-grade, the buried section must be waterproofed with insulation, silicone or other material. Buried section is corrosion-prone.
Stainless steel cable	•Above-grade •Pigtail to below-grade solid copper grounding electrode •Coax grounding kits	Stranded conductors are not recommended for below-grade grounding electrode system, other than usage as pigtails to below-grade system. Ensure conductor has adequate malleability when used around bends and corners.
Source: ATIS-0600334.2019(R2024)		

4.7.2 Bending and Routing Grounding, Bonding, and Down Conductors

The following requirements apply to all grounding, bonding, and down conductors:

- Sharp bends **shall** be avoided (ATIS-0600313.2019, section 11.3; ATIS-0600334.2019(R2024), section 13.4; and IEEE 1692-2023, section 8.4).
- Grounding, bonding, and down conductor bending radius **shall not** be less than 0.2 m (8 in.) and the conductor bend angles (included angle) **shall not** be less than 90 degrees (ATIS-0600313.2019(R2024), section 11.3; IEEE 142-2007, section 3.3.3.4; MIL-STD-188-124B; NFPA 780-2026, section 4.8.5; and TIA-607-E, section C.10 and 7.5.2). A diagonal run is preferable to a bend, even though it does not follow the contour or run parallel to the supporting structure. See Figure 4-40.
- Grounding, bonding, and down conductors **shall** be run as short, straight, and smoothly as practicable, with the fewest possible number of bends and curves (ATIS-0600313.2019(R2024), section 11.3; IEEE 1692-2023, section 8.4; and NFPA 70-2026, Article 750).
- Grounding, bonding, and down conductors **shall** be run in a direct manner with no sharp bends or narrow loops (ATIS-0600313.2019(R2024), section 11.3; ATIS-0600334.2019(R2024), section 13.4; and NFPA 70-2026, Article 750). Sharp bends and/or narrow loops increase the impedance and may produce flash points (also see NFPA 780-2026, section 4.8.5).
- All bends and curves **shall** be made toward the ground location (grounding electrode system or ground busbar).
- Grounding and bonding conductors **shall** be separated by at least 5 cm (2 in.) from other cable types, where practicable.

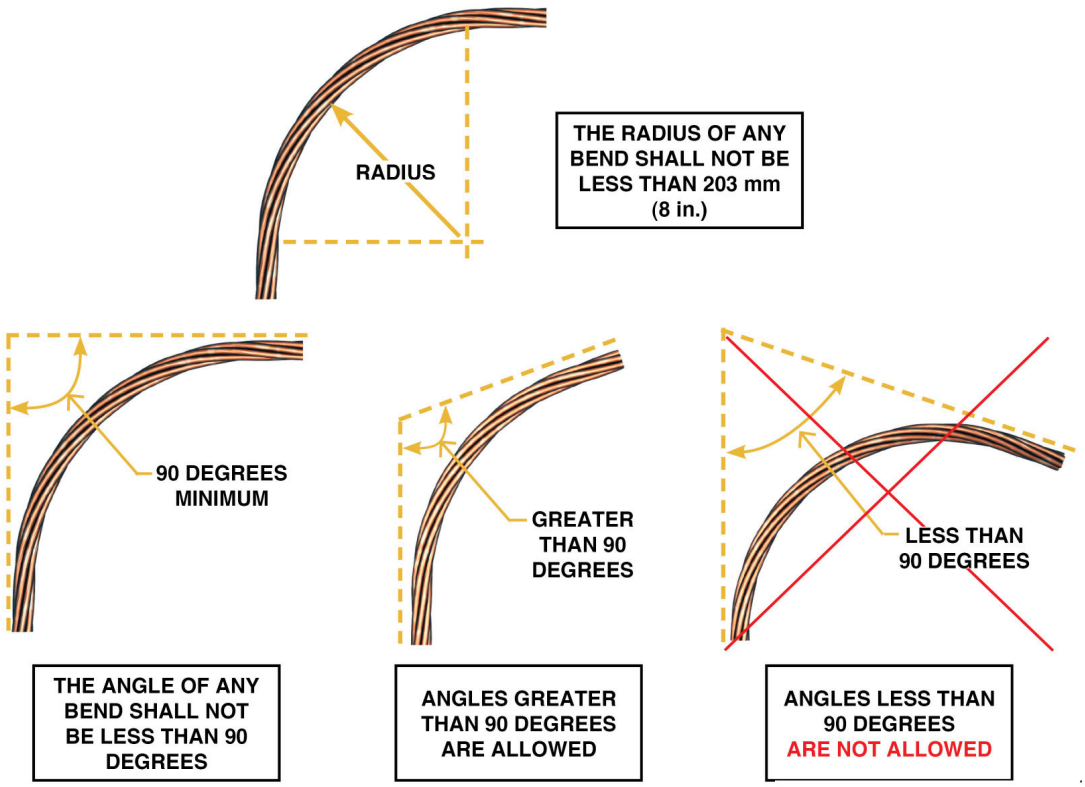


Figure 4-40. Minimum Bending Radius

4.7.3 Protecting and Securing Grounding, Bonding, and Down Conductors

Above-grade external grounding conductors, including straps, are exposed to movement by wind and other forces that can lead to damage or breakage over time. All grounding, bonding, and down conductors **shall** be appropriately protected and secured.

The following requirements apply when installing grounding and bonding conductors:

- Conductors **shall** be protected where exposed to potential physical damage (BICSI N3-20; ISO/IEC 30129:2015, section 8.3.4; NFPA 70-2026, Articles 250.64 and 750; NFPA 780-2026, section 4.8.11; and TIA-607-E, section 7.5.4). Such damage may arise from foot traffic or lawn maintenance equipment.
- Conductors exposed to damage **shall** be protected in a non-metallic conduit. The conduit should extend 30 cm (12 in.) above-grade and 15 cm (6 in.) below-grade.
- Down conductors exposed to physical damage **shall** be protected for a minimum distance of 1.8 m (6 ft) above-grade level, where applicable (NFPA 780-2026, section 4.8.11.2). See “Down Conductors” on page 4-43.
- Metallic guards and/or conduits used to protect conductors **shall** be bonded to the grounding conductor at both ends (ATIS-0600313.2019(R2024), section 11.4; NFPA 70-2026, Articles 250.64 and 750; and NFPA 780-2026, section 4.8.11.1). The bonding conductors **shall** be the same size as the protected conductor, where practicable.

IMPORTANT: Where conduit is used, it should be non-metallic (ATIS-0600313.2019(R2024), section 11.4).

- The conductor or its enclosure **shall** be securely fastened to the surface on which it is carried (NFPA 70-2026, Articles 250.64 and 750; and NFPA 780-2026, section 4.9).
- Above-grade conductors **shall** be securely fastened at intervals not exceeding 91 cm (3 ft), where practicable (ATIS-0600334.2019(R2024), section 8.3 and NFPA 780-2026, section 4.9).
- Conductors **shall** be secured using suitable hardware designed for this purpose.
- Where metallic fasteners are used on bare conductors, fasteners of the same material (or compatible) **shall** be used. See NFPA 780-2026, section 4.9.4, for additional information.
- Ferrous metallic fasteners that fully encircle the conductor **shall not** be used. These type of fasteners can form a choke point, resulting in a high impedance point.

4.7.3.1 Protecting and Securing Copper Strap

Copper straps **shall** be secured and protected using the same methods as conductors. Wind can cause copper straps to behave like airfoils; therefore, additional securing is likely needed to prevent damage. For protection and security, using a continuous protective covering designed for this purpose is advised (see Figure 4-41).

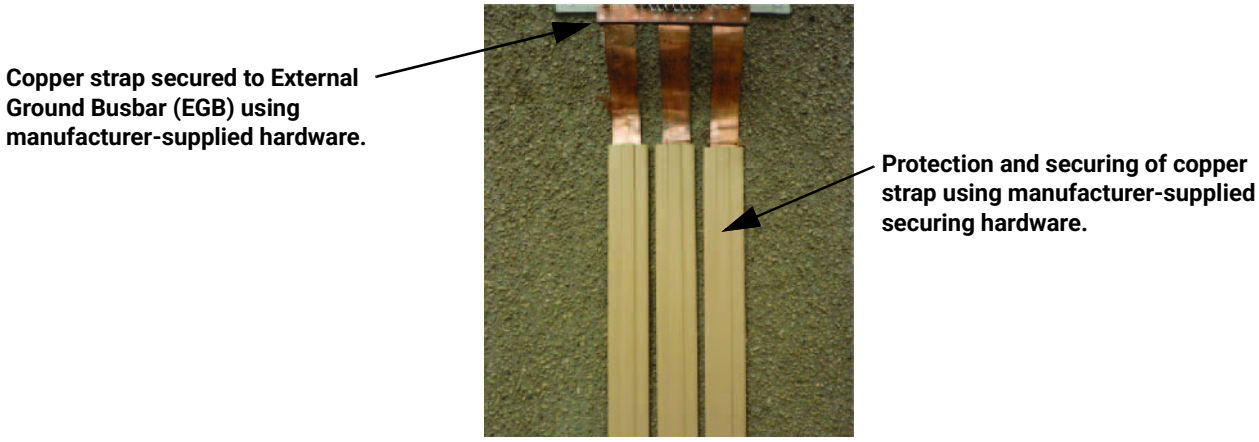


Figure 4-41. Example of Protecting and Securing Copper Strap

4.7.4 Down Conductors

Down conductors are conductors used to transfer objectionable or unwanted electrical currents and surges to earth from high locations, such as building rooftops. In some applications, down conductors are required to bond to the grounding electrode system. Such applications may include, but are not limited to, the following:

- Roof-mounted antennas
- Side-mounted antennas
- Rooftop-mounted towers
- Rooftop communications sites
- Roof- or side-mounted Access Points, Wireless Routers, Point-to-Points and similar devices

4.7.4.1 Down Conductor Sizing

Where bonding to the common grounding electrode system is accomplished using a lightning protection system, the down conductors **shall** be the same size as the lightning protection system main conductor, based on building height (see NFPA 780-2026, section 4.1, and the associated subsections). Listed aluminum lightning protection system conductors are permitted, but **shall not** be installed below-grade or within 457 mm (18 in.) of grade.

IMPORTANT: If aluminum lightning protection system conductors are used, they **shall not** be attached to a surface coated with alkaline-based paint, embedded in concrete or masonry, or installed in a location subject to excessive moisture (NFPA 780-2026, section 4.3.3).

IMPORTANT: Aluminum grounding conductors **shall not** be installed below-grade or within 460 mm (18 in.) of grade (NFPA 780-2026, section 4.2.2.3.1).

NOTE: Lightning protection system conductors **shall** be listed for the purpose.

See Figure 4-42 for an example of an aluminum conductor that transitions to copper prior to entering the earth.

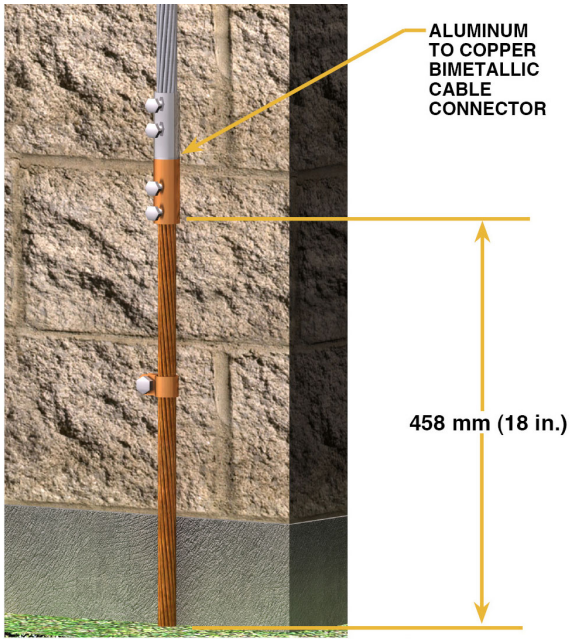


Figure 4-42. Aluminum Lightning Protection System Conductor Transitioning to Copper Prior to Entering Earth

If a listed lightning protection system conductor is used, it **shall** be sized appropriately according to the structure height. See Table 4-4 and Table 4-5 for lightning protection system grounding conductor sizing information (NFPA 780-2026, section 4.1, and associated subsections).

Table 4-4. Lightning Protection System Grounding Conductors for Structures Less than 22.9 m (75 ft) Tall (Class I Conductor)

Conductor Parameter	Copper		Aluminum	
	SI	US	SI	US
Size of each strand	1.04 mm²	17 AWG	2.08 mm²	14 AWG
Weight per length	278 g/m	187 lb/1000 ft	141 g/m	95 lb/1000 ft
Cross-section area	29 mm²	57,400 cir. mils	50 mm²	98,600 cir. mils

Table 4-5. Lightning Protection System Grounding Conductors for Structures Equal to or Greater than 22.9 m (75 ft) Tall (Class II Conductor)

Conductor Parameter	Copper		Aluminum	
	SI	US	SI	US
Size of each strand	1.65 mm²	15 AWG	2.62 mm²	13 AWG
Weight per length	558 g/m	375 lb/1000 ft	283 g/m	190 lb/1000 ft
Cross-section area	58 mm²	115,000 cir. mils	97 mm²	192,000 cir. mils

Where a lightning protection system is not installed, the down conductor **shall** be sized according to length as shown in Table 4-6, or a listed lightning protection system conductor may be used (see Figure 4-43).

Table 4-6. Copper Grounding Down Conductor Sizing (From MIL-HDBK-419-A)

Conductor length in linear m (ft)	Conductor size in mm^2 csa (AWG / MCM)
Less than 10 (Less than 33)	33.62 (2)
10.36 – 12.5 (34 – 41)	42.4 (1)
12.8 – 16 (42 – 53)	52 (1/0)
16.5 – 20 (54 – 66)	67.4 (2/0)
20.4 – 25.6 (67 – 84)	85 (3/0)
25.9 – 32 (85 – 105)	107 (4/0)
32.3 – 38.1 (106 – 125)	126.70 (250 MCM)
38.4 – 45.7 (126 – 150)	152 (300 MCM)
46 – 53.34 (151 – 175)	177 (350 MCM)
53 – 76.1 (176 – 250)	253.4 (500 MCM)
76.4 – 91.39 (251 – 300)	300 (600 MCM)
Greater than 91.39 (300)	380 (750 MCM)

Table 4-7. Standard Copper Wire Sizes Available for International Market

Conductor size in mm^2 csa	Conductor size in AWG / MCM
6	10
10	8
16	6
25	4
35	2
50	1/0
70	2/0
95	3/0
120	4/0
150	300 MCM
185	350 MCM
240	500 MCM
300	600 MCM
400	750 MCM

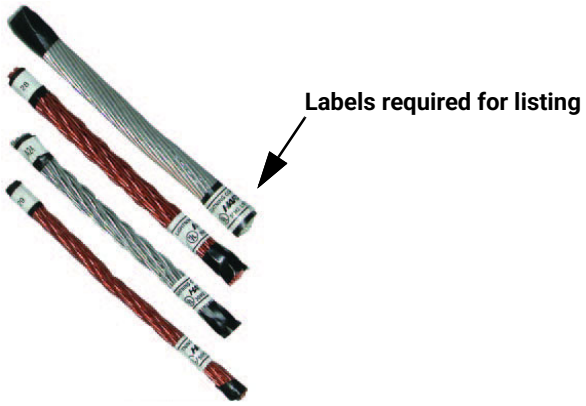


Figure 4-43. Lightning Protection System Grounding Conductor Examples

4.7.5 External Ground Busbar

The purpose of the External Ground Busbar (EGB) is to provide a convenient grounding termination point for antenna transmission lines (coaxial cables) and other cables prior to their entry into a building or shelter (ATIS-0600313.2019(R2024); ATIS-0600334.2019(R2024), section 7.5; and TIA-607-E, section D.2.2).

Antenna transmission lines (including waveguide) and other communications cables with metallic shields (and/or grounding conductor) **shall** be grounded as close as practicable to their point of entry into the building or shelter (ATIS-0600334.2019(R2024), section 6.6, and NFPA 70-2026, Article 750).

Requirements for EGBs are as follows:

- The EGB **shall** be constructed and minimally sized according to Table 4-8, ensuring the ground busbar is sufficiently large to accommodate all transmission lines and other grounding connections.
- The EGB **shall** be designed for grounding purposes and **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- The EGB **shall** be installed at the point where the antenna transmission lines and other communications cables enter the building or shelter.
- The EGB **shall** be bonded directly to the grounding electrode system with a downward run of 35 mm² csa (#2 AWG) or larger bare copper or tinned-copper conductor(s) (see Figure 4-44). It is recommended to use a larger conductor, such as 120 mm² csa (#4/0 AWG) (NWSM 30-4106:2017). The grounding conductor **shall** be installed in a direct manner with no sharp bends or narrow loops. See “Bending and Routing Grounding, Bonding, and Down Conductors” on page 4-41.
- Flat copper strap may also be used for bonding the EGB to the grounding electrode system and is the preferred method. See Figure 4-41 on page 4-43 for an example of copper strap.
- The connection of the grounding electrode conductor to the EGB **shall** use an exothermic weld or listed irreversible high-compression connections (ATIS-0600334.2019(R2024) section 7.3). Copper strap **shall** be connected to the EGB using manufacturer-supplied hardware designed for the purpose.

Table 4-8. External Ground Busbar Specifications

Item	Specification
Listing Requirement	**Shall** be listed by a Nationally Recognized Testing Laboratory (NRTL)
Material	Bare, solid alloy 110 (99.9%) copper busbar or plate of one-piece construction. May be tin-plated.
Minimum Dimensions	Height: 50 mm (2 in.). A height of 100 mm (4 in.) is the recommended minimum. Thickness: 6.35 mm (0.25 in.) Length: Variable to meet the application requirements and allow for future growth. A minimum length of 305 mm (12 in.) is recommended.
Mounting Brackets	Stainless steel
Insulators	Polyester fiberglass 2 kV minimum voltage rating
Conductor Mounting Holes	The number is dependent on the number of conductors to be attached. Holes should be 11 mm (7/16 in.) on 19 mm (3/4 in.) or 24.5 mm (1in.) centers for convenient use of two-hole lugs. Slotted hole patterns may be used if sized to the minimum dimensions listed previously.
Method of Attachment of Grounding Electrode Conductor	Exothermic welding Irreversible high-compression crimp connection

Ground busbars should be tinned and secured to the support bracket and structure using theft-deterrent security hardware. See Figure 4-44.

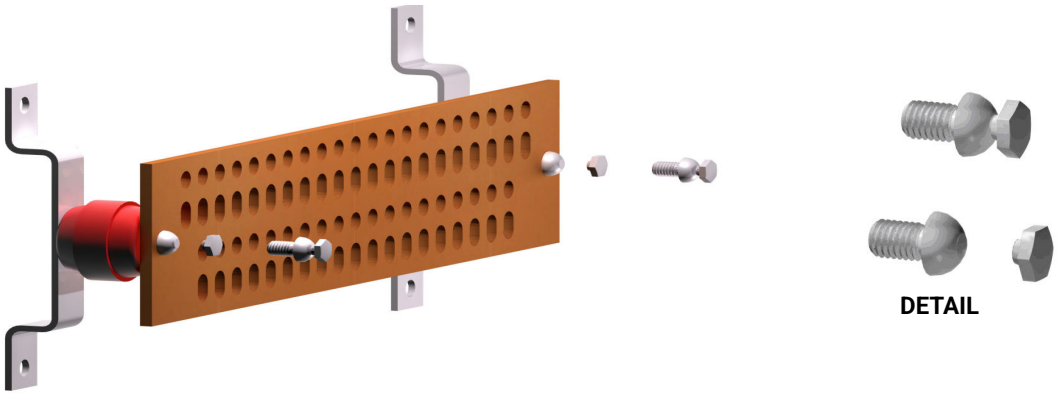


Figure 4-44. Example of Busbar Security Hardware

IMPORTANT: All transmission lines (including waveguide) and other communications cables with metallic shields (and/or grounding conductor) **shall** be grounded at their point of entry into the building.

NOTE: For improved lightning protection at the site, the RF transmission line entry point and EGB should be installed as low to the ground as practicable; 610 mm (2 ft) is the recommended maximum height for the RF transmission line entry point (see IEEE 1692-2023, section 9.3; and NWSM 30-4106:2017). See “Design Considerations to Help Reduce Effects of Lightning” on page 2-16.

NOTE: For reduced impedance to the grounding electrode system, solid copper strap may be used to connect the EGB to the grounding electrode system. Relatively small copper strap has significantly less inductance (impedance to lightning) than large wire conductors. For example, a 38.1 mm (1.5 in.) copper strap has less inductance than a 70 mm² csa (#2/0 AWG) wire. To further reduce the inductance to ground, several copper straps can be installed across the entire length of the external ground busbar and routed down to the external ground ring. See Figure 4-45.

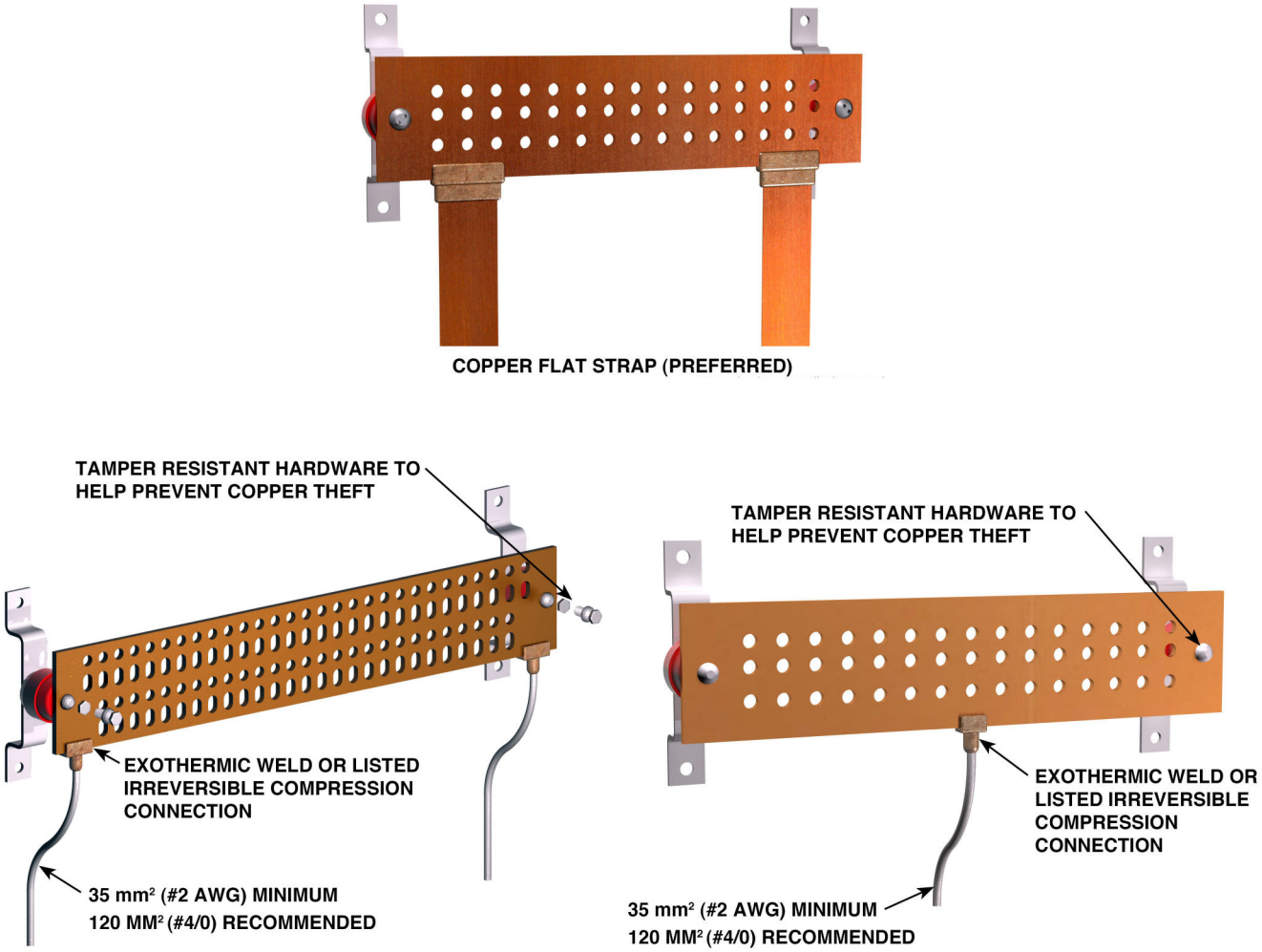


Figure 4-45. Typical External Ground Busbars (in Order of Preference)

4.7.5.1 Integrated Cable Entry Grounding System

Integrated cable entry grounding systems may be used in place of the EGB and PBB (see Figure 4-46). Requirements for integrated cable entry grounding systems are as follows:

- **Shall** be factory-assembled for grounding purposes.
- **Shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- **Shall** be installed per the manufacturer's instructions.
- Should be sized to accommodate future growth.

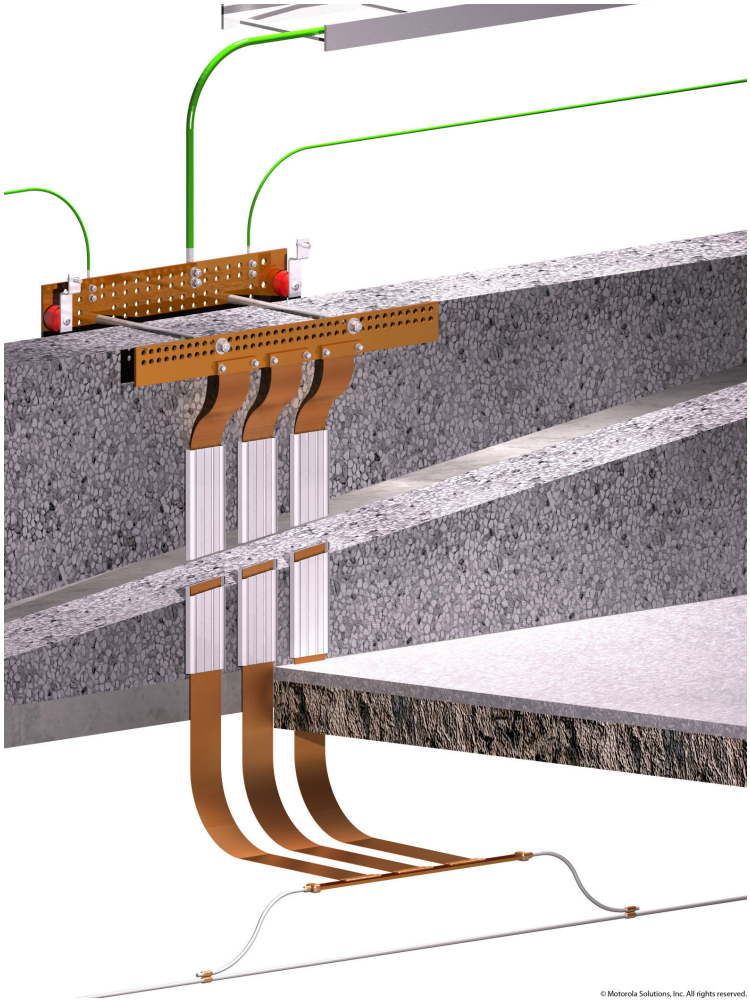


Figure 4-46. Integrated Cable Entry Grounding System

4.7.6 Tower Ground Busbar

Communications cables with an outer metallic shield (for example, coax, waveguide and shielded Category 5e/6/6a/8, etc.) **shall** be bonded to the tower to prevent lightning from creating a potential difference between the cables and the tower. A difference in potential can cause arcing, leading to cable damage.

The Tower Ground Busbar (TGB) serves as a convenient termination point on the tower for bonding multiple communications cables, such as coax, waveguide and shielded Category 5e/6/6a/8. A TGB may not be necessary on towers with three or fewer communications cables if cable bonding can be done neatly and professionally.

4.7.6.1 General Requirements for Tower Ground Busbars

The general requirements for installing TGBs are as follows:

- The TGB should be an integral part of the tower construction. If the TGB is not part of the tower construction, it **shall** be built and sized according to Table 4-9, ensuring it is large enough to accommodate all transmission lines and other grounding connections.
- The top and intermediate ground busbars **shall** be either solidly mounted to the tower using attachment hardware and fasteners that provide an effective electrical bond, or they **shall** be insulated from the tower and bonded to the structural steel using a separate grounding conductor. See Telcordia GR 3171 CORE.i02, section 10.2.2 for more information.
- The TGB **shall** be designed for grounding and **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).

CAUTION: Busbars installed on galvanized towers SHALL be tin-plated to prevent corrosion damage to the galvanized tower. See IEC 62305-3:2024, section D.5.6.2.2.1.

CAUTION: Contact the tower manufacturer for approved exothermic weld locations on the tower when exothermically welding connections.

- Where a galvanized tower is not protected from precipitation run-off of copper and copper alloys, the TGB **shall** be constructed from tinned-copper. See “Methods to Help Reduce Corrosion” on page 4-59.
- The TGB **shall** be installed beneath the communications cable ground kits to provide for a continuous downward discharge path for lightning.
- Grounding conductors bonded to the TGB **shall** be run as short, straight and smoothly as practicable. See “Bending and Routing Grounding, Bonding, and Down Conductors” on page 4-41.
- The TGB grounding electrode conductor may be sleeved in polyvinyl chloride (PVC) tubing for protection if desired (ATIS-0600313.2019(R2024), section 11.4). This may be necessary to prevent the grounding conductor from making incidental contact with the tower.
- The TGB should be secured using a type of security hardware to help deter theft (ATIS-0600037-2016, section 4.1.1.1). See Figure 4-44 on page 4-47 for an example.

Table 4-9. Tower Ground Busbar Specifications

Item	Specification
Listing Requirement	**Shall** be listed by a Nationally Recognized Testing Laboratory (NRTL)
Material	• Bare, solid Alloy 110 (99.9%) copper busbar or plate of one-piece construction. • **Shall be tin-plated if installing on a galvanized tower.** See “Dissimilar Metals and Corrosion Control” on page 4-55 for information regarding tower corrosion related to copper busbars.
Minimum Dimensions	• Height: 50 mm (2 in.). 100 mm (4 in.) is the recommended minimum height. • Thickness: 6.35 mm (0.25 in.) • Length: Variable to meet the application requirements and allow for future growth. 305 mm (12 in.) is the recommended maximum.
Mounting Brackets	Stainless steel
Conductor Mounting Holes	• The number is dependent on the number of conductors to be attached. • Holes to be 11 mm (7/16 in.) minimum diameter on 19 mm (3/4 in.) minimum centers for convenient use of two-hole lugs. • Slotted hole patterns may be used if sized to the minimum dimensions listed previously.

Table 4-9. Tower Ground Busbar Specifications

Item	Specification
Method of Attachment of Grounding Electrode Conductor	• Exothermic welding • Irreversible high-compression crimp connection • Listed two-hole lugs (intermediate tower ground busbars only)

4.7.6.2 Bottom Tower Ground Busbar Requirements

The requirements for installing the bottom TGB are as follows:

- See “General Requirements for Tower Ground Busbars” on page 4-50.
- The bottom TGB **shall** be installed below the communications cables’ ground kits, near the area of the tower at the point where the cables transition from the tower to the shelter. The TGB should be placed at a point where the ground kits may be attached without the need to extend the ground kit conductors.
- Where practicable, the bottom TGB **shall** be bonded directly to the tower using one of the following methods:
  - Bolting the busbar directly to the tower structure using appropriate stainless steel hardware. This **shall** provide a direct electrical bond. See Figure 4-47.
  - Securing the busbar to the tower using appropriate mechanical hardware and electrically bonding the busbar to the tower using a grounding conductor. The grounding conductor **shall** connect to the nearest tower leg or diagonal structural support at a point below the TGB. The grounding conductor **shall** be bonded to the tower using appropriate hardware, such as stainless steel beam clamps or stainless steel band/strap type clamps.
- The bottom TGB **shall** be bonded to the tower grounding electrode system with a 35 mm² csa (#2 AWG) or larger copper or tinned-copper conductor. For reduced impedance to the grounding electrode system, the bottom TGB can be connected to the external grounding electrode system using two grounding electrode conductors (see Figure 4-45 on page 4-48 for an example of two grounding electrode conductors).
- The busbar grounding electrode conductor **shall** attach to the busbar using exothermic welding or irreversible high-compression connector. Single-hole and two-hole lugs **shall not** be used.

IMPORTANT: Where practicable, the bottom TGB **shall** be bonded to the tower and the grounding electrode system. Refer to the following examples for detailed bonding information.

Figure 4-47 shows a bottom busbar that is directly bonded to the tower using appropriate stainless steel hardware. In this configuration, a bonding conductor from the busbar to the tower is not necessary.

Figure 4-48 through Figure 4-52 show typical installations utilizing busbars with insulated standoffs. In these configurations, a bonding conductor is required between the busbar and the tower.

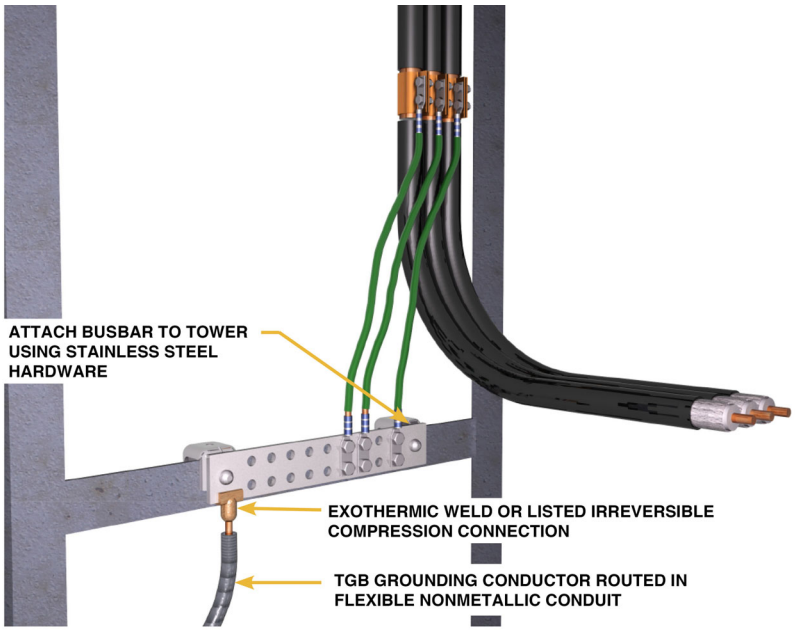


Figure 4-47. Busbar Configuration, Bottom Ground Kit on Angular Tower (Weatherproofing Not Shown): Example 1

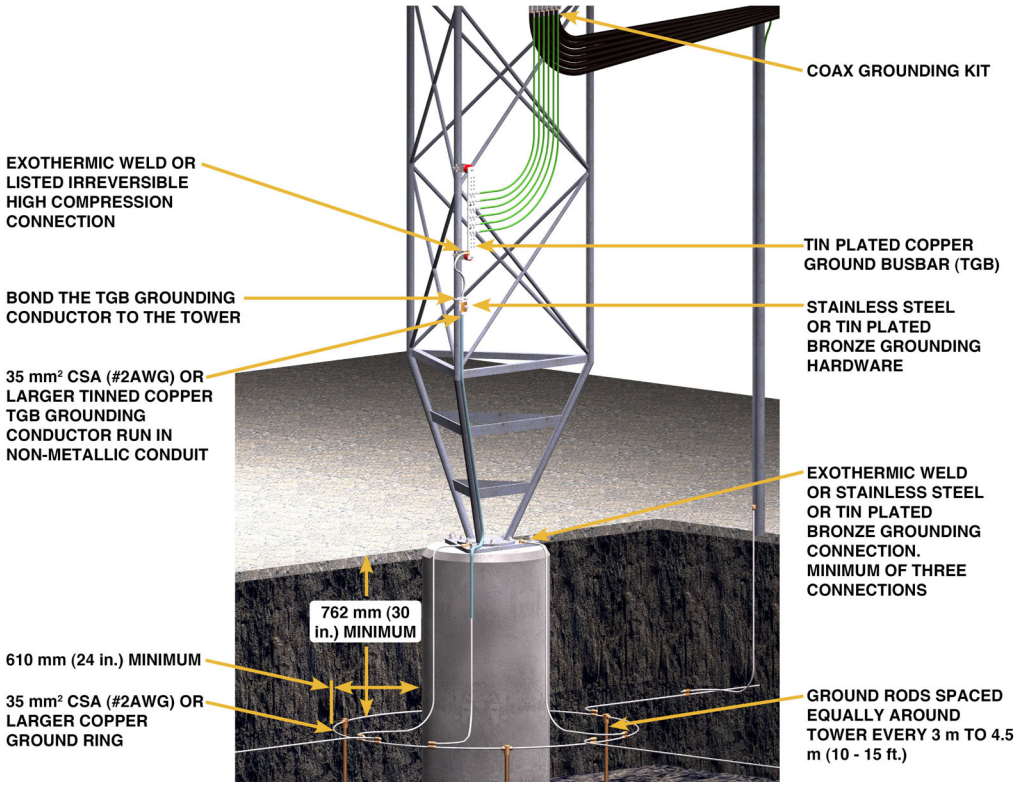


Figure 4-48. Bottom Tower Ground Busbar Configuration: Example 2

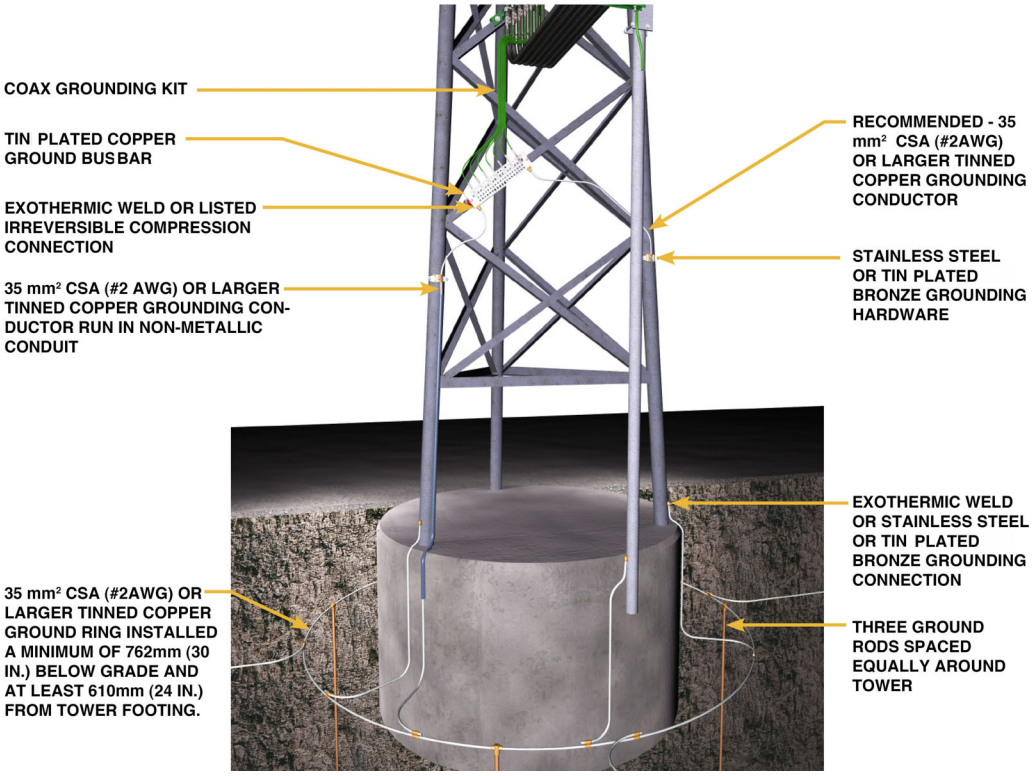


Figure 4-49. Bottom Tower Ground Busbar Configuration: Example 3

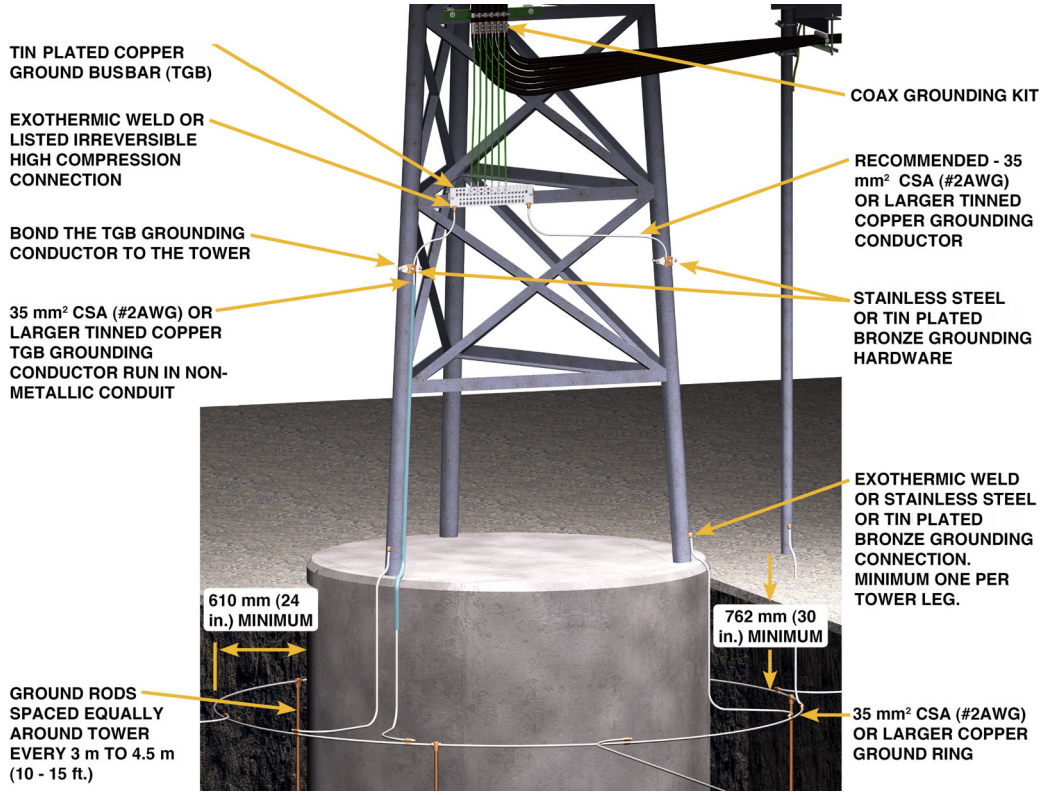


Figure 4-50. Bottom Tower Ground Busbar Configuration: Example 4

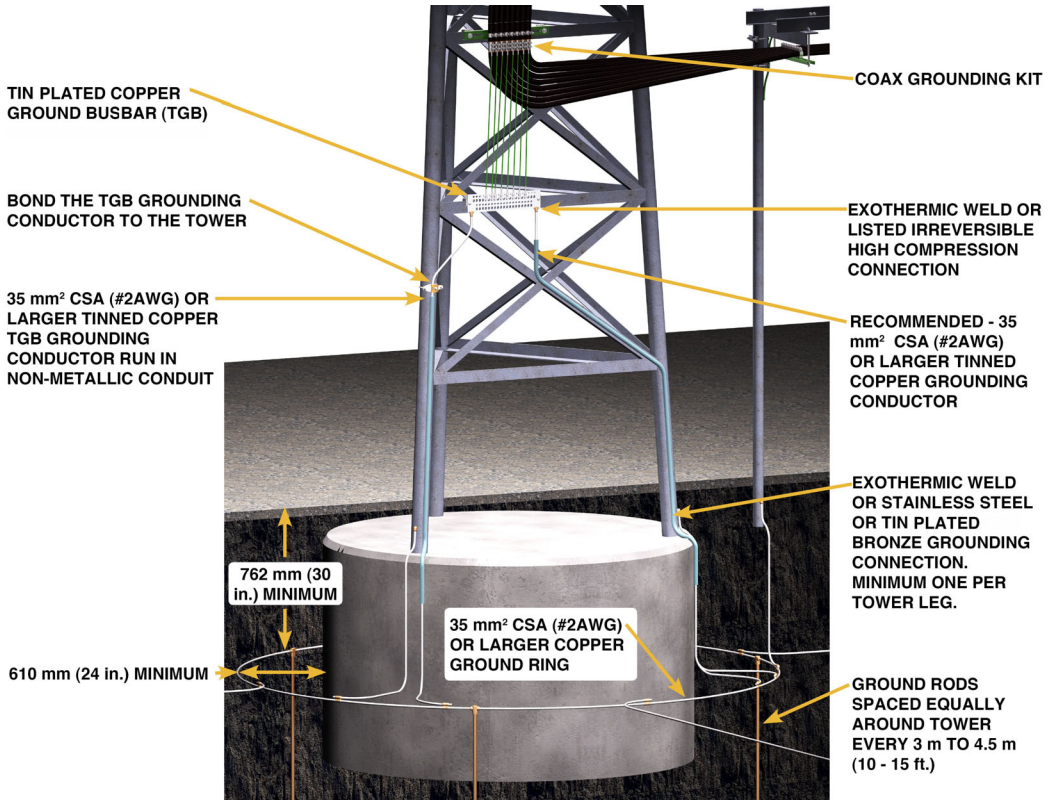


Figure 4-51. Bottom Tower Ground Busbar Configuration: Example 5

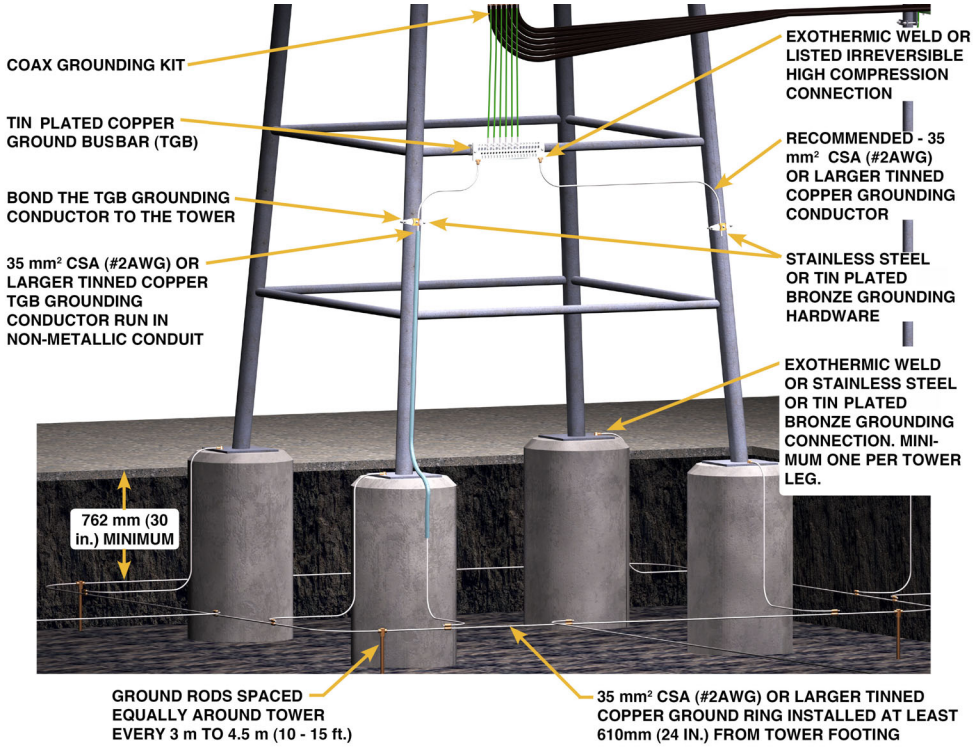


Figure 4-52. Bottom Tower Ground Busbar Configuration: Example 6

NOTE: The bottom Tower Ground Busbar should be tinned and secured using theft-deterrent security hardware to help prevent theft. The busbar should be stamped with “Stolen - Do Not Recycle” (ATIS-0600037-2016, section 4.1.1.1 and Telcordia GR-3171-CORE.i02, section 10.2.4). See Figure 4-44 on page 4-47.

4.7.6.3 Intermediate Tower Ground Busbar Requirements

Additional ground busbars may be installed at various heights on the tower to bond multiple communications cables’ ground kits to the tower, if not already included as part of the tower structure. The requirements for installing intermediate tower ground busbars (additional busbars installed along the vertical length of the tower) are as follows:

- See “General Requirements for Tower Ground Busbars” on page 4-50.
- Intermediate ground busbars **shall** be either solidly mounted to the tower using attachment hardware and fasteners that provide an effective electrical bond to the tower structure; or if insulated from the tower, bond to the structural steel of the tower with a separate grounding conductor. See Telcordia GR 3171 CORE.i02, section 10.2.2 for more information.
- The intermediate TGB **shall** be installed below the communications cables’ ground kits. The TGB should be placed at a point where the ground kits may be attached without the need to extend the ground kit conductors.
- The intermediate TGB **shall** be bonded directly to the tower using one of the following methods.
  - Bolting the busbar directly to the tower structure using appropriate stainless steel hardware. This **shall** provide a direct electrical bond. See Figure 4-47 on page 4-52 for an example. Note that the grounding electrode conductor is not required in this application.
  - Securing the busbar to the tower using appropriate mechanical hardware and electrically bonding the busbar to the tower using a grounding conductor. The grounding conductor **shall** be bonded to the tower using appropriate hardware, such as stainless steel beam clamps or stainless steel band/strap-type clamps. This conductor should be jacketed or protected in a non-metallic conduit to prevent incidental contact with the galvanized tower structure. See Figure 4-48 through Figure 4-52 for examples. Note that the grounding electrode conductor is not required in this application.
- Where used, the busbar grounding electrode conductor **shall** be bonded to the busbar using exothermic weld, irreversible compression connectors, or listed compression two-hole lugs. Single-hole lugs **shall not** be used.

NOTE: Using down conductors on metallic towers is not recommended for grounding and bonding cables, lightning rods, or for interconnecting TGBs. A down conductor has significantly higher impedance to earth than the tower structure. Using down conductors does not provide equal potential bonding between the communications cables and the tower. If a down conductor is used, it **shall** be bonded to the tower at the top, at the bottom, near and below each TGB, and at least every 60 m (200 ft), using appropriate hardware.

4.8 Dissimilar Metals and Corrosion Control

Although the types of metal used in a grounding electrode system do not affect the resistance to earth of the grounding electrode system, the metal selected should be resistant to corrosion in the type of soil in which it will be installed. The two aspects to consider regarding the corrosion resistance of a metal are the compatibility with the soil itself, and possible galvanic corrosion effects when it is electrically connected to neighboring metals at the site. See BS 7430:2026, section 8.11.

4.8.1 Corrosion Related to Soil Type

The compatibility of a metal with soil depends on the soil's chemical composition. The factors related to metal corrosion when in contact with soil include acidity or alkalinity (pH), salt content, soil porosity (aeration), and the presence of anaerobic bacteria. See BS 7430:2026, section 8.11.1.

The following is a list of soil types in order of increasing corrosive aggressiveness (BS 7430:2026, section 8.11.1):

- Gravelly soils (least aggressive)
- Sandy soils
- Silty soils (loam)
- Clays
- Peat and other organic soils
- Made up soils containing cinders (most aggressive)

The least aggressive soils tend to have high resistivity. Soil resistivity can be measured, which indicates corrosiveness under aerated conditions (BS 7430:2026, section 8.11.1). See “Performing Soil Resistivity Test” on page B-8 for measurement details.

More information about soil aggressiveness can be obtained by measuring the redox (from the words reduction and oxidation) potential of the soil, which indicates the risk of corrosion caused by anaerobic bacteria (BS 7430:2026, section 8.11.1). Test equipment for measuring redox potential is commercially available. The procedure for testing the redox potential is outlined in ISO 11271:2022(E) and BS 1377-3. A geotechnical firm may be necessary to measure the redox potential of the soil.

General guidance on the corrosiveness of certain grounding electrode system metals relative to soil composition is provided in Table 4-10 (BS 7430:2026, Table 9). A geotechnical firm might be needed to determine all the listed soil parameters.

The following general observations can be made from Table 4-10:

- Stainless steel ground rods are compatible with most soil types.
- Copper-clad steel or solid copper ground rods are common and effective materials for grounding electrodes. However, it is important to consider the negative effects of dissolved salts, organic acids, and acid soils (BS 7430:20126, section 8.11.1).
- Copper or copper-clad ground rods should not be used in soils where organic acids are present, unless protective measures are taken, such as encasing the ground rods in a grounding electrode encasement material. Organic acids are commonly found in soils with poor drainage and low aeration. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Galvanized ground rods should not be installed in soils with a redox potential below 200 mV.
- Protective measures should be implemented in soils containing dissolved salts or chlorides, such as encasing all grounding electrode system components in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Galvanized ground rods should not be used in acidic soils with a pH below 6.

Table 4-10.Corrosion Resistance Properties of Common Grounding Electrode System Metals as Related to Soil Composition

Soil Parameter		Grounding Electrode Metal		
		Copper	Galvanized Steel*	Austenitic Stainless Steel
Resistivity (Ω·cm)	< 700	Slightly Reduced	Moderately Reduced	Slightly Reduced
	700 to 4000	Slightly Reduced	Moderately Reduced	Generally Unaffected
	> 4000	Generally Unaffected	Generally Unaffected	Generally Unaffected
Redox Potential (mV)	< 200	Moderately Reduced	Considerably Reduced	Moderately Reduced
	200 to 400	Slightly Reduced	Slightly Reduced	Generally Unaffected
	> 400	Generally Unaffected	Generally Unaffected	Generally Unaffected
Moisture Content (%)	< 10	Generally Unaffected	Generally Unaffected	Generally Unaffected
	10 to 80	Slightly Reduced	Moderately Reduced	Slightly Reduced
	> 80	Slightly Reduced	Slightly Reduced	Slightly Reduced
Dissolved				
Salts		Moderately Reduced	Moderately Reduced	Slightly Reduced
Chlorides		Moderately Reduced	Moderately Reduced	Slightly Reduced
pH				
Acidic	< 6	Moderately Reduced	Considerably Reduced	Slightly Reduced
Neutral	6 to 8	Generally Unaffected	Generally Unaffected	Generally Unaffected
Alkaline	> 8	Slightly Reduced	Moderately Reduced	Generally Unaffected
Organic Acids	> 8	Considerably Reduced	Moderately Reduced	Slightly Reduced
* Motorola Solutions recommends against the use of galvanized ground rods (see “General Ground Rod Requirements” on page 4-12).				

4.8.2 Galvanic Corrosion

Galvanic corrosion (also called dissimilar metals corrosion) occurs when two dissimilar metals are electrically connected and coupled through an electrolyte, such as soil. When a metal is connected to a different metal, a potential difference exists between them. If these dissimilar metals are also in contact with low-resistivity soil, a complete circuit forms. Current flows from one metal to the other through the electrical connection and returns via the soil. This natural phenomenon is similar to how a battery provides current when its terminals are connected to a load (see IEC 62305-3:2024, section D.5.6.2.2.2 for more details). See Figure 4-53 for examples of installations with and without galvanic corrosion.

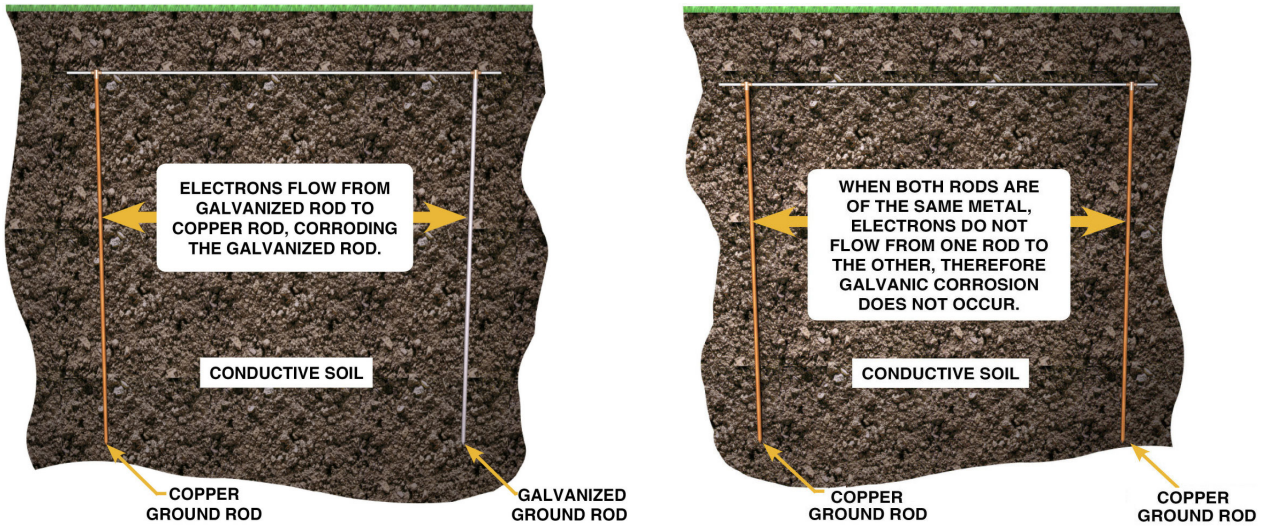


Figure 4-53. Installations With and Without Galvanic Corrosion

Metals may be listed in order of their respective potentials; such a list is called a galvanic series. A galvanic series of commonly used grounding electrode system metals and alloys is provided in Table 4-11. When a complete circuit exists, corrosion occurs on the metal listed higher in the galvanic series, known as the anode, which is the point where current exits and travels through the soil toward the metal listed lower in the series, called the cathode. For example, if a large copper grounding electrode system in conductive soil is directly or indirectly (through guys) electrically connected to a steel anchor, corrosion will happen on the anchor because steel is listed higher on the galvanic series than copper. See IEC 62305-3:2024, section D.5.6.2.2.2 for more details.

Table 4-11.Galvanic Series of Common Metals

Metal	
Magnesium	Base End or Anodic (Active) End
Zinc (material used to galvanize steel)	↕
Aluminum	
Steel, Iron	
Lead, Tin	
Brass, Copper, Bronze	
Silver	
Graphite	Noble End or Cathodic End
Source: MIL-HDBK-419A	

The rate of corrosion mainly depends on the soil's conductivity and the position of the metals in the galvanic series. The higher the soil conductivity (low resistivity) and the greater the separation between metals in the galvanic series, the faster the corrosion rate (see IEC 62305-3:2024, section D.5.6.2.2.2 for more details). Additionally, the corrosion rate is influenced by the relative surface areas of the metals (BS 7430:2026, section 8.11.2, and IEEE 142-2007). Installing a small anode (such as a galvanized steel guy anchor point) with a large cathode (like a copper grounding electrode system) should be avoided; this causes the current to be concentrated in a small area with high current density, which leads to corrosion of the galvanized steel (IEEE 142-2007).

4.8.3 Miscellaneous General Corrosion Information

This section contains miscellaneous guidelines to help prevent corrosion of the grounding electrode system and other metallic items at the communications site:

- Galvanized steel is strongly electronegative to copper and steel encased in concrete; therefore, careful consideration **shall** be given before galvanized ground rods are used at a site with a concrete-encased electrode. Copper, copper-clad steel or stainless steel rods should be used near concrete-encased electrodes to help prevent corrosion. See BS 7430:2026, section 8.11.1 and IEC 62305-3:2024, section D.5.6.2.2.2, for additional information.
- Steel encased in concrete has a potential similar to that of copper; therefore, it may be bonded to copper or copper-clad ground rods. See BS 7430:2026, section 8.11.1, and IEEE 142-2007 for additional information.

4.8.4 Installation of Grounding Electrode System in Corrosive Soils

Careful consideration **shall** be given when installing a grounding electrode system in soils containing corrosive elements, such as volcanic soils found in Alaska and Hawaii (and similar geographic areas). In these locations, it is recommended to install additional cathodic protection for the grounding electrode system.

Such cathodic protection may be implemented as described in FAA-STD-019G, section 4.4.6, and NWSM 30-4106:2017, section 2.8.2.6:

- A buried steel plate (acting as a sacrificial anode) is bonded to the grounding electrode system using a 120 mm² csa (#4/ 0 AWG) stranded bare copper conductor. The 120 mm² csa (#4/0) AWG conductor **shall** be exothermically welded to the grounding electrode system and to the sacrificial plate. The conductor **shall** be welded to the center of the plate, not near the edge or corners. The minimum size of the sacrificial plate **shall** be 10.16 cm x 10.16 cm (4 in. x 4 in.) and 12.7 mm (0.5 in.) thick. This sacrificial plate is in addition to any other required grounding electrodes at the site.
- The sacrificial plate **shall** be installed in the same general manner as described in “Ground Plate Electrodes” on page 4-21. Coke breeze should be used as the backfill material.
- Assistance from Motorola Solutions Engineering or other engineering firm is recommended in these cases.

4.8.5 Methods to Help Reduce Corrosion

This section provides general requirements and guidelines to help prevent corrosion of the grounding electrode system and other metal items at the communications site:

- Select the appropriate grounding electrode system components using Table 4-10 on page 4-57.
- Motorola Solutions recommends against the use of galvanized ground rods (see “General Ground Rod Requirements” on page 4-12).
- Tinned-copper conductors should be used when bonding to tower legs and other galvanized steel items. See ATIS-0600313.2019(R2024), section 10.7.
- Tinned-copper conductors **shall** be used when bonding to tower legs and other galvanized steel items with mechanical clamps (IEC 62305-3:2024, section D.5.6.2.2.2).
- Galvanic corrosion should be considered when installing a grounding electrode system near steel towers, steel poles, or lead-sheathed cables, as copper grounding components may accelerate the corrosion of these items. In such cases, tinned-copper conductors and stainless steel ground rods may be viable options.
- Galvanized ground rods should be avoided where concrete-encased electrodes are present at the site. In these cases, copper, copper-clad, or stainless steel rods should be used. See IEC 62305-3:2024, section D.5.6.2.2.2 for more information.
- When using tinned conductors or galvanized ground rods, care **shall** be taken during installation to avoid damaging surfaces. Damage to the surfaces of these grounding elements can increase the risk of deterioration due to galvanic action. (ATIS-0600313.2019(R2024), section 11.5, and ATIS-0600334.2019(R2024), section 13.6)

- Aluminum or copper-clad aluminum grounding conductors **shall not** be used (NFPA 70-2026, Article 250.64), unless otherwise allowed (such as in the above-ground portions of a lightning protection system).
- Copper **shall not** come into incidental contact with galvanized steel.
- Bare copper and tinned-copper conductors **shall not** be secured directly to metallic structures. The conductors **shall** be installed in a non-metallic conduit (or other methods) to prevent incidental contact with the structure.
- Copper **shall not** come into incidental contact with aluminum.
- Precipitation run-off from copper and copper alloys can attack galvanized parts (IEC 62305-3:2024, section D.5.6.2.2); therefore, bare copper conductors, copper busbars, or copper lightning rods **shall not** be installed above galvanized steel, such as a tower, unless the steel is protected against the precipitation run-off (IEC 62305-3:2024, section D.5.6.2.2.1).

CAUTION: Copper parts shed extremely fine particles, which may cause severe corrosive damage to galvanized parts, even where the copper and galvanized parts are not in direct contact (IEC 62305-3:2024, section D.5.6.2.2.1).

- Where a galvanized tower is not protected against precipitation run-off from copper or copper alloy busbars, the Tower Ground Busbar (TGB) **shall** be made of tinned-copper.
- Copper lightning rods (air terminals) **shall not** be used on galvanized towers. Instead, use tin-plated or stainless steel air terminals.
- Exothermically welded joints on galvanized material **shall** be thoroughly cleaned and coated with an approved corrosion inhibitor, such as a zinc-enriched paint.
- Copper/aluminum joints **shall** be avoided where practicable. In cases where they cannot be avoided, the connections **shall** be made using an AL/CU listed bimetallic transition connector (IEC 62305-3:2024, section D.5.6.2.2.2). Tinned-copper conductors should be used in these situations.
- Use a listed conductive antioxidant compound on all mechanical connections (ATIS-0600334.2019(R2024), section 9). The antioxidant compound **shall** be liberally installed between the two metals. See “Antioxidant Compound” on page 4-68.
- Where soil conditions are unfavorable, such as being highly acidic or alkaline, corrosion of the grounding electrode system components may be minimized by encasing the components in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Where soil conditions are unfavorable, such as soils containing dissolved salts or chlorides, corrosion of grounding electrode system components may be minimized by encasing the components in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Where soil conditions are unfavorable, such as highly acidic or alkaline, ground rod corrosion may be minimized by installing electrolytic ground rods with grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36 and “Electrolytic Ground Rods” on page 4-19.
- Where soil conditions are unfavorable, such as highly acidic or alkaline, the useful life of a grounding electrode system can be extended by using solid copper ground rods instead of copper-clad rods, provided that the soil conditions allow driving of the solid copper rod.
- Where soil conditions are unfavorable, such as highly acidic or alkaline, the useful life of buried grounding conductors can be extended by using larger conductors, such as 70 mm² csa (#2/0 AWG) instead of 35 mm² csa (#2 AWG). Grounding conductors larger than 35mm² csa (#2 AWG) may be stranded, but should be tinned to help reduce corrosion.
- In corrosive environments, consider using sacrificial magnesium anodes (IEEE 1692-2023, section 8.2). A corrosion specialist should be consulted.

- See “Guyed Towers” on page 4-89 for information regarding grounding techniques to help minimize galvanic corrosion of the guy anchors.

4.9 Bonding to the External Grounding and Bonding System

Bonding and connection techniques are essential for an effective external grounding and bonding system. Bonding **shall** be performed so as to ensure an adequate and reliable connection. The following subsections outline external grounding, bonding, and connection requirements.

4.9.1 General Requirements for Bonding to External Grounding

The following are the general requirements for external grounding system bonding and connections:

- Below-grade grounding electrode system connections **shall** be joined using exothermic welding or listed irreversible high-compression fittings (ATIS-0600313.2019(R2024), Figure 3(a) and IEEE 1692-2023, section 8.2).
- Above-grade grounding electrode system connections (such as grounding electrode conductor connection to ground busbars or tower legs) **shall** be joined using exothermic welding or listed irreversible high-compression fittings, unless allowed otherwise in this chapter (ATIS-0600313.2019(R2024), Figure 3(a)).
- Above-grade bonding connections, such as bonding to ancillary equipment or bonding coaxial ground kits, **shall** be joined using exothermic welding, listed irreversible high-compression fittings, listed irreversible compression lugs, or listed clamping devices.
- Exothermic welds and irreversible high-compression connections **shall** have a maximum DC resistance of one milliohm when measured between the bonded components with a four-terminal milli/micro-ohmmeter (FAA-STD-019G, section 4.2.1.1; MIL-HDBK-419A Volume I, section 7.3; and NWSM 30-4106:2017, section 2.8.5).
- Irreversible high-compression fittings, irreversible compression lugs, and other types of mechanical clamping devices **shall** be listed for the purpose, the type of conductor, and the size and number of conductors used.
- Connection devices **shall** be constructed from appropriate metal(s) so as not to react with the metals being bonded. See “Dissimilar Metals and Corrosion Control” on page 4-55.
- Paint, enamel, lacquer, and other nonconductive coatings **shall** be removed from threads and surface areas where connections are made to ensure good electrical continuity (NFPA 70-2026, Article 250.12 and TIA-607-E). The use of a star washer does not eliminate the requirement to remove non-conductive coatings from attachment surfaces. See Figure 4-54 and Figure 4-55 for the correct star/lock washer location. Star washers should only be used as a lock washer.

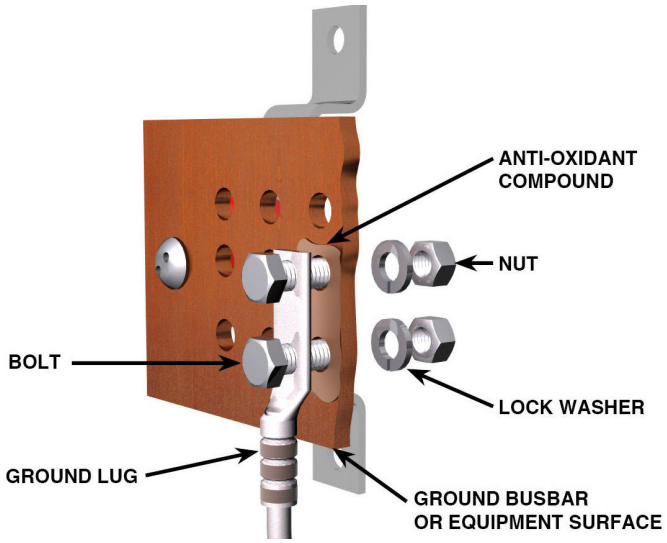


Figure 4-54. Proper Bonding to Busbars

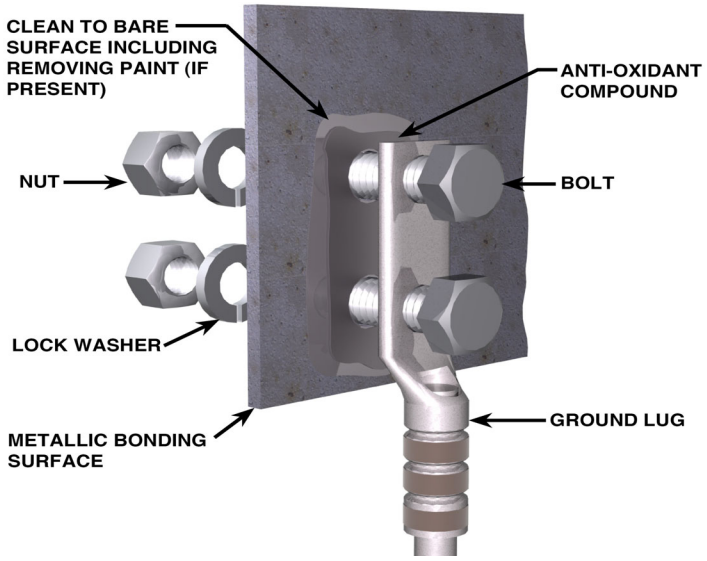


Figure 4-55. Proper Bonding of Ancillary Support Equipment

- Bonding surfaces **shall** be cleaned to remove dirt, corrosion and oxidized material from the connection surface area (ATIS-0600334.2019(R2024), section 9).
- Mechanical joints **shall** be protected with a listed conductive anti-oxidation compound (ATIS-0600334.2019(R2024), section 9 and TIA-607-E). Excess antioxidant compound **shall** be removed after completion of the bonding connection. See “Antioxidant Compound” on page 4-68.
- After bonding to a painted or galvanized steel structure, the area **shall** be thoroughly cleaned and coated with an approved corrosion inhibitor (such as a zinc-enriched paint).
- Exothermic welding is the preferred method for establishing bonding connections to the external grounding electrode system.

IMPORTANT: Exothermic welding or listed irreversible high-compression fittings are the only acceptable methods for below-grade bonding. Other mechanical connection methods **shall not** be used below-grade.

4.9.2 Above-Grade Mechanical Lugs and Connection Devices

Mechanical bonding connections are typically accomplished using listed single-hole lugs, listed two-hole lugs, or listed clamps.

Mechanical bonding requirements are as follows:

- Lugs and connection devices **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL), such as CSA or UL (reference documents CSA C22.2 NO. 41:22 and UL 467-2022).
- Lugs and connection devices **shall** be listed for the purpose, the type of conductor, and the size and number of conductors used. See Figure 4-58 on page 4-65 for an example of a lug with listed markings.
- Lugs and connection devices used on solid conductors **shall** be listed for use on solid conductors. See product documentation for listing details.
- Lugs used **shall** be designed for a minimum of 0.64 cm (0.25 in.) fastening hardware, where practicable.
- Lugs and connection devices **shall** be constructed from tinned-copper, tinned-copper alloy, or stainless steel.
- Connection devices used as part of lightning protection systems **shall** be listed for the purpose.
- Lug attachment to conductors **shall** be by exothermic weld or irreversible compression connection. See Figure 4-56 for examples of exothermic weld connections and Figure 4-58 for an example of an irreversible compression connection.



Figure 4-56. Lugs Exothermically Welded to Conductor

NOTE: In this standard, a 2-ton connection is considered irreversible compression; a 12-ton connection is considered irreversible high-compression.

NOTE: A tonne is also known as a metric ton.

- Irreversible compression lugs and fittings **shall** be capable of being crimped to a minimum of 1.81437 tonne (2-tons) of force.
- Irreversible compression lugs and fittings **shall** be crimped to the conductor with a minimum of 1.81437 tonne (2-tons) of force.
- Two-hole long barrel lugs are preferred over single-hole lugs and **shall** be used where practicable. Two-hole lugs prevent movement of the lug.

IMPORTANT: Where aluminum lightning protection system conductors are used, appropriately listed connection devices **shall** be used.

IMPORTANT: Setscrew-style lugs and split bolts **shall not** be used anywhere in the external grounding and bonding system.

General guidance on the appropriate hardware and bonding device is provided in Table 4-12.

Table 4-12. Recommended Bonding Matrix for Above-Grade Objects

Item to be Bonded	Hardware		Connector				
	Stainless Steel	Silicon Bronze	Tin-Plated Copper/ Bronze Clamp	Tin-Plated Bronze Pipe Clamp	Tin-Plated Fence Fabric Clamp	Tin-Plated Conduit Clamp	Stainless Steel Clamp
Black Pipe (Fire Suppression Systems)	✓		✓	✓			
Galvanized Steel Conduit	✓					✓	
Aluminum Conduit	✓					✓	
Galvanized Steel	✓		✓				
Guy Wires	✓						✓
Copper Water Pipe	✓	✓		✓			
Galvanized Water Pipe	✓			✓			
Galvanized Fence/Gate Post (where exothermic welding is not possible)	✓			✓			
Galvanized Fence Fabric	✓				✓		
Generator Exhaust Pipes	✓		✓				
Rebar	✓		✓	✓			
Strut Channel (Painted)	✓	✓	✓				
Strut Channel (Galvanized)	✓		✓				

See Figure 4-57 for typical pipe bonding clamps.

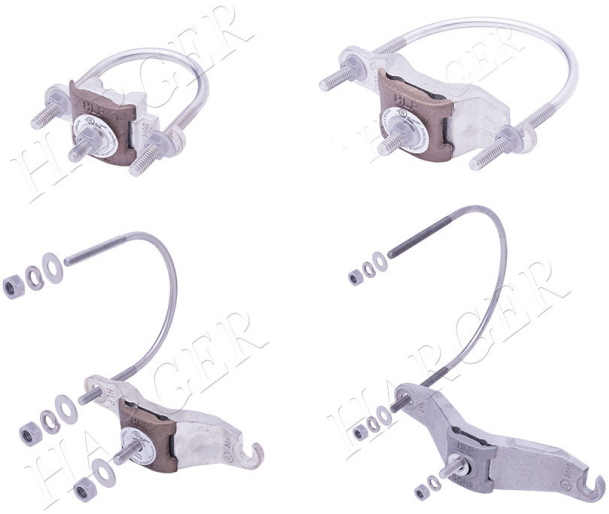
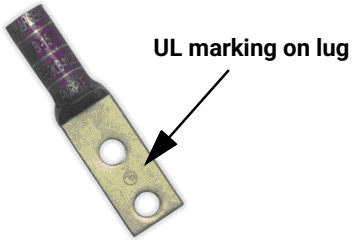


Figure 4-57. Examples of Pipe Bonding Clamps

Figure 4-58 illustrates the typical irreversible compression crimping process for a lug. Refer to BICSI N3-20 and the lug and/or compression tool manufacturer for specific instructions.



STEP 1:
Choose a lug appropriate for the application and conductor size.



STEP 2:
Strip conductor jacket to appropriate length for the lug.



STEP 3:
Verify conductor fits properly into lug. There should be no exposed conductor between the lug and the conductor jacket. The conductor should reach the inspection hole.



STEP 4:
Apply appropriate antioxidant compound inside lug.



STEP 5:
Apply appropriate antioxidant compound to conductor.



STEP 6:
Insert conductor into lug.

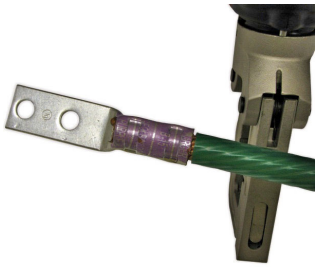


STEP 7:
Position the lug so it makes contact with the conductor jacket.





STEP 8:
Crimp long barrel lugs in at least two locations: place the first crimp adjacent to inspection window.
Place the second crimp adjacent to the conductor jacket.



STEP 9:
Remove excess antioxidant compound from the lug and conductor jacket. Connection is complete.

Figure 4-58. Typical Irreversible Compression Crimping Process

Table 4-13 lists the color code for typical irreversible compression lugs. Refer to the specific compression lug documentation for details.

Table 4-13.Typical Irreversible Compression Lug Color Code

Conductor Size	Lug Color Code
# 6 AWG	Blue
# 6 AWG Solid	Red
# 4 AWG	Gray
# 2 AWG	Brown
# 2 AWG Solid	White
# 1 AWG	Green
# 1/0 AWG	Pink
# 2/0 AWG	Black
# 3/0 AWG	Orange
# 4/0 AWG	Purple
250 kcmil	Yellow
500 kcmil	Brown
750 kcmil	Black

4.9.3 Securing Hardware

Securing hardware refers to the fasteners (such as bolts, nuts, screws and washers) used to attach a ground lug or clamping device to a busbar or a metallic object. Minimum requirements for securing hardware are as follows:

- All securing hardware **shall** be constructed from 300 series stainless steel or silicon bronze (BICSI N3-20 and FAA-STD-019G, section 4.2.3.4.2), unless otherwise specified or permitted.

NOTE: 300 series stainless steel is commonly identified as 18-8.

- For saltwater environments where corrosion is a concern, Type 316 stainless steel or silicon bronze are the recommended materials.
- The bolts or screws **shall** be sized appropriately to match the lug size. The recommended minimum diameter bolt size is 6.35 mm (0.25 in.).
- Securing hardware **shall** be sufficiently torqued to ensure a reliable bond while not over-compressing the lock washer.

IMPORTANT: Select securing hardware to ensure no other metal types are inadvertently used. Mixing other metal types with stainless steel can cause severe corrosion, resulting in an ineffective electrical bond and a potential RF interference point.

NOTE: Use a magnet to screen for incorrect hardware metals. 400 series stainless steel and common galvanized or carbon steels will stick to the magnet, but 300 series stainless steel will not.

4.9.4 Above-Grade Mechanical Bonding Requirements

Above-grade bonding connections to communication system devices, ancillary equipment, or busbars typically require the use of mechanical lugs or clamps bonded to the grounding conductor and attached to the equipment being bonded. See Figure 4-57 on page 4-64 for bonding device examples.

Requirements for above-grade mechanical bonding are as follows:

- Lugs and clamps **shall** meet the requirements of 4.9.2 “Above-Grade Mechanical Lugs and Connection Devices,” on page 4-63.
- Paint, enamel, lacquer and other nonconductive coatings **shall** be removed from threads and surface areas where connections are made to ensure good electrical continuity (NFPA 70-2026, Article 250.12 and TIA-607-E). The use of a star washer does not eliminate the requirement to remove non-conductive coatings from attachment surfaces. See Figure 4-54 on page 4-62 for the correct location of the star/lock washer. Star washers should only be used as a lock washer.
- Bonding surfaces **shall** be cleaned to remove dirt, corrosion and oxidized material in the connection surface area (ATIS-0600334.2019(R2024), section 9).
- All mechanical joints **shall** be protected with a listed conductive anti-oxidation compound (ATIS-0600334.2019(R2024), section 9, and TIA-607-E). See “Antioxidant Compound” on page 4-68 for antioxidant compound requirements.
- After bonding to a painted or galvanized steel structure, the area **shall** be thoroughly cleaned and coated with an approved corrosion inhibitor (such as a zinc-enriched paint).
- Two-hole long barrel lugs are preferred over single-hole lugs and **shall** be used where practicable. Two-hole lugs prevent movement of the lug.
- Where two-hole lugs are used, securing hardware **shall** be used in both holes.
- Lugs **shall** be secured to the surface using a combination of nuts, bolts, and lock washers where both sides of the bonding surface are accessible (see Figure 4-55 on page 4-62).
- Bolts **shall** be tightened sufficiently to maintain the contact pressures required for effective bonding, but **shall not** be over-tightened to the extent that deformation of bond members occurs (FAA-STD-019G, section 4.2.3.4.2).
- If connecting ground lugs or compression terminals to ancillary equipment, such as air conditioners and vent hoods, a lock washer **shall** be placed on the nut side. See Figure 4-55 on page 4-62 for an example.

4.9.5 Bonding Objects in Blind Locations

Bonding locations where the rear of the object being bonded is inaccessible for installation of a nut are commonly referred to as blind locations. Common examples of blind locations are door frames, metallic siding, and vent covers.

Follow all requirements in “Bonding to the External Grounding and Bonding System” on page 4-61 and all subsections. Two-hole lugs **shall** be used where practicable. A lock washer **shall** be installed between the lug and the bolt/screw head.

The following methods may be used where the metallic object to be bonded is thick enough to engage at least two threads from the fastener:

- Drill and tap the correct size hole(s) in the object for the fastener being used. Attach the ground lug using stainless steel hardware.
- Drill the appropriate size hole(s) in the object for the fastener being used. Attach the ground lug using a stainless steel thread-forming machine screw(s).

NOTE: A typical thread-forming machine screw used in this application has approximately 32 threads per inch.

The following methods may be used if the metallic object is too thin to engage at least two threads from the fastener:

- Attach the ground lug using an existing screw already present for securing the metallic object. If practicable, a two-hole lug **shall** be used. If a two-hole lug is used, secure the second hole using one of the following additional options:
  - Attach the ground lug using appropriate stainless steel screw(s) that penetrates to wood or metal framing.
  - Drill a hole of the appropriate size and install an internally threaded rivet. Attach the ground lug using stainless steel hardware.
  - Punch a small hole in the metal using an awl. Attach the ground lug with stainless steel thread-forming machine screw(s). Punching a hole with an awl helps create more surface area for thread contact.
- In some applications, using stainless steel sheet metal screws may be the only available option for attaching certain items, such as metallic siding. Sheet metal screws **shall** be used only when no other alternatives are available. A recommended best practice is to first punch a small hole in the metal using an awl.

Attaching a stainless steel threaded stud to the metallic object using capacitive discharge welding might also be a viable option. The threaded stud serves as an attachment point for a ground lug. Refer to the capacitive discharge welding tool documentation for specific welding instructions and requirements.

4.9.6 Antioxidant Compound

Antioxidant compound helps prevent oxidation of mechanical bonds to help maintain good electrical connections. All mechanical bonding joints **shall** be protected with a listed conductive antioxidant compound (ATIS-0600333.2013(S2023), section 9.2.2, and ATIS-0600334.2019(R2024), section 9). The requirements for antioxidant compounds are as follows:

- The antioxidant compound **shall** be a conductive type and designed for use on electrical connections.
- The antioxidant compound **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- The antioxidant compound **shall** be listed for the type(s) of metal it is applied on.
- The antioxidant compound **shall** be used according to the manufacturer's instructions.
- Use the type of antioxidant shown in Table 4-14 for each combination of connection device and bonding surface.

Table 4-14.Antioxidant Compounds for Bonding Surface Types

<table>
<tr><th rowspan="2">Connection Device Metal</th><th colspan="5">Bonding Surfaces</th></tr>
<tr><th>Copper or copper alloys (such as bronze and brass)</th><th>Tin-plated</th><th>Steel</th><th>Galvanized steel</th><th>Aluminum</th></tr>
<tr><td>Copper or copper alloys (bronze, brass)</td><td rowspan="3">Use copper antioxidant (typically copper-colored)</td><td>Use copper antioxidant (typically copper-colored)</td><td colspan="3">N/A. Copper or copper alloys are not approved as connection devices to steel, galvanized steel, or aluminum bonding surfaces. Tin-plated or stainless steel connection devices are required.</td></tr>
<tr><td>Tin-plated</td><td colspan="4">Use zinc antioxidant (typically gray-colored)</td></tr>
<tr><td>Stainless steel</td><td>Use copper or zinc antioxidant</td><td colspan="3">Use zinc antioxidant typically gray-colored)</td></tr>
<tr><td colspan="6">NOTE: Follow manufacturer’s instructions when applying antioxidant compound.</td></tr>
</table>

4.9.7 Below-Grade Bonding Methods

The only acceptable connection bonding methods for use below-grade are exothermic welding and listed irreversible high-compression fittings. Other types of mechanical connection methods **shall not** be used below-grade (see ATIS-0600313.2019(R2024), Figure 3(a)). See 4.9.9 “Exothermic Welding,” on page 4-71 and “Irreversible High-Compression Fittings” below for details.

IMPORTANT: In some cases, exothermic welding may not be feasible due to safety concerns, such as at chemical or petroleum facilities, or site-specific conditions like a high water table. In these instances, listed irreversible high-compression connections **shall** be used.

4.9.8 Irreversible High-Compression Fittings

WARNING: Wear safety glasses and other recommended personal protective equipment when working with high-compression fittings.

NOTE: In this standard, a 2-ton connection is considered irreversible compression; a 12-ton connection is considered irreversible high-compression.

Irreversible high-compression connections are approved for both above-grade and below-grade bonds and serve as an effective alternative to exothermic welding for below-grade use. Irreversible high-compression connections may be used in some applications where exothermic welding is impracticable due to safety concerns (such as at chemical or petroleum plants) and/or site-specific conditions (such as a high water table).

See Figure 4-59 for examples of high-compression connectors and tools. Figure 4-60 shows the typical installation process for an irreversible 90° splice connection between two conductors. Refer to the connector manufacturer and tool manufacturer for specific instructions.

General requirements for irreversible high-compression connections are as follows:

- Connectors and fittings **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL), such as CSA or UL (CSA C22.2 NO. 41:22 and UL 467-2022).
- Connectors and fittings **shall** be listed for the size and number of conductors being bonded.
- Connectors and fittings used underground **shall** be listed for direct burial.
- Connectors and fittings **shall** be rated for at least 10.9 tonnes (12-tons) of force and **shall** be compressed to 10.9 tonnes (12-tons) of force (FAA-STD-019G, sections 4.2.3.2 and 4.4.4.2).
- The crimping tool and connector manufacturer’s instructions and requirements **shall** be followed.
- The manufacturer-recommended compression tool **shall** be used. Where applicable, the appropriate die set **shall** be used for the compression fitting.
- The compression systems **shall** include a crimped die index for inspection purposes.
- The connectors and fittings **shall** be made of the same material (or compatible) as the materials being bonded to avoid dissimilar metal reactions.
- Aluminum connectors and fittings **shall not** be used.
- Conductors **shall** be cleaned prior to crimping to ensure good electrical contact. A wire brush is recommended for cleaning the conductor.

NOTE: Some compression connectors and lugs come pre-filled with an antioxidant compound. In these instances, additional compound is not required.

- Connections **shall** be coated with a conductive antioxidant compound before crimping (see “Antioxidant Compound” on page 4-68).

- All irreversible high-compression connections **shall** be inspected to help ensure an acceptable bonding connection.
- Irreversible high-compression connections **shall** have a maximum DC resistance of one milliohm (1 mΩ) when measured between the bonded components using a 4-terminal milli/micro-ohmmeter (FAA-STD-019G, sections 4.2.1.1; MIL-HDBK-419A Volume I, section 7.3; and NWSM 30-4106:2017, section 2.8.5). See Figure 4-65 on page 4-75 for a testing example.

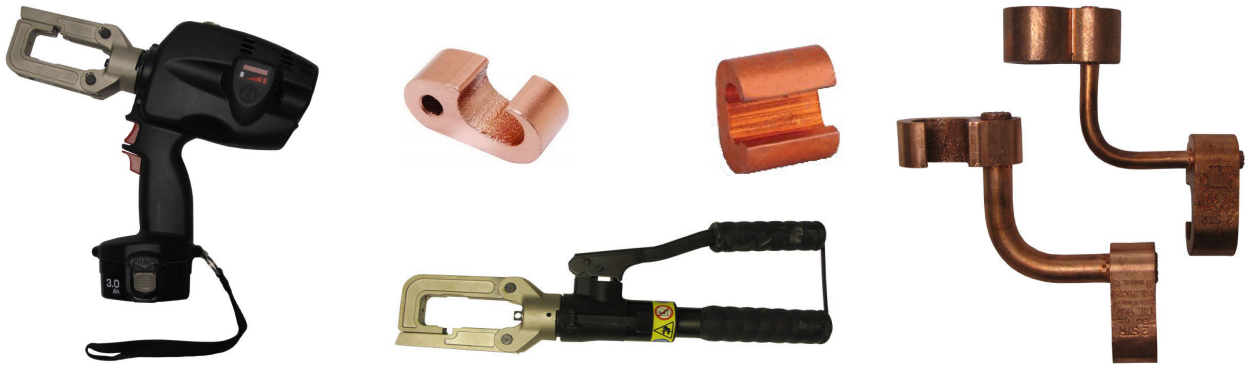
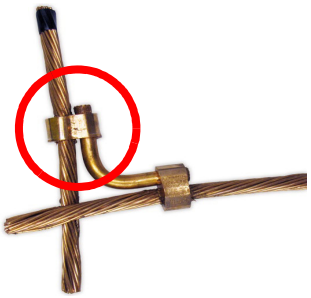


Figure 4-59. Irreversible High-Compression Connector Examples and Typical Crimping Tools



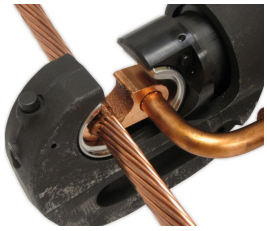
STEP 1: Select appropriate connector for application and conductor size.

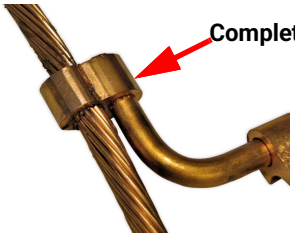


STEP 2: Apply appropriate antioxidant compound to connector.

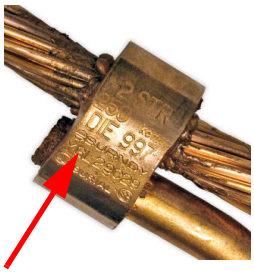


STEP 3: Clean conductor with wire brush as needed. Place conductor into connector.





STEP 4: Select appropriate crimping tool and die. Center connector in die to ensure full embossment.
Cycle crimping tool until audible pressure release is heard (tool specific).



Die index is visible on connector.

Figure 4-60. Typical High-Compression 90° Splice Connection Process

4.9.9 Exothermic Welding

Exothermic welding is a technique used to join electrical connections without needing an external heat source like electricity or gas. The process relies on a reaction between granular metals that, when combined, produce a molten metal. This reaction, which occurs in seconds, takes place in a graphite crucible. The liquid metal then flows from the crucible into a mold where it contacts the ends of the conductors to be welded. The temperature of the molten metal is high enough to fuse the conductors' metal, creating a strong molecular bond. Exothermic welding alloys are available for copper to copper and copper to steel (including stainless steel) connections. Figure 4-61 shows examples of completed exothermic welds.

WARNING: To help prevent injury from molten metal or sparks and to reduce the risk of fire, follow the safety warnings and requirements provided by the exothermic welding manufacturer. Personnel performing an exothermic weld SHALL wear appropriate attire and safety gear.

CAUTION: If exothermically welding connections to a tower, contact the tower manufacturer for approved welding locations on the tower.

IMPORTANT: Exothermic welding might be prohibited by certain component manufacturers, such as some towers or fences. Other appropriate bonding methods listed in this chapter are permitted in these cases.

NOTE: The molds for copper-clad ground rods differ from those used for solid copper, galvanized steel, and stainless steel rods of the same size. The copper-clad rod is of nominal size, while the other rods are full size.

NOTE: Some molds, even when correctly maintained, may last for only 50 welds.



Figure 4-61. Examples of Completed Exothermic Welding

General requirements for exothermic welding are as follows:

- The manufacturer's instructions and safety requirements **shall** be observed.
- Heavy clothing, work shoes or boots, gloves, a hard hat, and safety glasses **shall** be worn when performing exothermic welding.
- Exothermic welding **shall** only be performed if another person capable of providing first aid is present.
- The molds **shall** be inspected for excessive wear or other defects.
- A suitable fire extinguisher and attendant **shall** be nearby during the exothermic welding process.
- The correct weld material for the metals being welded **shall** be used.
- All metal parts **shall** be cleaned before welding.
- All metal parts and molds **shall** be dried before welding.
- Molds appropriate for the conductors and/or rods being welded **shall** be used.

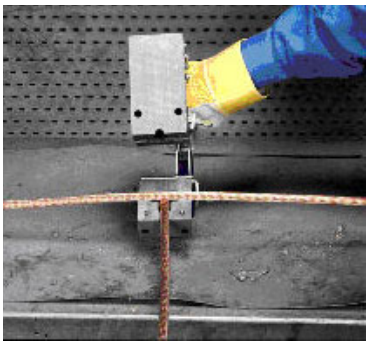
4.9.9.1 Traditional Exothermic Welding Process

WARNING: The exothermic welding process produces hot, molten material with temperatures exceeding 1400°C (2500°F) and a localized release of smoke. Do not look directly at the "flash" of light from the ignition of the welding materials, keep hands away from the reaction, and avoid inhalation of smoke/fumes.

IMPORTANT: Molds **shall** be adequately dried before attempting a weld. This is typically accomplished using an industrial heat gun or a small propane torch. Failure to dry the mold may result in molten weld material violently spraying out and/or an ineffective weld.

NOTE: Because it allows the operator to start the process from a distance, Motorola Solutions recommends using electronic ignition exothermic welding equipment instead of the traditional process.

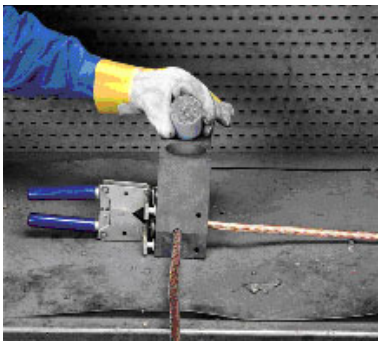
Figure 4-62 illustrates the typical traditional exothermic weld process.



STEP 1:
Clean and dry conductors and mold. Insert conductors into mold.



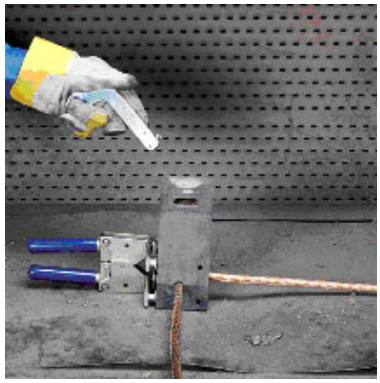
STEP 2:
Close handle clamp and lock mold. Insert disk into mold.



STEP 3:
Pour weld metal into mold.



STEP 4:
Sprinkle starting material over the weld metal and close lid.



STEP5:
Ignite using a flint igniter. To avoid burns, keep hands away from mold while reaction takes place.



STEP 6:
Wait 15 to 20 seconds for the reaction to complete, then open the mold and remove the welded connection.
Remove slag from the mold before making the next connection.

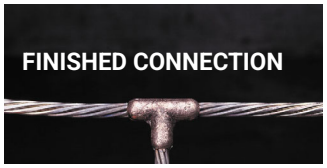


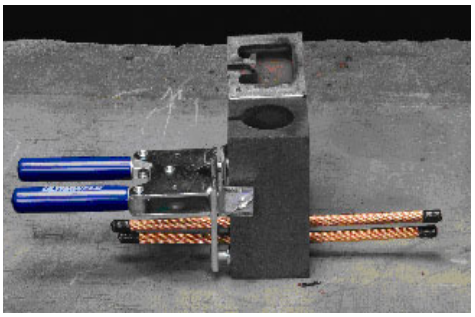
Figure 4-62. Traditional Exothermic Welding Process

4.9.9.2 Electronic Ignition Exothermic Welding Process

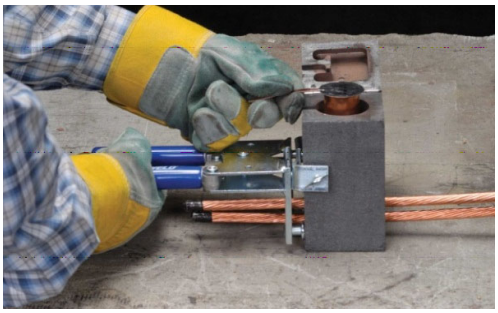
WARNING: The exothermic welding process produces hot, molten material with temperatures exceeding 1400°C (2500°F) and a localized release of smoke. Do not look directly at the "flash" of light from the ignition of the welding materials, and avoid inhalation of smoke/fumes

IMPORTANT: Molds **shall** be adequately dried before attempting a weld. This is typically accomplished using an industrial heat gun or a small propane torch. Failure to dry the mold may result in molten weld material violently spraying out and/or an ineffective weld.

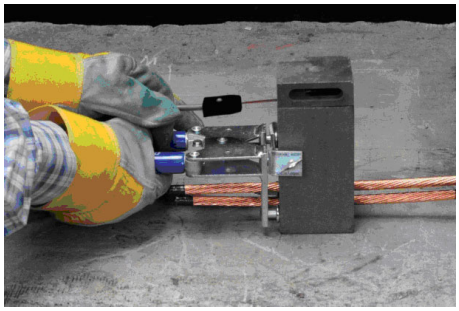
Exothermic welding products formerly required starting materials and a flint igniter as ignition sources. Electronic ignition is now used to trigger the exothermic process. Motorola Solutions recommends this method because it allows the operator to start the process from a distance, reducing the risk of burns. Figure 4-63 illustrates the typical electronic exothermic weld process.



STEP 1:
Clean and dry conductors and mold.
Insert conductors into mold.



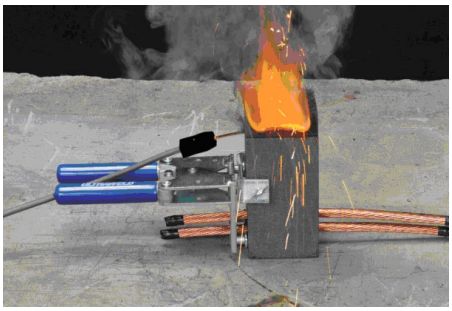
STEP 2:
Close and lock handle clamp.
Insert drop-in cartridge into mold.



STEP 3:
Attach ignition cord to the electronic igniter.



STEP 4:
Press and hold igniter button(s).



STEP 5:
Reaction occurs. Wait 15-20 seconds, open mold and remove connection.
Remove slag before making the next connection.



FINISHED CONNECTION

Figure 4-63. Electronic Ignition Exothermic Welding Process

4.9.9.3 Exothermic Weld Inspection Criteria

All exothermic welds **shall** be inspected to ensure appropriate bonding. The weld connections **shall** have a maximum DC resistance of one milliohm (1 mΩ) when measured between the bonded components using a 4-terminal milliohm/micro-ohmmeter (FAA-STD-019G, section 4.2.1.1; MIL-HDBK-419A Volume I, section 7.3; and NWSM 30-4106:2017, section 2.8.5). Figure 4-64 shows an acceptable connection and some common unacceptable connections. See Figure 4-65 for a testing example.



Acceptable connection
Bright, smooth surface finish, no slag deposits or flashing around the connection.



Unacceptable connection
Not enough weld metal.



Unacceptable connection
Excessive slag and leakage due to improperly seated mold.



Unacceptable connection
Conductor not adequately cleaned.

Figure 4-64. Examples of Exothermic Welds



For illustration purposes, the grounding electrode system components are shown above-grade.

Figure 4-65. Example of Micro-Ohmmeter Testing

4.9.9.4 Common Exothermic Weld Problems

Table 4-15 provides guidance on some common exothermic weld problems and possible solutions.

Table 4-15.Common Exothermic Weld Problems

Problem	Possible Solution
Connection not sticking to the busbar	Weld to the edge of the busbar. Preheat the busbar (do not use a torch directly on the weld location).
Connection not sticking to galvanized steel	Completely r emove galvanized coating with a rasp or similar tool.
Burn through on fence post	Use smaller-sized gate jumper. Fill the post with sand past the connection point. Do not use water.
Melt through on cable to ground rod	Verify conductor is not under tension and support if required.
Inadequate weld, not enough weld material, incomplete weld, or pitting of weld material	Clean and dry mold before attempting to weld.

4.9.10 Bonding Summary

Table 4-16 lists approved bonding conductors and bonding methods for typical sites. The table is not meant to be an all-inclusive list. Specific site design and/or conditions may require deviations from this matrix. If deviations are needed, consulting with Motorola Solutions Engineering is recommended.

Table 4-16.Bonding Summary

Metallic Item to be Bonded		Approved Conductor		Approved Connection Method				
Item	Bonded To	Type	Min. Size	Exothermic Weld	Irreversible High-Compression Connector	Listed 2-Hole Lug[1]	Listed Single-Hole Lug[1]	Listed Mechanical Clamp Designed for the Purpose[2]
Guy wire	Grounding conductor	Tinned-copper or galvanized guy wire	#2 AWG	–	–	–	–	✓
Galvanized steel fence or gate post	Grounding conductor	Copper or tinned-copper[3]	#2 AWG	✓	–	–	–	✓
Galvanized steel fence fabric	Grounding conductor	Tinned-copper	#2 AWG	–	–	–	–	✓
Fence deterrent wire	Grounding conductor	Tinned-copper	#2 AWG	–	–	–	–	✓
Gate frame	Gate supporting post	Jacketed flexible copper bonding jumper[4]	#6 AWG	✓	–	–	–	✓
Fuel tank footing or supplied grounding post	Grounding conductor	Copper or tinned-copper[3]	#2 AWG	✓[5]	–	✓	–	–

Table 4-16.Bonding Summary (continued)

Metallic Item to be Bonded		Approved Conductor		Approved Connection Method				
Item	Bonded To	Type	Min. Size	Exothermic Weld	Irreversible High-Compression Connector	Listed 2-Hole Lug[1]	Listed Single-Hole Lug[1]	Listed Mechanical Clamp Designed for the Purpose[2]
Generator frame or supplied grounding post	Grounding conductor	Copper or tinned-copper[3]	#6 AWG or #2 AWG if routed below-grade	✓[5]	—	✓	—	—
Bollard post	Grounding conductor	Copper or tinned-copper	#2 AWG	✓	—	—	—	—
Galvanized steel tower leg or grounding plate	Tower grounding electrode conductor	Copper or Tinned-copper[3]	#2 AWG	✓[5]	—	✓[6]	—	✓
Bottom tower ground busbar	Grounding electrode conductor	Copper or Tinned-copper	#2 AWG	✓	✓	—	—	—
Tower ground busbar	Tower structure	N/A: Direct mechanical bond		—	—	—	—	Appropriate stainless steel clamp and hardware
Intermediate tower ground busbar	Tower ground busbar bonding jumper	Jacketed copper or Tinned-copper	#2 AWG	✓	✓	✓	—	—
Intermediate tower ground busbar bonding jumper	Tower structure	Jacketed copper or Tinned-copper	#2 AWG	✓[5]	—	—	—	✓
External ground busbar	Grounding electrode conductor	Copper or Tinned-copper	#2 AWG	✓	✓	—	—	—
External ground busbar	Copper strap	N/A		✓	—	—	—	Per Mfr Design
Communication cable grounding kits	Ground busbar	Copper or Tinned-copper	#6 AWG	✓	—	✓	✓	—
Ice bridge/cable bridge supporting post	Grounding conductor	Copper or Tinned-copper[3]	#2 AWG	✓	—	—	—	✓[7]
Ice bridge/cable bridge sections	Ice bridge/cable bridge support Post	Jacketed Copper	#6 AWG	✓	—	—	—	✓[7]

Table 4-16.Bonding Summary (continued)

Metallic Item to be Bonded		Approved Conductor		Approved Connection Method				
Item	Bonded To	Type	Min. Size	Exothermic Weld	Irreversible High-Compression Connector	Listed 2-Hole Lug[1]	Listed Single-Hole Lug[1]	Listed Mechanical Clamp Designed for the Purpose[2]
Ice bridge/cable bridge sections	Ice bridge/cable bridge bonding jumper	Jacketed Copper	#6 AWG	✓[5]	—	✓	—	—
HVAC unit	Grounding conductor	Copper or Tinned-copper	#2 AWG	—	—	✓	—	—
Copper or copper-clad grounding electrode	Ground ring or grounding electrode conductor	Copper or Tinned-copper	#2 AWG	✓	✓	—	—	—
Stainless steel grounding electrode	Ground ring or grounding electrode conductor	Copper or Tinned-copper	#2 AWG	✓	✓	—	—	—
Galvanized steel grounding electrode	Ground ring or grounding electrode conductor	Tinned-copper	#2 AWG	✓	✓	—	—	—
Metallic items requiring bonding	Grounding conductor	Copper or Tinned-copper	#6 AWG or #2 AWG if routed below-grade	✓[5]	—	✓	✓[8]	✓
Tower top amplifier	Grounding conductor	Jacketed copper or Tinned-copper	#6 AWG or #2 AWG if TTA contains a surge protective device	—	—	✓	✓	—

1. Listed tin-plated compression lug
2. Listed stainless steel or tin-plated copper alloy with stainless steel hardware
3. Tinned-copper is required if using mechanical clamps.
4. Such as 133-strand
5. As permitted by manufacturer
6. To plate only if exothermic welding is not permitted by tower.
7. Mechanical clamps are only allowed if exothermic welding is not permitted at the specific site.
8. Objects subject to vibration **shall not** use single-hole lugs.

4.10 Minimum Site Grounding (Earthing) Requirements

This section provides the minimum requirements for installing a grounding electrode system at a communications site and for bonding site equipment to the grounding electrode system. Reasonable efforts **shall** be made to meet the grounding electrode system resistance design goal, as defined in “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-81.

The recommended first steps for installing a typical grounding electrode system are as follows:

- Determine the site type classification (Light Duty, Standard Duty or Extra Duty). See “Site Type Classification Definitions” on page 4-6.
- Review Table 4-17 and the appropriate sections in this chapter to determine the minimum design requirements and recommendations for the site type.

Table 4-17.Grounding Electrode System Requirements Matrix

Site Type	Grounding Electrode System Design					
	Resistance Design Goal[1]	Single Ground Rod	Building Ground Ring[2]	Tower Ground Ring[2]	Supplemental Techniques	Concrete-encased Electrodes
Light Duty Site (A)	25 Ω	✓ [3]	—	N/A	Recommended to achieve the 25 Ω design goal [4]	Recommended for new construction
Standard Duty Sites (B):						
Building only	10 Ω	—	✓	N/A	Recommended to achieve the 10 Ω design goal [4]	Recommended for new construction
Building and tower	10 Ω	—	✓	✓	Recommended to achieve the 10 Ω design goal [4]	Recommended for new construction
Building and tower in high-lightning area	10 Ω	—	✓	✓	Radials recommended [5]	Recommended for new construction
Building only at site with high soil resistivity [6]	10 Ω	—	✓	N/A	✓ [4]	Recommended for new construction
Building and Tower at Site with High Soil Resistivity [6]	10 Ω	—	✓	✓	✓ [4]	Recommended for new construction
Extra Duty Sites (B2):						
Communications or 911-Dispatch Center with co-located tower	5 Ω	—	✓	✓	Radials recommended [5]	Recommended for new construction
Core, Master, or Prime Site with co-located tower	5 Ω	—	✓	✓	Radials recommended [5]	Recommended for new construction

1. See “Supplemental Grounding Techniques to Help Achieve Resistance Design Goal” on page 4-82
2. With ground rods (or other electrodes) installed every 3 m to 4.5 m (10-15 ft) as described in this chapter
3. Two ground rods are recommended regardless of the actual resistance to earth.
4. Such as electrolytic grounds rods, grounding electrode encasement material, ground mesh, radial grounding conductors, or other supplemental techniques appropriate for the site.
5. Or another supplemental technique appropriate for the site
6. Soil resistivity is considered high when the resistance design goal cannot be achieved without supplemental grounding techniques.

- Determine the resistance design goal requirement of the grounding electrode system, based on the site type classification (Light Duty, Standard Duty, or Extra Duty).
- Perform a soil resistivity test at the site as described in Appendix B, “Soil Resistivity Measurements”.
- Calculate the resistance of a single ground rod as described in Appendix B, “Soil Resistivity Measurements”.
- Continue to the subsections “Type “A” Sites: Light Duty” or “Type “B” and “B2” Sites: Standard and Extra Duty”, based on site type classification.

NOTE: This document considers areas with a lightning flash density greater than 2 flashes/km^2/year to be high-lightning areas. See “Lightning Activity and Exposure” on page 4-4.

4.10.1 Type “A” Sites: Light Duty

Continued from “Minimum Site Grounding (Earthing) Requirements” on page 4-79:

- Determine whether the single ground rod meets the minimum 25 Ω requirement. If it does not, an additional ground rod or other grounding electrode, will be required. See “Type “A” Site Grounding (Earthing)” on page 4-83 for additional information.
- Install the ground rod(s) as described in “Ground Rod Requirements at Light Duty (Type A) Sites” on page 4-15.

NOTE: It is recommended to use two grounding electrodes as the minimum installation, even if a single electrode achieves 25 Ω.

4.10.2 Type “B” and “B2” Sites: Standard and Extra Duty

Continued from “Minimum Site Grounding (Earthing) Requirements” on page 4-79:

- Using a site drawing, determine where to install the minimum required ground rods, while maintaining equal separation between rods. See “External Building and Tower Ground Ring” on page 4-25 for additional information regarding ground rod placement requirements along ground rings. In general, a ground rod should be installed every 3 m to 4.5 m (10 to 15 ft).
- Determine whether radial grounding conductors should be installed at the site, such as if the site is located in a geographic area that is highly prone to lightning or when the site is normally occupied, such as a dispatch center. See “Radial Grounding Conductors” on page 4-29.
- Calculate the resistance of the grounding electrode system using “Estimating Resistance of Complex Ground Rod Systems” on page B-31 or consult with an engineering firm.
- If the resistance design goal cannot be achieved, recalculate using one or more of the supplemental techniques described in “Supplemental Grounding Techniques to Help Achieve Resistance Design Goal” on page 4-82.
- Create a detailed drawing of the site grounding electrode system based on the previous steps.
- Install the grounding electrode system using components and techniques detailed in this chapter.
- Test the grounding electrode system resistance to earth as described in Appendix D, “Testing/Verification of Grounding (Earthing) Electrode System and Bonding Continuity”.
- Bond all external metal objects to the grounding electrode system as required throughout this chapter. See “Metallic Objects Requiring Bonding” on page 4-108.

4.10.3 Grounding (Earthing) Electrode System Resistance Requirements

To disperse lightning energy into the earth without causing dangerous over-voltages, the shape and dimensions of the grounding electrode system are more important than its specific resistance value. However, a low-resistance grounding electrode system is generally recommended (IEC 62305-3, section D.5.4.1). Efforts should be made to reduce the grounding electrode system resistance to the lowest practicable level (MIL-HDBK-419A, section 2.2.3).

NOTE: Although grounding electrode system resistance is important and should be achieved whenever practicable, it alone does not determine whether the grounding electrode system can effectively dissipate and control lightning energy. The resistance of the grounding electrode system is only a general indicator of quality. Proper design and installation of the grounding electrode system, including ground rings, ground rods, radial grounding conductors, and the bonding of systems and equipment, are just as crucial as the resistance to earth.

Effective grounding electrode system shape and dimensions are achieved by correctly installing the required and recommended grounding electrode system components listed throughout this chapter. The required and recommended grounding electrode system components include, but are not limited to, the following:

- **Building ground ring**. See “External Building and Tower Ground Ring” on page 4-25.
- **Tower ground ring**. See “External Building and Tower Ground Ring” on page 4-25.
- **Ground rods** installed and spaced around the building and tower ground rings. See “General Ground Rod Requirements” on page 4-12.
- **Radial grounding conductors** for high lightning prone geographical areas, sites that are normally occupied (such as 911 dispatch centers), sites with high soil resistivity, or sites where bedrock prohibits the driving of ground rods. See “Radial Grounding Conductors” on page 4-29.
- **Bonding of all grounding electrode system components**. See “Common Grounding” on page 4-7 and “Bonding to the External Grounding and Bonding System” on page 4-61.
- **Bonding of all ancillary equipment.** See “Metallic Objects Requiring Bonding” on page 4-108.

The grounding electrode system resistance requirement is determined based on the classification of the site. Communications sites are classified by this standard into the three categories listed below, as defined in “Site Type Classification Definitions” on page 4-6.

- **Type A:** Light Duty
- **Type B:** Standard Duty
- **Type B2:** Extra Duty

4.10.3.1 Type “A” Sites: Light Duty

Type “A” sites **shall** have a grounding electrode system **resistance design goal of 25 Ω or less for a single grounding electrode** (NFPA 70-2026, Article 250.53; MIL-HDBK-419A, section 2.2.2.1; and TIA-607-E, section D.2.3). See Figure 4-66 for a typical single grounding electrode installation for a Type A site.

If the design goal of 25 Ω cannot be achieved throughout the year with a single grounding electrode, then the grounding electrode **shall** be augmented with at least one additional grounding electrode (NFPA 70-2026, Article 250.53). See “Soil Resistivity Variability and Factors Affecting Soil Resistivity” on page B-4 for information regarding the seasonal variations in grounding electrode resistance. See Figure 4-13 on page 4-16 for an example of two parallel ground rods.

NOTE: It is recommended to use two grounding electrodes as the minimum installation, even if a single electrode achieves 25 Ω.

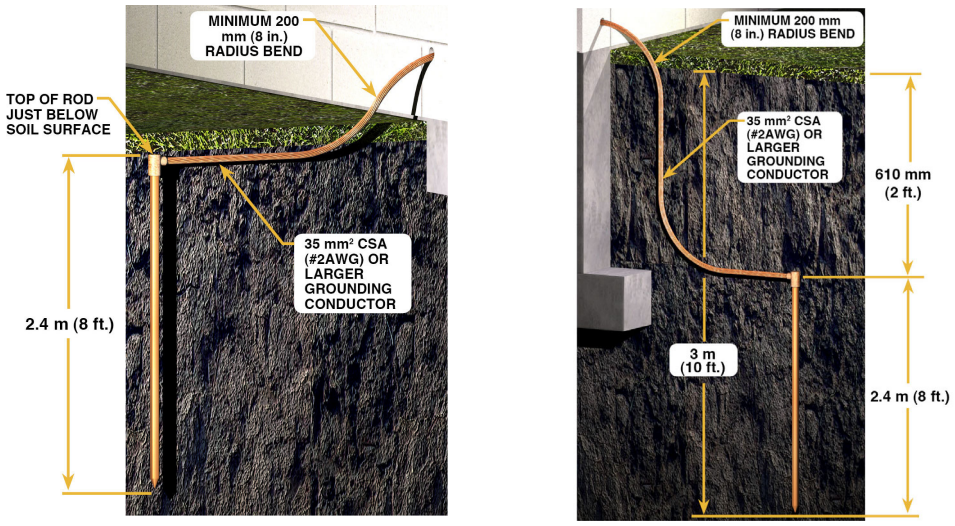


Figure 4-66. Typical Single Grounding Electrode Installations For Type A Sites

4.10.3.2 Type “B” Sites: Standard Duty

Type “B” sites **shall** have a grounding electrode system **resistance design goal of 10** Ω or less (AS/NZS 5070.1:2008 (R2019); FAA-STD-019G, section 4.4.3; IEC 62305-3:2024, section 5.4.1; ITU Earthing and Bonding Handbook; MIL-HDBK-419A; and MIL-STD-188-124A).

4.10.3.3 Type “B2” Sites: Extra Duty

Type “B2” sites **shall** have a grounding electrode system **resistance design goal of 5** Ω or less (see APCO ANS 2.106.1-2019, section 3.10.3; IEEE 142-2007, section 4.1.3; IEEE 1100-2005, section 9.9.1.3; IEEE 1692-2023, section 8.1; NENA-STA-027.3-2018, section 7.4.2; NWSM 30-4106:2017, section 2.9; and TIA-607-E, section D.2.3.2).

4.10.4 Supplemental Grounding Techniques to Help Achieve Resistance Design Goal

It is recommended to calculate the predicted grounding electrode system resistance based on the soil resistivity at the site and the planned grounding electrode system design. If the predicted resistance does not meet the design goal, the system design can be adjusted before installation using the techniques described below. Refer to Appendix B or an engineering firm for assistance with the resistance calculations.

If the resistance design goal cannot be met with the minimum required grounding electrode system (see “Minimum Site Grounding (Earthing) Requirements” on page 4-79), efforts **shall** be made to reach the goal through supplemental grounding techniques. At sites with high (poor) soil resistivity, it may be difficult to achieve the grounding electrode system resistance design goal without enhancements.

Type B and B2 sites that do not meet the resistance design goal **shall** require enhancements to the grounding electrode system.

Sites in high lightning prone geographical areas (see “High Lightning Geographic Region Defined” on page 4-6) and normally-occupied sites such as dispatch centers, should also include enhancements to the grounding electrode system, regardless if the resistance requirements are met. See ATIS-0600313.2019(R2024), section 10.3.2.

NOTE: If the resistance design goal for a Type B or B2 site cannot be achieved after reasonable and appropriate attempts to enhance the grounding electrode system, no further grounding is required at the site. It is recommended to seek review from Motorola Solutions Engineering or another engineering firm if the resistance design goal is not met.

Some techniques for enhancing the grounding electrode system are as follows:

- Installation of radial grounding conductors. See “Radial Grounding Conductors” on page 4-29.
- Installation of concrete-encased electrodes in new construction. See “Concrete-Encased Electrodes” on page 4-23.
- Installation of longer ground rods throughout the site. See “Ground Rod Installation Requirements” on page 4-13.
- Installation of electrolytic ground rods in place of conventional ground rods. See “Electrolytic Ground Rods” on page 4-19.
- Installation of wire mesh. See “Wire Mesh” on page 4-33.
- Use of grounding electrode encasement materials. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Specific design by Motorola Solutions Engineering or other engineering firm.

NOTE: Doubling the length of a ground rod decreases its resistance to earth by about 45% (assuming uniform soil).

4.10.5 Type “A” Site Grounding (Earthing)

At sites classified as Type “A”, a single ground rod may be adequate if it maintains 25 ohms or less consistently throughout the year. If a single ground rod cannot achieve 25 ohms or less throughout the year, then the ground rod **shall** be supplemented with an additional grounding electrode (NFPA 70-2026, Article 250.53; MIL-HDBK-419A, section 2.2.2.1; and TIA-607-E, section D.2.3). See Figure 4-13 on page 4-16 for an example of an augmented ground rod (additional ground rod in parallel). Other alternative methods may also be used, such as the following:

- Installing concrete-encased electrodes during new construction and bonding to the ground rod. See “Concrete-Encased Electrodes” on page 4-23.
- Installing a longer rod capable of maintaining 25 Ω or less throughout the year. See “Ground Rod Installation Requirements” on page 4-13.
- Installing an electrolytic ground rod capable of maintaining 25 Ω or less throughout the year. See “Electrolytic Ground Rods” on page 4-19.
- Installing a small ground ring. See Figure 4-120 on page 4-150.

NOTE: It is recommended to use two grounding electrodes as the minimum installation, even if 25 Ω is achieved with a single grounding electrode.

A typical Type “A” grounding system is shown in Figure 4-66. At an existing building, the AC power system grounding electrode system will typically serve adequately as the communications Type “A” grounding electrode system.

A supplemental Type “A” grounding electrode system may need to be installed if the site has an RF transmission line (or other communications cables) entry point at a location different from the AC power utility's entrance. If a supplemental Type “A” grounding electrode system is installed, it **shall** be bonded to the electrical service grounding electrode system and any other grounding electrode system at the site (see Figure 4-67). See “Common Grounding” on page 4-7. For an example of bonding a supplemental grounding electrode system to an existing AC power service grounding electrode system, see Figure 4-103 on page 4-127, Figure 4-106 on page 4-130, Figure 4-107 on page 4-131, and Figure 4-120 on page 4-150.

NOTE: A single 2.4 m × 15.9 mm (8 ft × 0.625 in.) ground rod requires a soil resistivity of approximately 6,250 ohm-cm or less throughout the year to achieve a resistance value of 25 Ω; a 3 m × 15.9 mm (10 ft × 0.625 in.) ground rod would require 7,500 ohm-cm; a 4.9 m × 15.9 mm (16 ft × 0.625 in.) ground rod would require 11,200 ohm-cm; and a 6.1 m × 15.9 mm (20 ft × 0.625 in.) ground rod would require 13,600 ohm-cm. Refer to Appendix B for additional information.

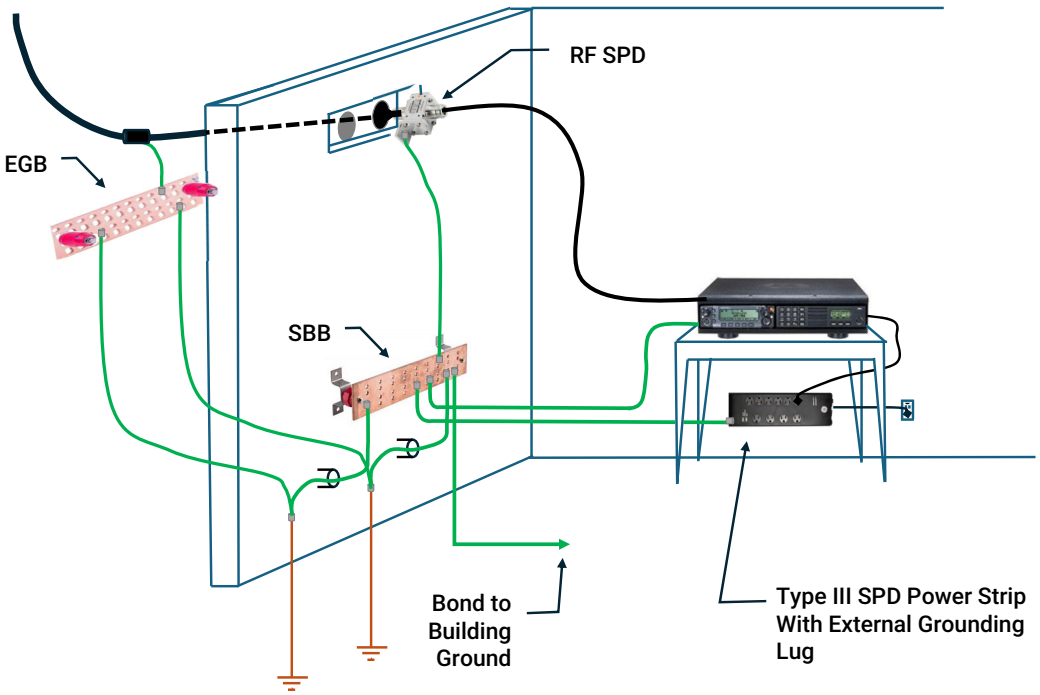


Figure 4-67. Example of Control Station Installation at Type A Site

4.10.6 Tower Grounding (Earthing)

An external grounding electrode system for a communications tower is required to dissipate lightning energy before it reaches the associated communications facility. Although it is impossible to prevent all lightning energy from entering the communications facility, most of the lightning energy can be controlled and diverted to the earth (ATIS-0600313.2019(R2024), section 10.1, and ATIS-0600334.2019(R2024), section 5.1). Antenna masts and metal support structures **shall** be grounded (NFPA 70-2026, Article 750.60 and 750.66).

IMPORTANT: For towers installed in high-lightning-prone geographical areas or sites that are normally occupied (such as 911 dispatch centers), radial grounding conductors should be employed to improve the equalization of the grounding electrode system (see ATIS-0600313.2019(R2024), section 10.3.2, and ATIS-0600334.2019(R2024), section 5.4). Where radials are used, each tower leg should be bonded to the ground ring with two conductors (ATIS-0600313.2019(R2024), section 10.3.2). Where two grounding conductors are used, they should be separated from each other by 90 degrees. See “Radial Grounding Conductors” on page 4-29. This is recommended even if the grounding electrode system resistance design goal is achieved without using radial grounding conductors.

Towers can be classified into three basic categories (ATIS-0600334.2019(R2024), section 6.3):

- Metallic Self-Supporting (including monopoles)
- Metallic Guyed
- Non-metallic Poles

WARNING: High voltage hazards may be present with utility pole and transmission tower installations. Only properly trained and qualified personnel SHALL perform communications equipment installations and maintenance at these locations. Qualification and training SHALL be determined by the utility and/or authority having jurisdiction. Installations at these locations require careful coordination with the utility to ensure a safe installation and SHALL adhere to applicable OSHA regulations (or their equivalents). Installations at these locations SHALL comply with all installation and clearance requirements of the *National Electrical Safety Code*® (or equivalent) and the utility. Consultation with Motorola Solutions Engineering, another engineering firm, and/or the utility is required for installations at these locations.

CAUTION: Some antenna support structures, such as water storage tanks, may require specialized grounding and bonding methods due to the risk of corrosion. Using tinned-copper conductors and stainless steel ground rods could be effective for reducing corrosion in these cases. Consultation with both the tank owner and an engineering firm is recommended.

4.10.6.1 Self-Supporting Towers (Including Monopoles)

Self-supporting towers **shall** minimally be grounded (earthed) as follows:

4.10.6.1.1 General Requirements for Self-Supporting Towers

- The tower **shall** be encircled by a ground ring (ATIS-0600334.2019(R2024), section 5; MIL-HDBK-419A; Telcordia GR-3171-CORE.i02, section 10.2.5; and TIA-222-I, section 10.4.2.2).
- The tower ground ring **shall** be installed at least 610 mm (2 ft) from the base or footing of the tower structure (ATIS-0600334.2019(R2024), section 5.3.1, and TIA-222-I, section 10.4.2.2).
- The tower ground ring **shall** be installed according to “External Building and Tower Ground Ring” on page 4-25.
- The tower ground ring **shall** be bonded to the building ground ring in at least two points using two 35 mm² csa (#2 AWG) or larger, bare, copper, or tinned-copper grounding conductors (ATIS-0600334.2019(R2024), Figure 1; MIL-STD-188-124B; and TIA-607-E, section D.2.5). See “External Building and Tower Ground Ring” on page 4-25, Figure 4-25 on page 4-26, and Figure 4-27 on page 4-27.
- The tower's support piers (concrete footings) should have the rebar electrically connected to the tower holding (anchor) bolts (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-607-E, section D.2.4). See Figure 4-68.
- Install radial grounding conductors if needed. See “Radial Grounding Conductors” on page 4-29 and “Dispatch Centers Co-Located With Communications Towers” on page 4-135.

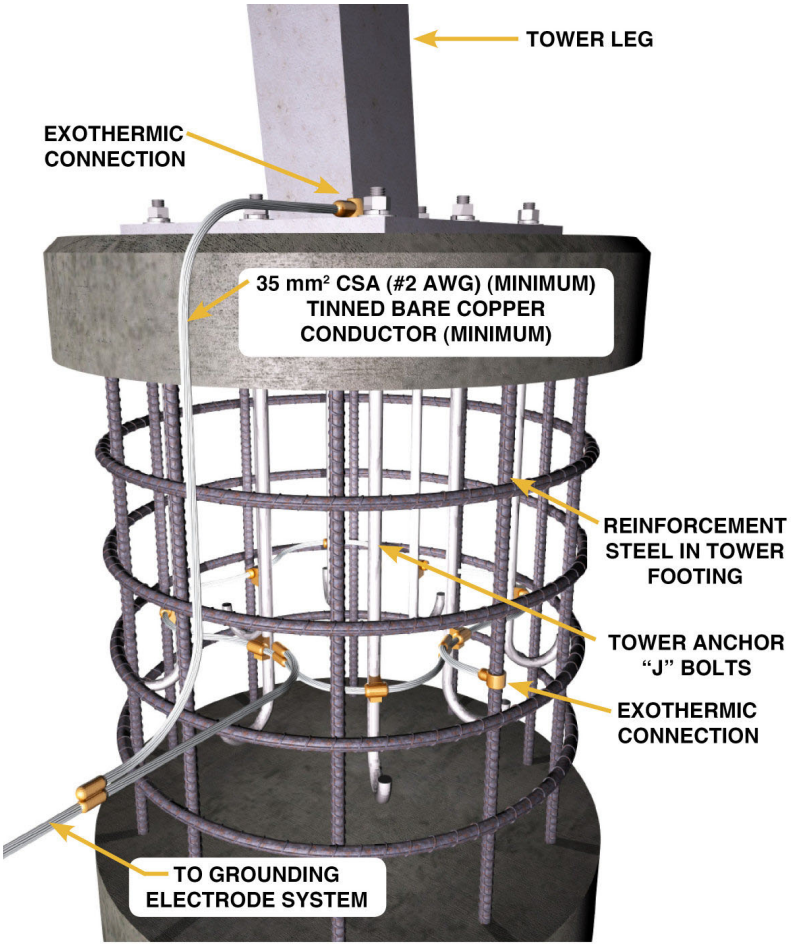


Figure 4-68. Tower Anchor Bolts Bonded to Rebar Cage and Grounding Electrode System

4.10.6.1.2 Ground Rod Requirements for Self-Supporting Towers

IMPORTANT: When only two ground rods are used, the ground rods **shall** be separated from each other as much as practicable (ideally the sum of their respective lengths). See "Ground Rod Resistance Characteristics and Sphere of Influence" on page 4-10.

IMPORTANT: Tower ground rings **shall** contain ground rods as needed to limit the distance between ground rods from 3 m to 4.5 m (10 to 15 ft).

- **For towers not exceeding 1.5 m (5 ft) in base width (including monopoles):** the tower ground ring **shall** include at least two ground rods installed on opposite (diametrically opposed) sides (ATIS-0600313.2019 (R2024), section 10.3.1, and ATIS-0600334.2019(R2024), section 5.2). Additional ground rods **shall** be added as needed to keep the distance between ground rods between 3 m and 4.5 m (10 to 15 ft). See Figure 4-69 on page 4-87 and Figure 4-70 on page 4-88 for examples.

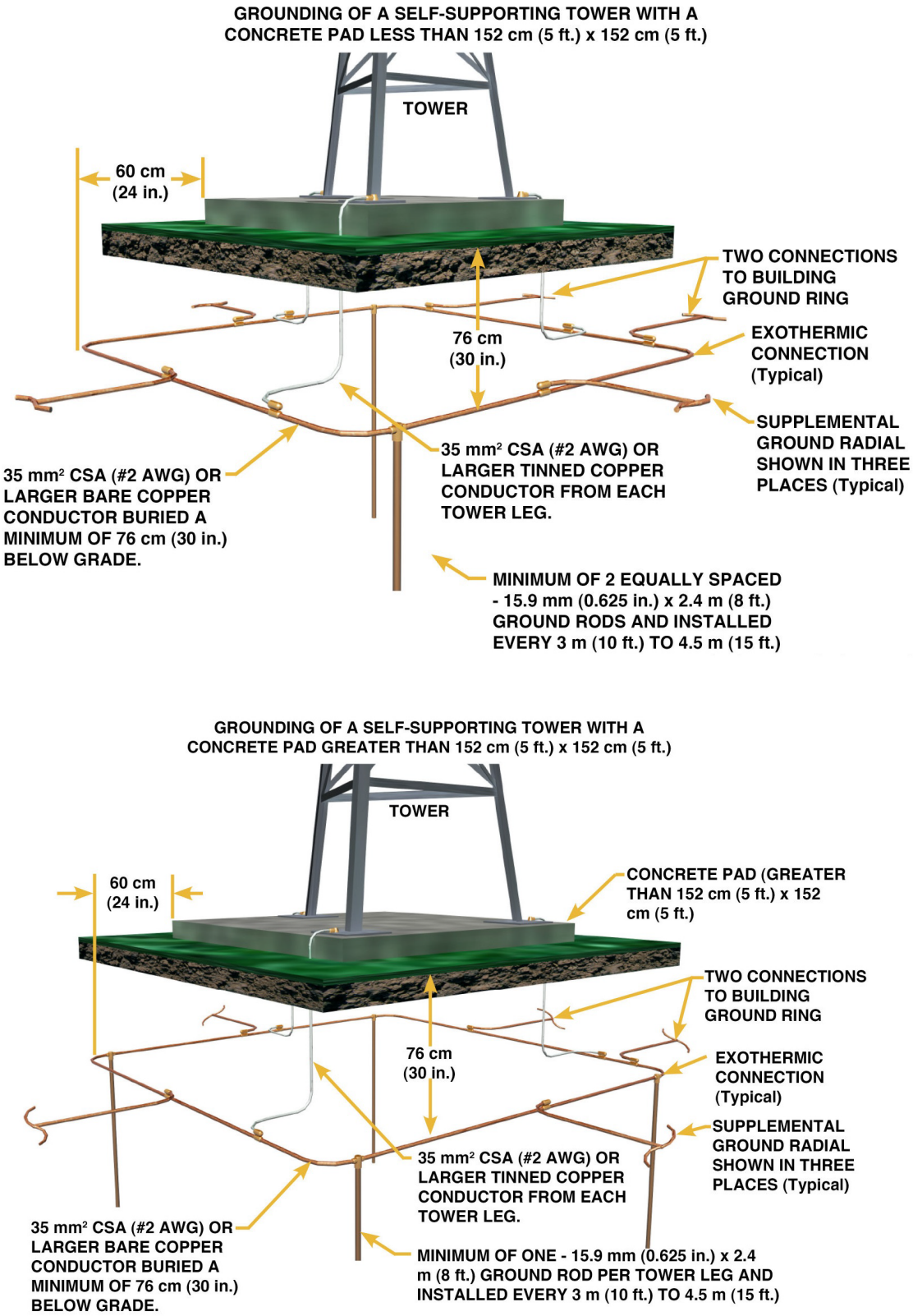


Figure 4-69. Examples of Self-Supporting Tower Grounding

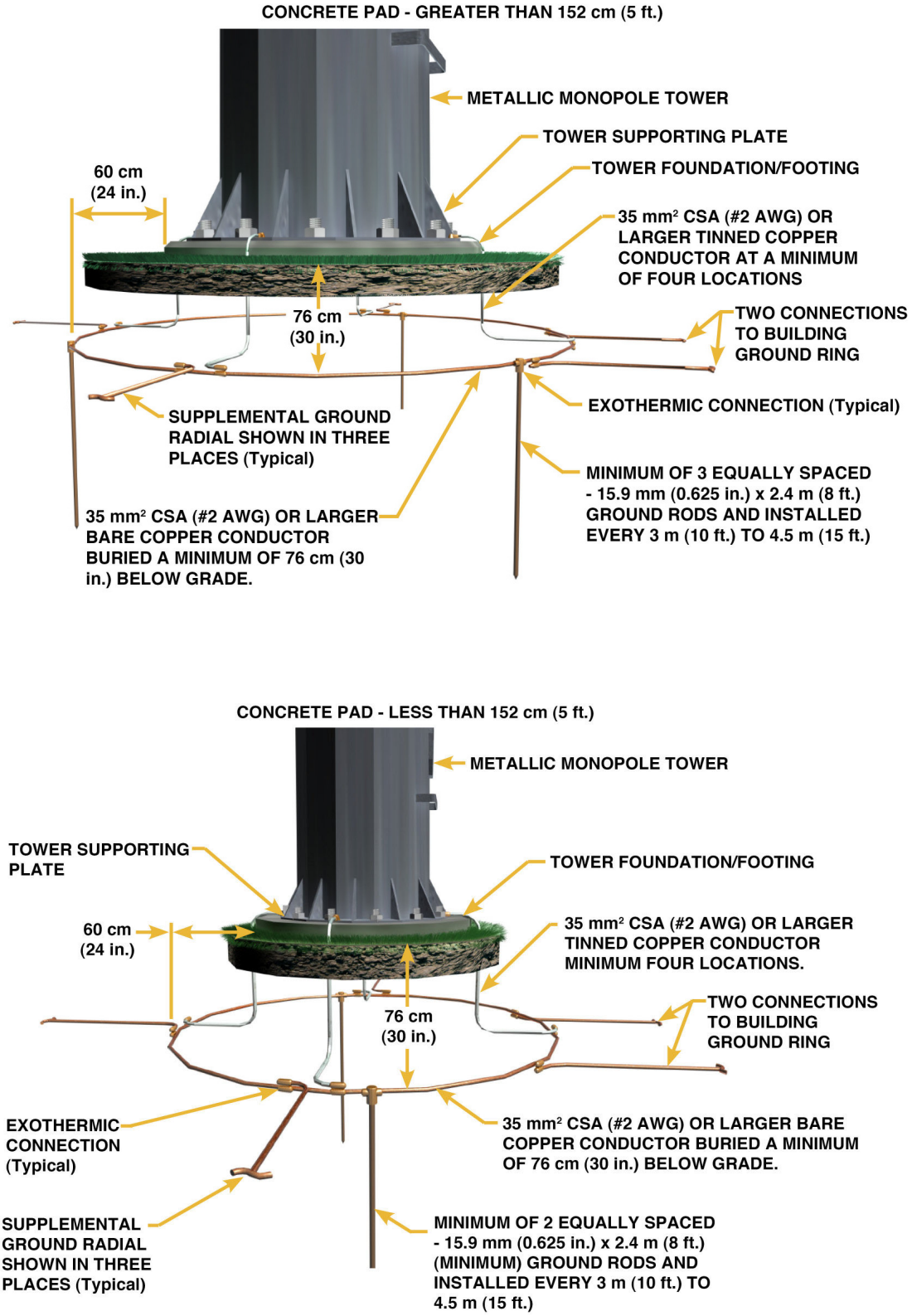


Figure 4-70. Examples of Monopole Tower Grounding

- **For towers with a base width equal to or exceeding 1.5 m (5 ft) (excluding monopoles):** the tower ground ring **shall** include at least one ground rod near each tower leg (ATIS-0600313.2019(R2024), section 10.3.1; ATIS-0600334.2019(R2024), section 5.3.2; and Telcordia GR-3171-CORE.i02, section 10.2.6) and additional ground rods as necessary to keep the distance between ground rods between 3 m and 4.5 m (10 to 15 ft). See Figure 4-69.
- **For monopole towers with a base width of 1.5 m (5 ft) or more:** the tower ground ring **shall** include at least three evenly spaced ground rods and additional rods as needed to keep the distance between ground rods between 3 m and 4.5 m (10 to 15 ft). See Figure 4-70.
- Ground rods **shall** meet the specifications and be installed according to "General Ground Rod Requirements" on page 4-12.
- In situations where site-specific soil conditions prevent the driving of a vertical ground rod, ground rods (conventional or electrolytic) may be installed horizontally, or ground plates may be used instead. The horizontal ground rods and ground plates **shall** be installed as described in this chapter.
- Horizontal ground rods and ground plates **shall** be installed at the same interval as required for vertical ground rods (intervals not exceeding 3 m to 4.5 m (10 to 15 ft)).

4.10.6.1.3 Bonding and Conductor Requirements for Self-Supporting Towers

- Each leg of a self-supporting tower **shall** be bonded to the tower ground ring using 35 mm² csa (#2 AWG) or larger, bare, copper, or tinned-copper grounding conductors. If the bonding connection to the tower leg uses mechanical hardware, tinned-copper conductors **shall** be used. See "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38. See Figure 4-69 on page 4-87.
  - In high lightning areas, each leg should be bonded to the tower ground ring using two grounding conductors separated by at least 90 degrees, as shown in Figure 4-31 on page 4-31.
- Monopole towers **shall** be bonded to the tower ground ring using at least four equally spaced 35 mm² csa (#2 AWG) or larger, bare, copper, or tinned-copper grounding conductors. If the tower manufacturer only provides three connection points, then three conductors are acceptable. See TIA-607-E, section D.2.4.2 for more information. See Figure 4-70.
- The tower grounding conductors **shall** be exothermically bonded to the tower structure unless the tower manufacturer specifically directs otherwise (TIA-607-E, section D.2.4.2). If mechanical hardware is used instead of exothermic welding, tinned-copper conductors **shall** be used. See "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38.
- Grounding conductors **shall** meet the requirements of "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38. Tinned-copper conductors should be used to help prevent galvanic corrosion.

CAUTION: Before performing exothermic welding on a tower, contact the manufacturer to confirm approved welding locations.

4.10.6.2 Guyed Towers

Guyed towers **shall** minimally be grounded (earthed) as follows:

4.10.6.2.1 General Requirements for Guyed Towers

- The tower **shall** be encircled by a ground ring (ATIS-0600334.2019(R2024), section 5.3; MIL-HDBK-419A; Telcordia GR-3171-CORE.i02, section 10.2.5; and TIA-222-I, section 10.4.2.2).
- The tower ground ring **shall** be installed at least 610 mm (2 ft) from the tower structure base or footing (ATIS-0600334.2019(R2024), section 5.3.1, and TIA-222-I, section 10.4.2.2).
- The tower ground ring **shall** be installed in accordance with to "External Building and Tower Ground Ring" on page 4-25.

- The tower ground ring **shall** be bonded to the building ground ring in at least two points using two 35 mm² csa (#2 AWG) or larger, bare, copper, or tinned-copper grounding conductors (ATIS-0600334.2019(R2024), Figure 1; MIL-STD-188-124B; and TIA-607-E, section D.2.5). See “External Building and Tower Ground Ring” on page 4-25, Figure 4-25 on page 4-26 and Figure 4-27 on page 4-27.
- Install radial grounding conductors if needed. See “Radial Grounding Conductors” on page 4-29 and “Dispatch Centers Co-Located With Communications Towers” on page 4-135.
- The tower's support piers (concrete footings) should have the rebar electrically connected to the tower holding (anchor) bolts (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-607-E, section D.2.4). Ensure all anchor bolts and rebar cage are bonded together (ATIS-0600334.2019(R2024), section 6.3.1). See Figure 4-68 for an example on a self-supporting tower.

4.10.6.2.2 Ground Rod Requirements for Guyed Towers

- The tower ground ring **shall** include at least two ground rods installed on opposite sides (diametrically opposed) (ATIS-0600313.2019(R2024), section 10.3.1, and ATIS-0600334.2019(R2024), section 5.2) and additional ground rods as needed to limit the distance between ground rods from 3 m to 4.5 m (10 to 15 ft).
- Ground rods **shall** meet the specifications and be installed according to “General Ground Rod Requirements” on page 4-12.
  - In situations where site-specific soil conditions prevent the driving of a vertical ground rod, ground rods (conventional or electrolytic) may be installed horizontally, or ground plates may be used instead. The horizontal ground rods and ground plates **shall** be installed as described in this chapter.
  - Horizontal ground rods and ground plates **shall** be installed at the same interval as required for vertical ground rods (intervals not exceeding 3 m to 4.5 m (10 to 15 ft)).

IMPORTANT: When only two ground rods are used, the ground rods **shall** be separated from each other as much as practicable (ideally the sum of their respective lengths). See “Ground Rod Resistance Characteristics and Sphere of Influence” on page 4-10.

IMPORTANT: Tower ground rings **shall** contain ground rods as needed to limit the distance between ground rods from 3 m to 4.5 m (10 to 15 ft).

4.10.6.2.3 Bonding and Conductor Requirements for Guyed Towers

- The tower **shall** be bonded to the grounding electrode system using one of the following techniques (see Figure 4-71 on page 4-91 and TIA-607-E, section D.2.4.1):
  - The tower bottom plate is bonded to the tower ground ring using at least three equally spaced 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper grounding conductors.
  - Each leg is bonded to the tower ground ring using 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper grounding conductors. If the bonding connection to the tower leg uses mechanical hardware, tinned-copper conductors **shall** be used.
  - The tower side face plates (minimum of three) are bonded to the tower ground ring using 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper grounding conductors. If the bonding connection to the tower side face plate uses mechanical hardware, tinned-copper conductors **shall** be used.
- The tower grounding conductors **shall** be bonded to the tower structure using exothermic welding unless the tower manufacturer specifically directs otherwise. If mechanical hardware replaces exothermic welding, tinned-copper conductors **shall** be used. See “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.
- Grounding conductors **shall** meet the requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38. Tinned-copper conductors should be used to help prevent galvanic corrosion.

CAUTION: Before performing exothermic welding on a tower, contact the manufacturer to confirm approved welding locations.

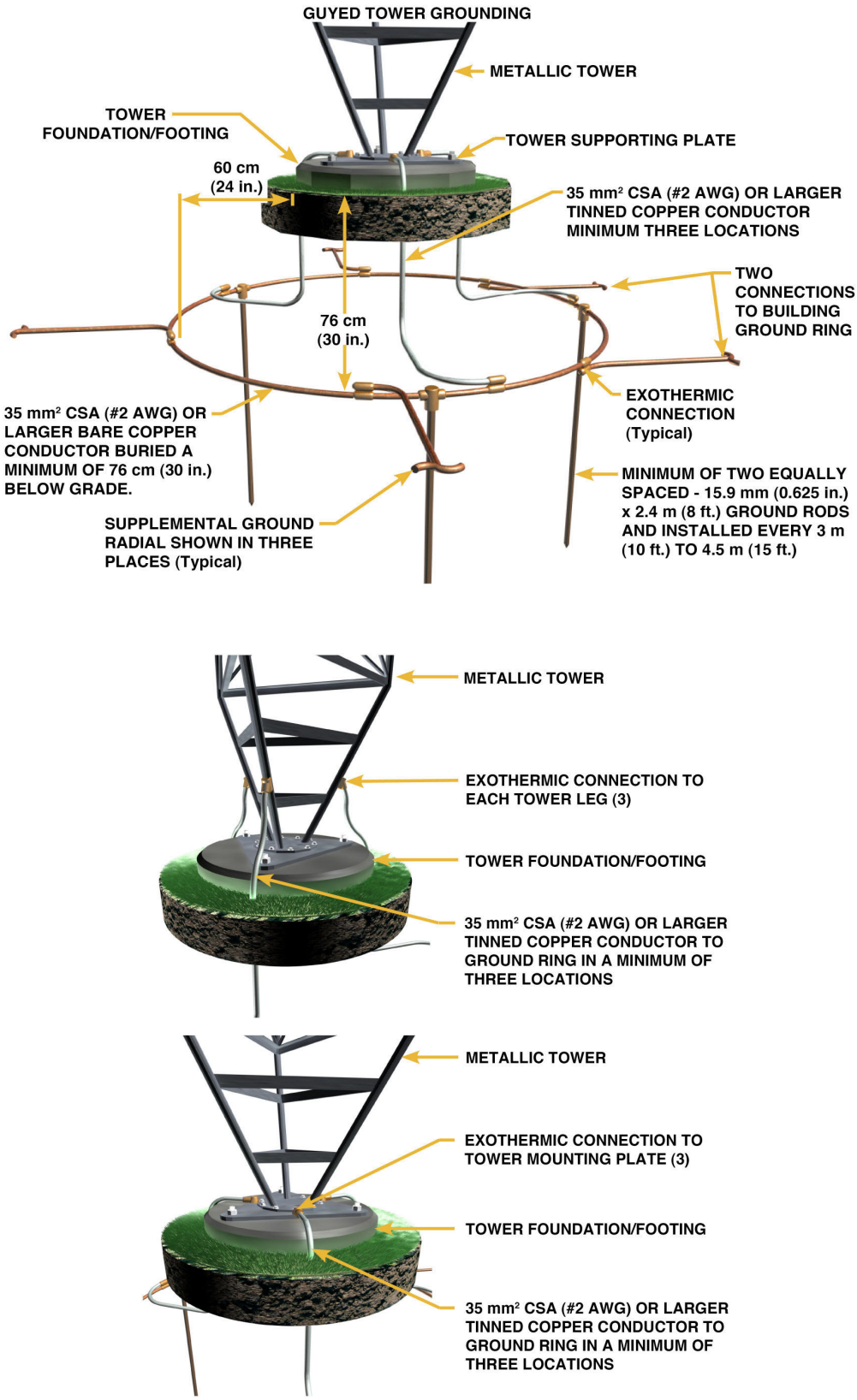


Figure 4-71. Examples of Guyed Tower Grounding

4.10.6.2.4 Steel Guy Anchor Point Grounding

Grounding steel guy anchor points requires special attention due to the possibility of galvanic corrosion damage to the anchor points.

IMPORTANT: Although various methods for grounding guy anchor points exist, any deviations from the requirements and guidelines in this section **shall** be designed by an engineering firm. A corrosion specialist should be consulted for all guy anchor installations.

NOTE: Non-metallic guy wires do not require grounding.

Steel guy wire anchor points **shall** minimally be grounded as outlined in the following sections.

4.10.6.2.5 New Construction

- The guy anchor **shall** be installed in a way that prevents direct contact with soil. This is achieved by encasing the guy anchor in reinforced concrete along its entire embedded length. The concrete encasement **shall** extend at least 152 mm (6 in.) above-grade (see TIA-222-I, ANNEX H and TIA-607-E, Figure 30).

NOTE: Encasing the anchor in reinforced concrete along its entire embedded length helps prevent galvanic corrosion between the guy anchor and copper components of the grounding electrode system. Galvanized steel in concrete has a potential similar to that of copper (see “Miscellaneous General Corrosion Information” on page 4-59). Additionally, encasing the entire embedded length of the anchor in reinforced concrete reduces the risk of galvanic corrosion that could otherwise occur between the part of the anchor in contact with soil and the part encased in concrete.

- A ground rod **shall** be installed at each guy anchor point (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-222-I, section 10.4.2.1). In situations where site-specific soil conditions prevent the driving of a vertical ground rod, alternative electrodes may be installed as described in this chapter. These alternatives include horizontally installed ground rods, ground plates, or ground rings. Consultation with an engineer is advisable in such cases.
- Ground rods **shall** meet the specifications and be installed according to “General Ground Rod Requirements” on page 4-12.
- The ground rod **shall** be installed at least 610 mm (2 ft) from the guy anchor footing.
- The guy anchor **shall** be bonded to the ground rod using a 35 mm² csa (#2 AWG) or larger, bare, tinned, copper conductor (see Figure 4-72) (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-222-I, section 10.4.2.1).
- All guy wires at a guy anchor point **shall** be bonded to the ground rod (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-607-E, section D.2.4.1) using a 35 mm² csa (#2 AWG) or larger, bare, **tinned**, copper conductor (see Figure 4-72). **Stranded conductor shall be used** to help prevent conductor breakage due to vibrations. Alternatively, the guy anchor point should be grounded as shown in Figure 4-73 on page 4-94, using galvanized guy wire as the above-grade conductor (see NWSM 30-4106:2017, section 2.7.9.6). **Using galvanized guy wire is the preferred method.**

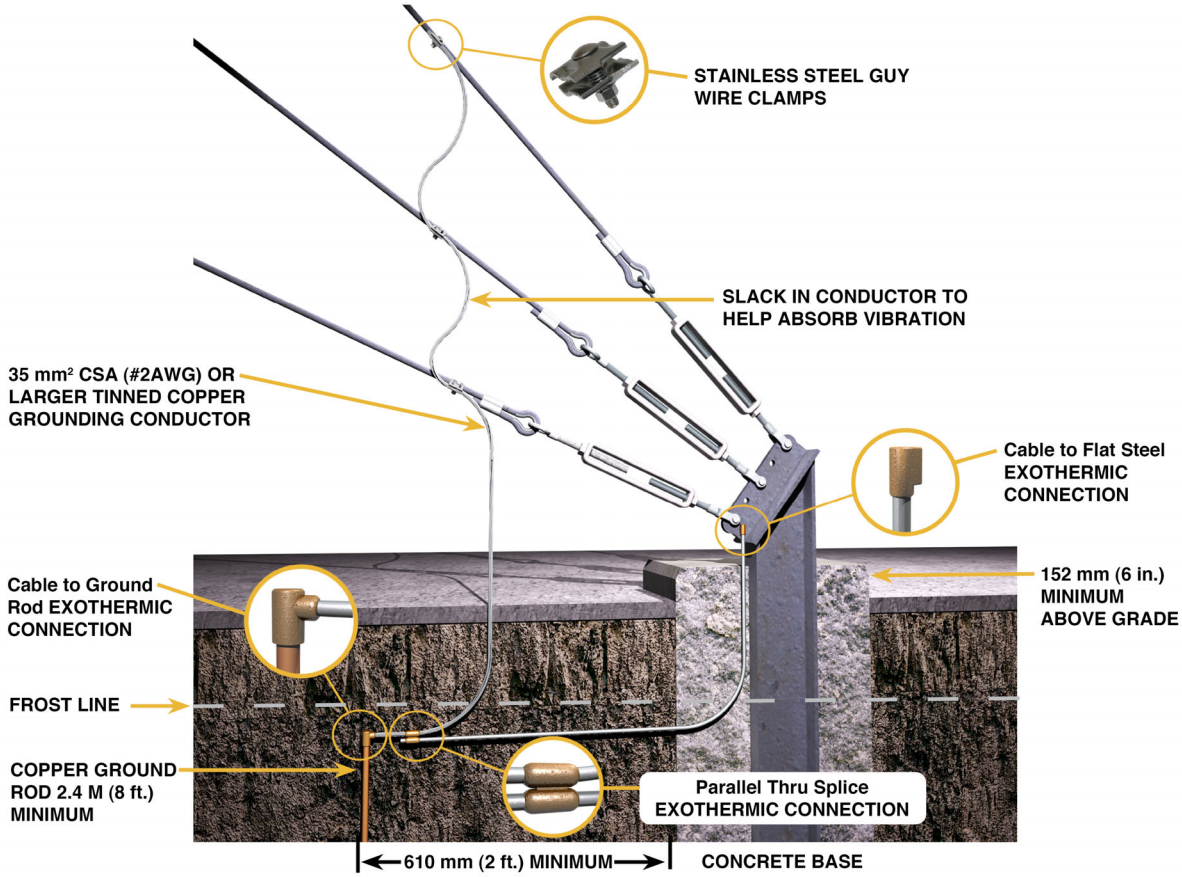


Figure 4-72. Guy Anchor Point Grounding for New Construction

- The grounding conductor **shall** be connected to each guy wire using stainless steel or other approved clamps. Each connection **shall** be coated with a listed conductive antioxidant compound. See “Antioxidant Compound” on page 4-68.

CAUTION: Do not attempt to exothermically weld to tower guy wires.

- The grounding conductor **shall** be connected to the guy wires above the turnbuckles.
- The grounding conductor **shall** maintain a continuous, smooth flow from the guy wire attachment point to the grounding electrode. An S-shape pattern **shall** be used to help absorb guy wire vibrations and prevent breakage of the grounding conductor.

IMPORTANT: Grounding conductors used at guy anchor points **shall** be tinned-copper to help prevent galvanic corrosion and **shall** be stranded to help prevent conductor breakage due to vibrations. **Alternatively, galvanized guy wire may be used as shown in Figure 4-73 (NWSM 30-4106:2017).**

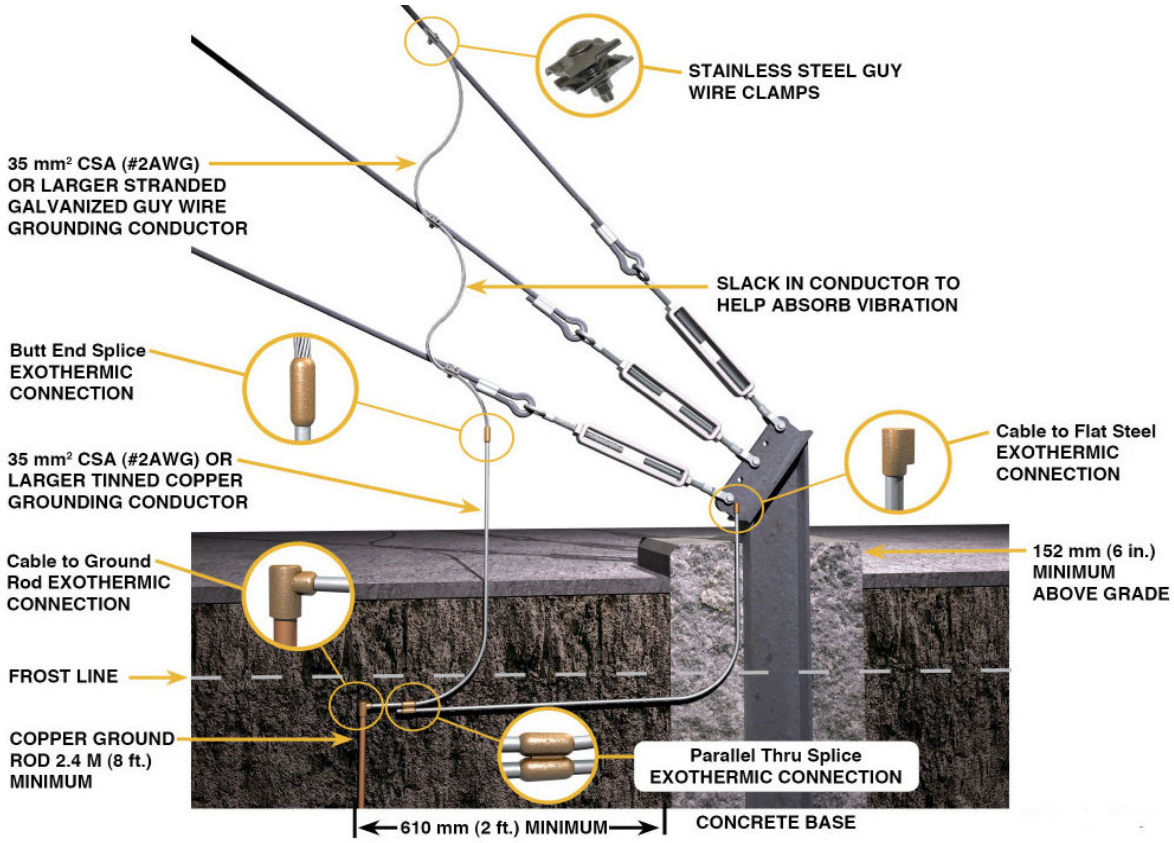


Figure 4-73. Guy Anchor Point Grounding for New Construction (Using Guy Wire as the Above-Grade Bonding Conductor)

4.10.6.2.6 Existing Anchor Points in Direct Contact with Soil

A corrosion control specialist **shall** be consulted for new grounding at existing guyed tower anchor points (see TIA-222-I, ANNEX H). Some example solutions provided by the corrosion specialist may include one or more of the following:

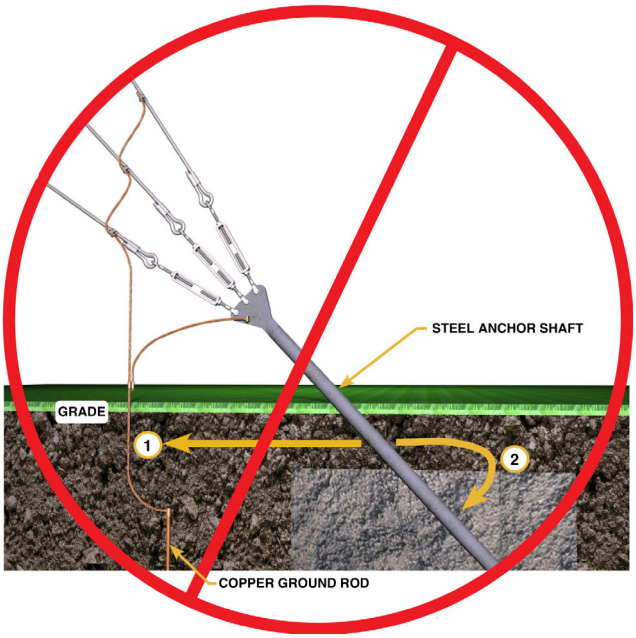
- Cathodic protection utilizing sacrificial anodes (see TIA-222-I, ANNEX H).
- Cathodic protection utilizing an impressed current (see TIA-222-I, ANNEX H).
- Encasement of the guy anchor with concrete or gravel backfill greater than 150 mm (6 in.) around the anchor (see TIA-222-I, section 9.4.3.2.1 and ANNEX H).
- Coating the steel that directly contacts soil (or gravel backfill in corrosive soil conditions) with a special corrosion control product (see TIA-222-I, section 9.4.3.2.1 and ANNEX H).
- Grounding the guy anchor point using a ground rod (TIA-222-I, section 10.4.2.1). Ground rods **shall** meet the specifications and be installed according to “General Ground Rod Requirements” on page 4-12.
  - In situations where site-specific soil conditions prevent the driving of a vertical ground rod, alternative electrodes may be installed as described in this chapter. These alternatives include horizontally installed ground rods, ground plates, or ground rings. Consultation with an engineer is advisable in such cases.
  - To mitigate galvanic corrosion between the galvanized guy anchor point and the ground rod, the ground rod should be constructed from galvanized steel.
- Bonding the guy anchor point to the ground rod using a 35 mm² csa (#2 AWG) or larger, bare, tinned-copper conductor (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-222-I, section 10.4.2.1).

- Bonding all guy wires at the guy anchor point to the ground rod using a 35 mm² csa (#2 AWG) or larger, bare, **tinned-copper** conductor (ATIS-0600313.2019(R2024), section 10.3.1, and TIA-222-I, section 10.4.2.1).
  - **A stranded conductor shall be used to help prevent conductor breakage due to vibrations**.
  - Alternatively, the guy anchor point may be grounded as shown in Figure 4-73, using galvanized guy wire as the above-grade conductor (see NWSM 30-4106:2017, section 2.7.9.6). **Using galvanized guy wire is the preferred method.**
- The grounding conductor **shall** be connected to each guy wire using stainless steel or other approved clamps. Each connection **shall** be coated with a listed conductive antioxidant compound. See “Antioxidant Compound” on page 4-68.

CAUTION: Do not attempt to exothermically weld to tower guy wires.

- The grounding conductor **shall** be connected to the guy wires above the turnbuckles.
- The grounding conductor **shall** maintain a continuous, smooth flow from the guy wire attachment point to the grounding electrode. An S-shape pattern **shall** be used to help absorb guy wire vibrations and prevent breakage of the grounding conductor.
- See Figure 4-74 and Figure 4-75 for details.

IMPORTANT: Grounding conductors used at guy anchor points **shall** be tinned-copper to help prevent galvanic corrosion and **shall** be stranded to help prevent conductor breakage due to vibration. **Alternatively, galvanized guy wire may be used as shown in Figure 4-73.**



1. Corrosion from steel anchor shaft to copper ground rod and other copper grounding electrode system components.

2. Corrosion from steel anchor shaft to the portion of anchor shaft encased in concrete (steel encased in concrete is similar to copper)

Figure 4-74. Example of Guy Anchor Galvanic Corrosion

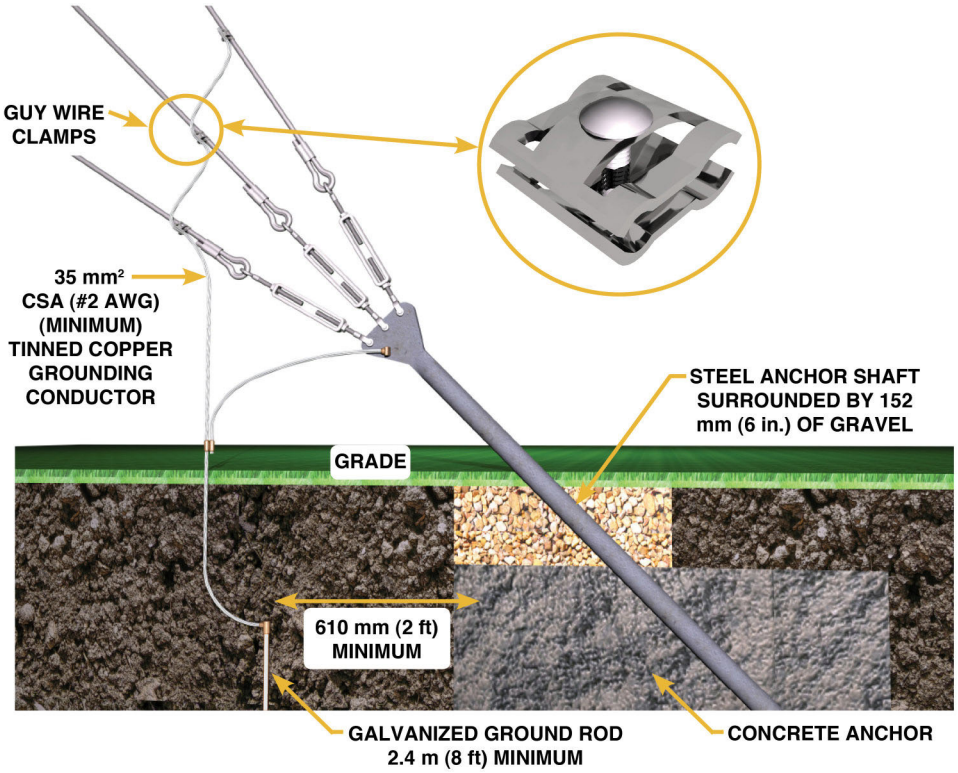


Figure 4-75. Guy Anchor Point Grounding for Existing Construction

4.10.6.2.7 Cathodic Protection for Guy Anchors

Additional corrosion control can be obtained through the use of cathodic protection. See MIL-HDBK-419A Volume I, section 2.10; FAA-STD-019G, section 4.4.6; ITU Bonding and Earthing Handbook, section 3.12; and TIA-222-I, section 9.4.3.2.1 and Annex H for additional information.

IMPORTANT: Cathodic protection systems should be installed only under the advice and direction of a corrosion specialist.

Galvanic and electrolytic corrosion happen when current flows from the anchor into the surrounding soil (see Figure 4-74). The goal of cathodic protection is to reverse the current direction, causing it to flow to the anchor instead of away from it, thereby helping to prevent corrosion of the anchor. This can be done by installing galvanic anodes or by providing an impressed current.

By electrically connecting a metal (galvanic anode) that ranks higher on the galvanic series and placing it close to the structure, current can be directed to the guy anchor. This causes the installed metal anode to corrode instead of the guy anchor. Because of this, the metal is called a sacrificial anode and must be periodically inspected to ensure it has not corroded beyond use. Additional sacrificial anode material may need to be added over time. A common sacrificial anode used is magnesium, which is packaged in a prepared backfill mixture to improve its conductivity with soil.

The number, size, type, and location of galvanic anodes should be determined by a corrosion specialist and must be sufficient to ensure current flows correctly, overcoming all other influences at the site. The effectiveness of an installed system should be periodically monitored over the structure's lifespan by a corrosion specialist. This can be done by measuring the potential of the protected anchor relative to a reference electrode placed in the ground. A sufficiently negative potential indicates that current is flowing to the anchors as intended for corrosion control. See TIA-222-I for more information.

IMPORTANT: Any type of corrosion control installation technique does not eliminate the need for monitoring and maintenance throughout the structure's life (see TIA-222-I for more information).

4.10.6.3 Non-metallic Poles

NOTE: Non-metallic poles are typically wood, carbon fiber, or concrete. The antenna supports and transmission lines **shall** be grounded as shown in Figure 4-76.

Non-metallic tower structures **shall** minimally be grounded as follows (see Figure 4-76 and TIA-607-E, section D.2.4.3):

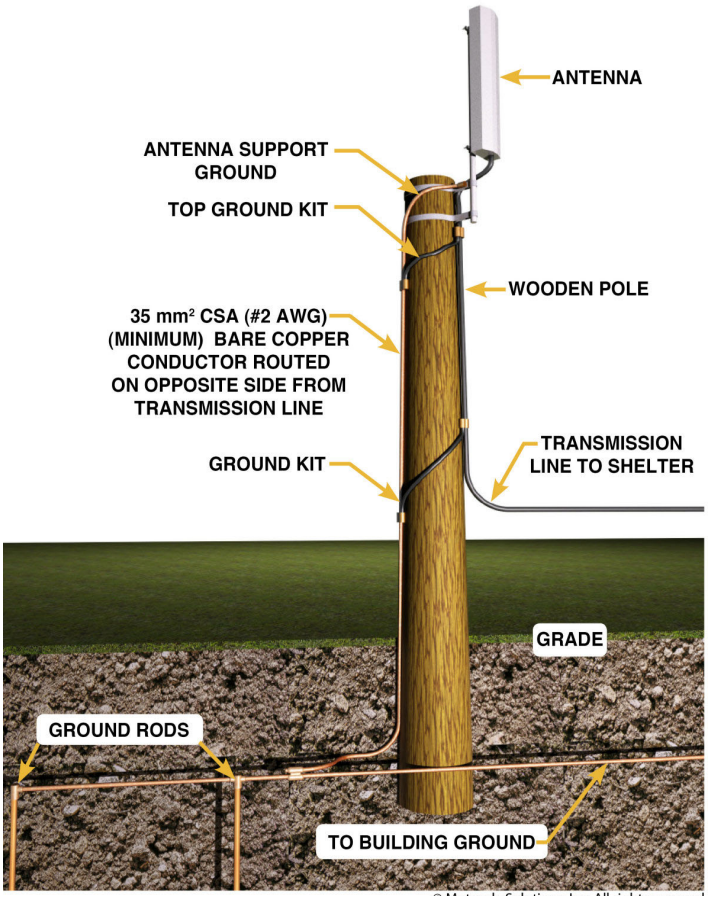


Figure 4-76. Non-metallic Pole Grounding

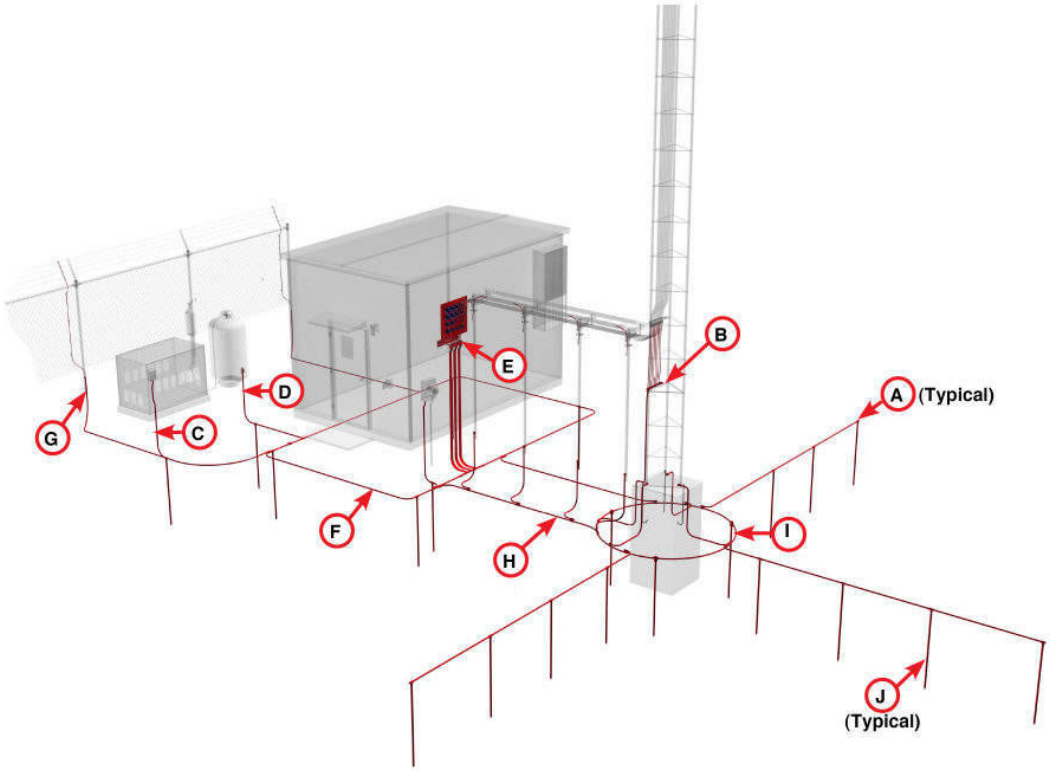
- A vertical grounding conductor **shall** be installed along the length of the pole.
- The vertical grounding conductor **shall** be made of 35 mm² csa (#2 AWG) or larger, solid, bare copper or tinned-copper (ATIS-0600334.2019(R2024), section 6.5). It is recommended to size the grounding conductor according to Table 4-6.
- The grounding conductor **shall** be installed according to "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38.
- The vertical grounding conductor **shall** connect to a radial grounding conductor or tower ground ring (with rods).
- The radial grounding conductor **shall** be installed according to "Radial Grounding Conductors" on page 4-29.

- The ground ring **shall** be installed according to “External Building and Tower Ground Ring” on page 4-25.
- Ground rods **shall** meet the specifications and be installed according to “General Ground Rod Requirements” on page 4-12.
- The non-metallic pole grounding electrode system **shall** be bonded to the building grounding electrode system. See “Common Grounding” on page 4-7.

4.10.7 Dedicated Communications Building Grounding (Earthing)

All dedicated communications buildings **shall** have a correctly installed external grounding electrode system. The grounding electrode system resistance **shall** meet the requirements of “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-81.

A typical site grounding electrode system layout is shown in Figure 4-77. The building grounding electrode system requirements are as follows, and **shall** also include any supplemental grounding required to meet the resistance design goal. See “Minimum Site Grounding (Earthing) Requirements” on page 4-79.



A:	Grounding Radials
B:	Tower Ground Busbar and Down Conductors
C:	Generator Grounding Conductor
D:	Fuel Tank Grounding Conductor
E:	External Ground Busbar
F:	Shelter Ground Ring
G:	Fence Grounding Conductor
H:	Ground Ring Bonding Conductor (2 minimum)
I:	Tower Ground Ring
J:	Earthing Electrodes (Ground Rods)

Figure 4-77. Dedicated Communications Building Grounding

- Installation of concrete-encased electrodes as part of new construction. See “Concrete-Encased Electrodes” on page 4-23.
- Where practicable, the building **shall** be encircled by a ground ring installed according to “External Building and Tower Ground Ring” on page 4-25 (see IEEE 1692-2023, section 8.2).
- The building ground ring **shall** have vertical ground rods installed as follows:
  - Below the External Ground Busbar (EGB)
  - At each corner of the shelter
  - Additional ground rods **shall** be installed as needed to reduce the spacing between rods from 3 m to 4.5 m (10 to 15 ft) (ATIS-0600334.2019(R2024), section 5.3.2).
- The ground rods **shall** be installed according to “General Ground Rod Requirements” on page 4-12.
  - In situations where site-specific soil conditions prevent the driving of a vertical ground rod, ground rods (conventional or electrolytic) may be installed horizontally, or ground plates may be used. The horizontal ground rods and ground plates **shall** be installed as described in this chapter.
  - Horizontal ground rods and ground plates **shall** be installed at the same interval as required for vertical ground rods (intervals not exceeding 3 m to 4.5 m (10 to 15 ft)).
- The ground rods **shall** be exothermically welded to the ground ring or as otherwise allowed in “Bonding to the External Grounding and Bonding System” on page 4-61.
- The building ground ring **shall** be bonded to the tower ground ring using a minimum of two 35 mm² csa (#2 AWG) or larger bare copper or tinned-copper conductors. See “External Building and Tower Ground Ring” on page 4-25 and Figure 4-27 on page 4-27.
- The tower (if applicable) **shall** be grounded according to “Tower Grounding (Earthing)” on page 4-84 (see IEEE 1692-2023, section 8.2).
- Determine if radial grounding conductors should be installed at the site. See “Radial Grounding Conductors” on page 4-29. A minimum of four radial grounding conductors are recommended (IEEE 1692-2023, section 8.2).
- Ground and bond the external generator if installed as described in “Grounding (Earthing) Generators External to the Building” on page 4-99.
- Ground and bond devices and metallic objects as described in this chapter.

4.10.8 Grounding (Earthing) Generators External to the Building

Generators installed outside of the building, within 1.8 m (6 ft) of the building, **shall** be bonded to the nearest practicable point on the grounding electrode system as shown in Figure 4-78, using a 16 mm² csa (#6 AWG) or larger, copper or tinned-copper conductor (ATIS-0600313.2019(R2024), Figure 3(a) and ATIS-0600334.2019(R2024), section 5.3.3). Grounding conductors routed below-grade or partially below-grade **shall** be 35 mm² csa (#2 AWG) or larger.

External generator grounding **shall** comply with the following:

- Bonding to the generator chassis **shall** be done according to the manufacturer's requirements. Two-hole compression lugs **shall** be used where practicable (see Figure 4-55 on page 4-62).
- The grounding conductors **shall** meet the requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.
- Bonding to the grounding electrode system (below-grade) **shall** be made using exothermic welding or listed irreversible high-compression fittings. Bonding to an available ground busbar (above-grade) **shall** be made using exothermic welding, listed irreversible high-compression fittings, or listed two-hole compression lugs (see Figure 4-54 on page 4-62 for a compression lug example). See “Bonding to the External Grounding and Bonding System” on page 4-61.

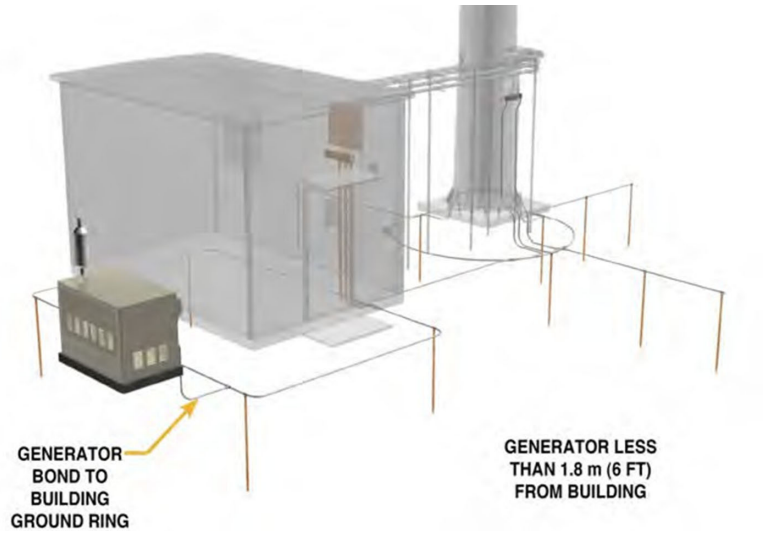


Figure 4-78. Generator Grounding: Less than 1.8 m (6 ft) from Building

Generators installed more than 1.8 m (6 ft) away from the building **shall** be bonded to the nearest practicable point on the grounding electrode system, as describe previously, for generators within 1.8 m (6 ft) of the building. In addition, the generator **shall** have a ground rod installed nearby and bonded to the generator (ATIS-0600313.2019(R2024), Figure 3(a)) as shown in Figure 4-79. Installation of the addition generator ground rod **shall** comply with the following:

- The additional ground rod **shall** meet the requirements of “General Ground Rod Requirements” on page 4-12.
- The additional ground rod **shall** be installed using methods described in “General Ground Rod Requirements” on page 4-12.
- The grounding conductor between the ground rod and generator **shall** be 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper. The grounding conductor **shall** meet the requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.
- Bonding to the ground rod **shall** be made using exothermic welding or listed irreversible high-compression fittings. See “Bonding to the External Grounding and Bonding System” on page 4-61.

If site specific soil conditions prohibit the installation of a vertical ground rod, other grounding electrodes for the soil may be used. These could include a horizontal ground rod, a ground plate, a ground ring around the generator, and/or a concrete-encased electrode within the generator pad. Refer to the specific grounding electrode section in this chapter for specifications and installation requirements.

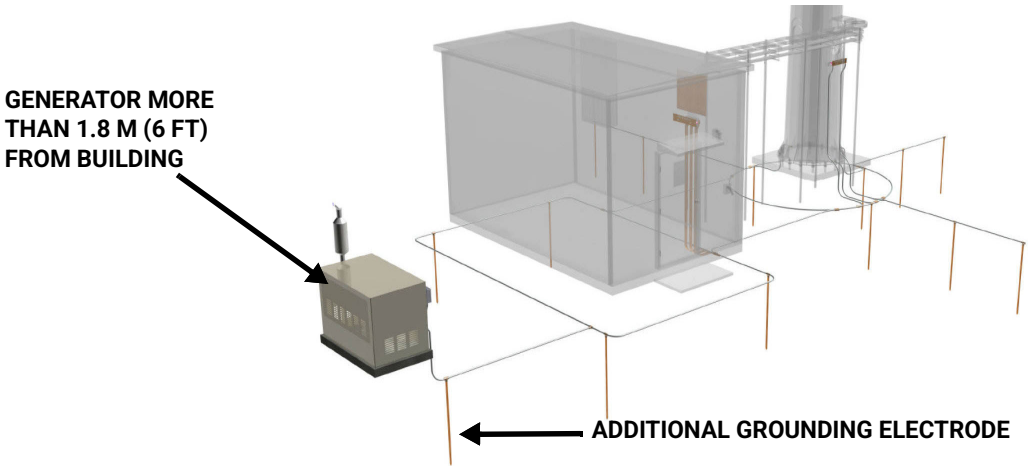


Figure 4-79. Generator Grounding: More than 1.8 m (6 ft) from Building

4.10.9 Outdoor Cabinet Grounding (Earthing) and Bonding

Outdoor cabinets are grounded similarly to a dedicated communications building or shelter (ATIS-0600313.2019(R2024), section 1.1, and TIA-607-E, section D.2.5). See “Dedicated Communications Building Grounding (Earthing)” on page 4-98 for details.

Outdoor cabinets **shall** be grounded as follows (see Figure 4-80):

- The cabinet **shall** be encircled with a ground ring. The ground ring **shall** meet the requirements of “External Building and Tower Ground Ring” on page 4-25.
- The ground ring **shall** be installed at least 914 mm (3 ft) from the cabinet foundation/pad.
- The cabinet ground ring **shall** have a ground rod installed at each corner and as needed to limit the distance between rods from 3 m to 4.5 m (10 to 15 ft).
- The cabinet ground ring **shall** be bonded to the tower ground ring as detailed in “External Building and Tower Ground Ring” on page 4-25.
- Towers associated with outdoor cabinets **shall** be grounded as detailed in “Tower Grounding (Earthing)” on page 4-84.
- Generators associated with the outdoor cabinet **shall** be grounded and bonded as described in “Grounding (Earthing) Generators External to the Building” on page 4-99.
- RF transmission lines and other communications cables with an outer metallic shield **shall** be grounded and bonded as detailed in “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104.
- Metallic objects near the cabinet **shall** be bonded to the cabinet grounding electrode system as detailed in “Metallic Objects Requiring Bonding” on page 4-108.
- The cabinet grounding electrode system **shall** be bonded to the cabinet's internal ground point and cabinet housing using a 35 mm² csa (#2 AWG) or larger, copper or tinned-copper grounding conductor. The conductor **shall** be installed according to “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.

In addition to the requirements described previously, the following recommendations should be considered:

- Cabinets installed on pads that incorporate a footing should consider the use of concrete-encased electrodes, in addition to the ground ring. See “Concrete-Encased Electrodes” on page 4-23.
- Wire mesh should be considered for outdoor cabinet grounding where the available land for installing a traditional grounding electrode system is limited. See “Wire Mesh” on page 4-33.
- Depending on the location of the cabinet's internal ground point, the grounding conductor installed between the grounding electrode system and the cabinet's internal ground point may need to be routed through the concrete footing/pad to allow for direct conductor routing. This requires the grounding conductor to be installed before the concrete is poured.



Figure 4-80. Cabinet Grounding System

4.11 Bonding of RF Preamplifiers and Other Active Devices on Towers

RF preamplifiers and other active devices are commonly installed on towers. The active devices can include, but are not limited to, the following:

- RF preamplifiers (Tower-Top Amplifier)
- Self-contained microwave radios
- Point-to-point radios
- Point-to-multi-point radios
- Wireless access points
- Wireless routers
- Security cameras

Devices installed on towers are exposed to lightning and therefore require special installation and grounding techniques. The device installation and grounding requirements are as follows (see Figure 4-81):

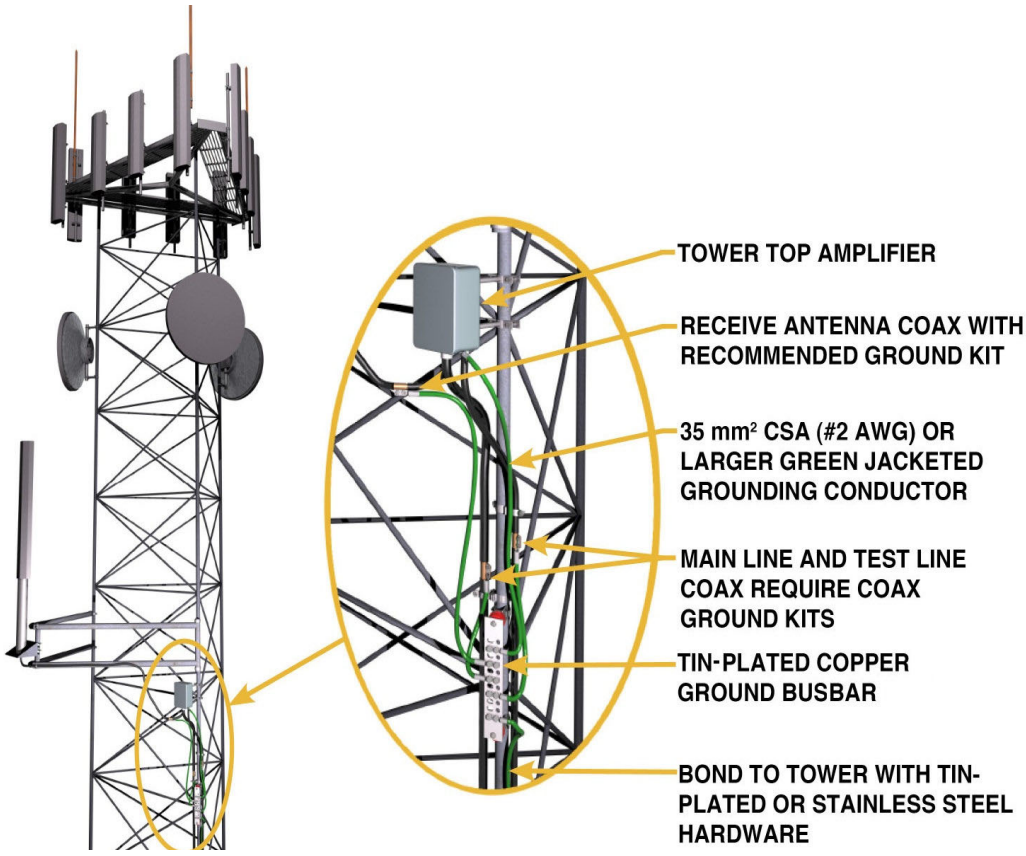


Figure 4-81. Tower-Top Amplifier Grounding/Bonding

- The device **shall** be installed, grounded, and connected according to the manufacturer's instructions.
- The device should not be installed on the extreme top of the tower unless protected by a lightning protection system strike termination device (or equivalent) or tower cross arm (or equivalent).
- The device **shall** be bonded to the tower structure using a 16 mm² csa (#6 AWG) tinned and/or jacketed copper conductor. Devices that contain internal surge protective devices (such as RF preamplifiers) **shall** be bonded to the tower using 35 mm² csa (#2 AWG) grounding conductors. Smaller grounding conductors may be used, but only when the device cannot support a 35 mm² csa (#2 AWG) conductor.
- The grounding conductor length **shall** be no longer than necessary and **shall** flow toward earth.
- Connection to the tower **shall** be made using tower manufacturer-approved methods (typically a type of mechanical clamp). Connection to the tower may also include bonding to a nearby Tower Ground Busbar (TGB).
- RF transmission lines and other device input/output cables **shall** be grounded and bonded as described in "Grounding and Bonding of RF Transmission Lines and Communications Cables" on page 4-104.
- RF preamplifier input transmission lines (from receive antennas) should be grounded and bonded before connection to the amplifier. Grounding/bonding is achieved using a ground kit (see "Grounding and Bonding of RF Transmission Lines and Communications Cables" and Figure 4-81). This is especially important in high-lightning environments.

NOTE: External Surge Protective Devices (SPD) associated with an active device and installed on a tower **shall** be grounded in the same manner as previously described for active devices.

4.12 Grounding and Bonding of RF Transmission Lines and Communications Cables

Transmission lines (including waveguides) and other communications cables with an outer metallic shield (such as shielded Category 5e, 6, 6a, or 8) **shall** be bonded to the tower to prevent lightning from creating a potential difference between the tower and the cable and to help drain lightning energy to earth. A potential difference could cause arcing between the tower and the cable, resulting in damage to the cable.

See Figure 4-82 through Figure 4-85 for examples of transmission line grounding conductor attachment methods.



Figure 4-82. Transmission Line Ground Kit

IMPORTANT: Ground kits **shall not** crush or crimp the cable. Crushing or crimping the cable can negatively affect the impedance characteristics of the cable.

All transmission lines and other communications cables with an outer metallic shield **shall** be bonded to the tower using ground kits as follows:

4.12.1 Ground Kit General Installation Requirements

- The ground kits **shall** be designed for the type of cable. Consideration should be given to ground kits used on aluminum cables. See Figure 4-82.
- The ground kit bonding conductor **shall** be 16 mm² csa (#6 AWG) or larger.
- The ground kits **shall** be installed according to the manufacturer's instructions.
- The ground kits **shall not** crush, crimp, or pierce the cable.
- The ground kits **shall** be sealed to prevent weather-related damage, including water and corrosion, to the cables (ATIS-0600313.2019(R2024), section 10.5).
- The ground kits **shall** be attached to an effectively grounded vertical or diagonal tower member using methods approved by the tower manufacturer, typically a mechanical clamp. The ground kits may be attached to a nearby tower ground busbar instead of directly to the tower structure; see "Tower Ground Busbar" on page 4-49. See Figure 4-83 through Figure 4-85 for examples of methods used to attach directly to the tower. (ATIS-0600313.2019(R2024), section 10.5)
- The ground kit grounding conductors **shall** be installed without drip loops, parallel to the cable, and pointed downward toward the earth to provide a direct discharge path for lightning (ATIS-0600313.2019(R2024), section 10.5.1). All bends **shall** be gradual and sweeping to minimize inductance (ATIS-0600313.2019(R2024), section 10.5).

NOTE: Cables that, due to their construction, cannot reasonably have a ground kit installed, such as cables with a thin foil shield and drain wire, may not require a ground kit if the cable drain can be bonded to earth at the required SPD near the building entry point.

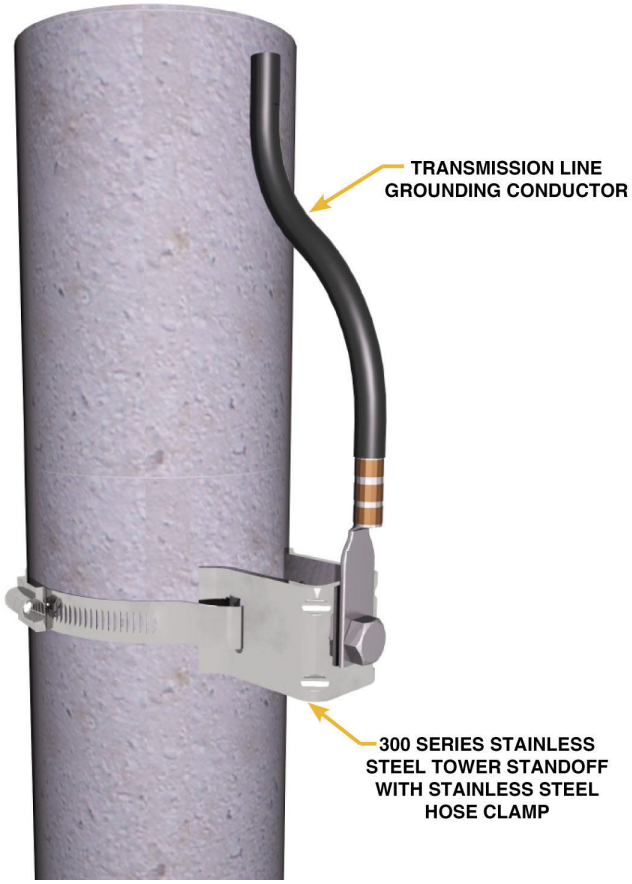


Figure 4-83. Grounding Transmission Line Top and Middle (Tubular Tower)

4.12.1.1 Ground Kit Locations

- See Figure 4-86 on page 4-107 and Figure 4-87 on page 4-108.
- Ground kits **shall** be installed near the top of the vertical run, which is the top of the main line for coax and waveguide, close to the antenna or device (ATIS-0600334.2019(R2024), section 6.6; ATIS-0600313.2019(R2024), section 10.5.1; and IEEE 1692-2023, section 8.8).
- A ground kit should be installed on the input coax (from the receive antenna) to a tower-top amplifier. See Figure 4-81 on page 4-103. This is especially important in areas of high lightning activity.
- Ground kits **shall** be installed at the bottom of the tower above the vertical-to-horizontal transition point (ATIS-0600313.2019(R2024), section 10.5.1; ATIS-0600334.2019(R2024), section 6.6; and IEEE 1692-2023, section 8.8).
- If the tower is greater than 61 m (200 ft) in height, an additional ground kit **shall** be installed at the tower midpoint (ATIS-0600334.2019(R2024), section 6.6). Additional ground kits (equally spaced) **shall** be installed as necessary to reduce the distance between ground kits to 61 m (200 ft) or less.
- In high lightning activity areas, ground kits should be installed at spacing between 15.2 to 22.9 m (50 to 75 ft) (ATIS-0600313.2019(R2024), section 10.5.1; ATIS-0600334.2019(R2024), section 6.6; and IEEE 1692-2023, section 8.8).

IMPORTANT: In areas with high lightning activity, ground kits should be installed every 15.2 to 22.9 m (50 to 75 ft). Ground kits should be installed on input coax cables (from receive antennas) of tower-top amplifiers.

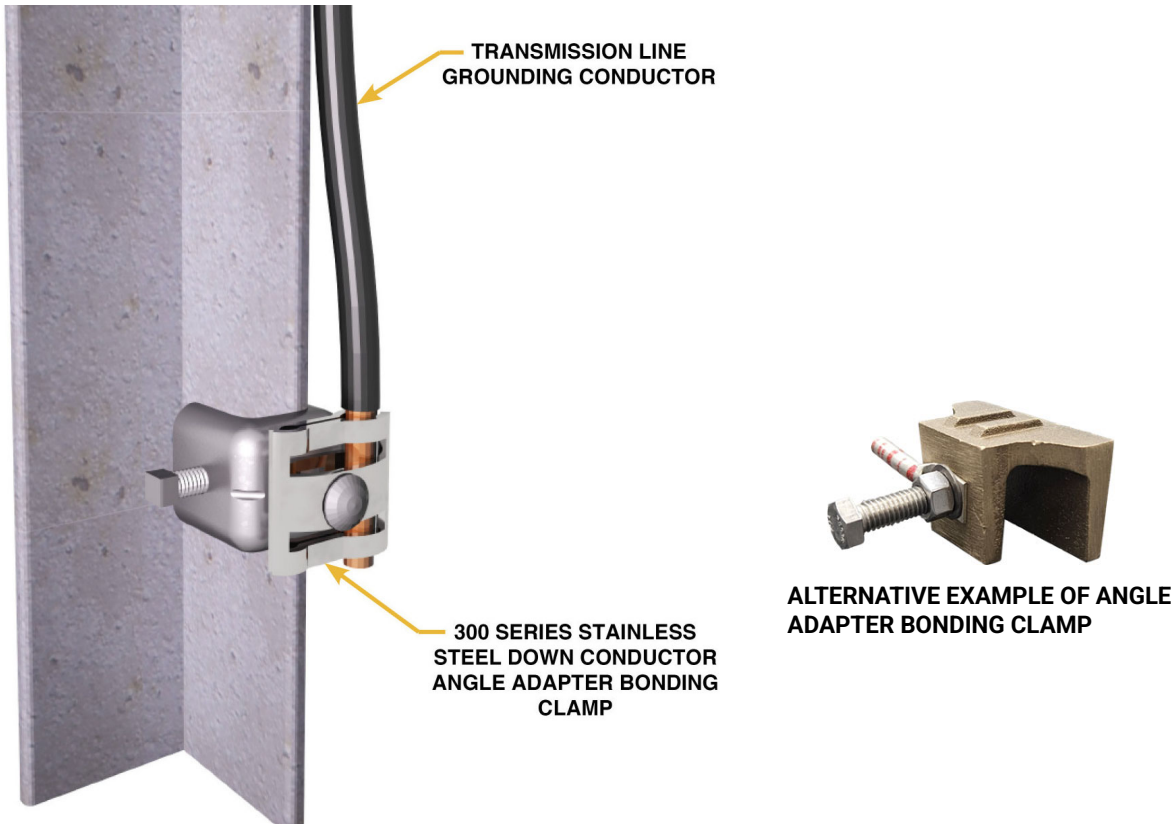


Figure 4-84. Grounding Transmission Line Top And Middle (Angular Tower)

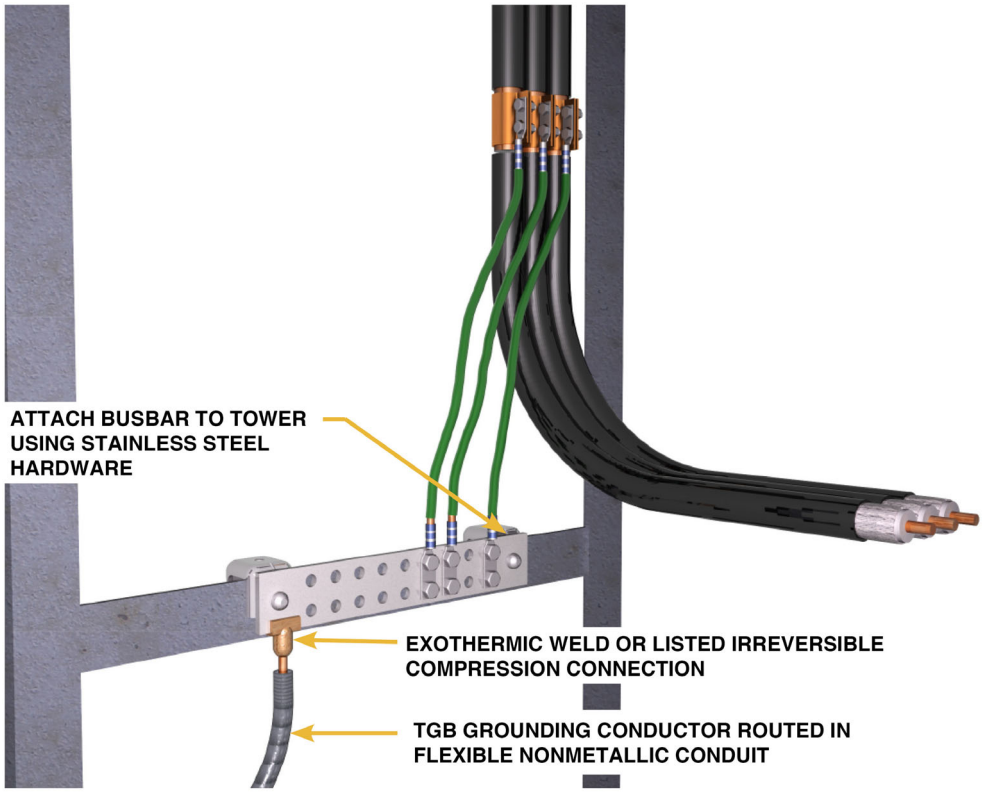


Figure 4-85. Busbar Configuration, Bottom Ground Kit on Angular Tower (Weatherproofing Not Shown)

- Ground kits **shall** be installed near the building, shelter, equipment housing or cabinet entry point (ATIS-0600313.2019, section 10.5.3; ATIS-0600334.2019(R2024), section 6.6; MIL-HDBK-419A; and NFPA 70-2026, Article 750). The ground kits **shall** be bonded to the External Ground Busbar (EGB) if installed or directly to the grounding electrode system, ensuring a continuous downward flow toward the grounding electrode system is maintained.

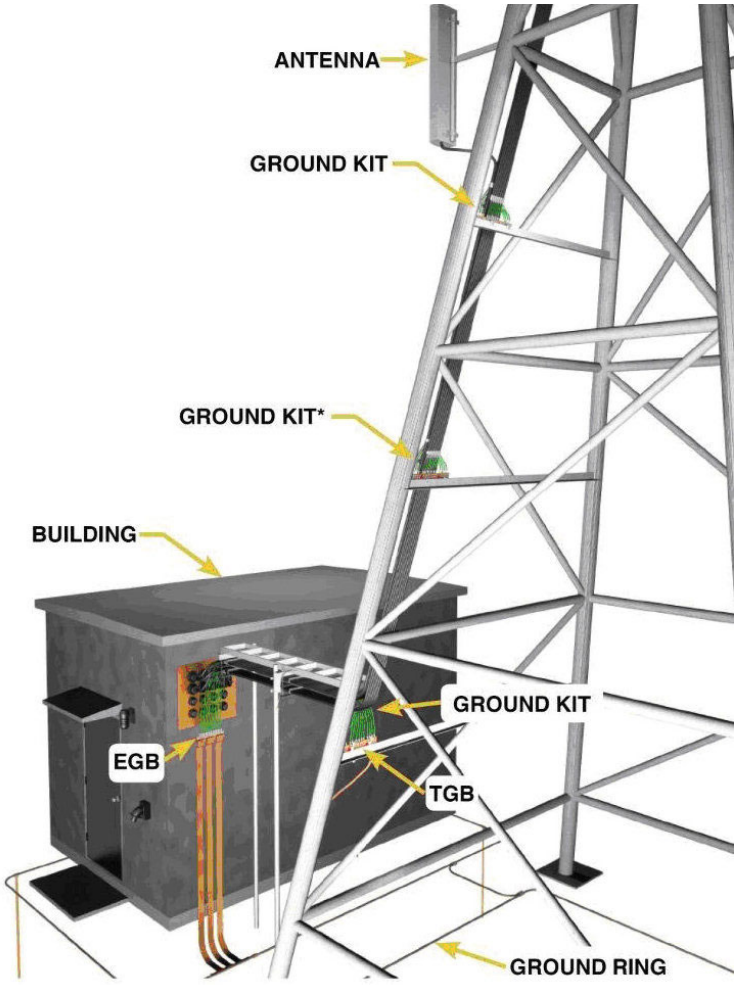


Figure 4-86. Location of Transmission Line Grounding Kits

NOTE: Using down conductors on metallic towers is not recommended for grounding and bonding cables, lightning rods, or for interconnecting TGBs. A down conductor has significantly higher impedance to earth than the tower structure. Using down conductors does not provide equal potential bonding between the communications cables and the tower. If a down conductor is used, it **shall** be bonded to the tower at the top, at the bottom, near and below each TGB, and at least every 60 m (200 ft), using appropriate hardware.

NOTE: Communications cables installed on a non-metallic pole structure **shall** be bonded to the pole's vertical grounding conductor in the same manner as previously described.
See Figure 4-76 on page 4-97.

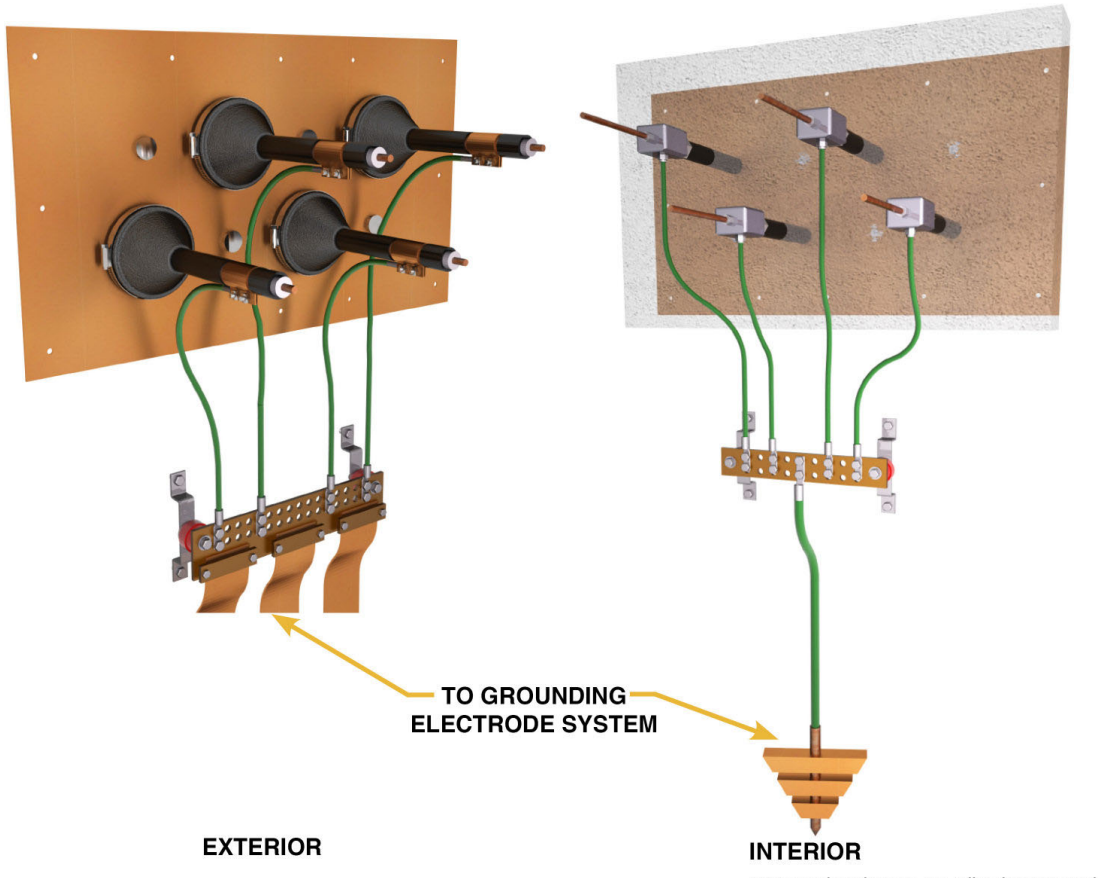


Figure 4-87. Transmission Line Grounding At Building Entry Point (Weatherproofing Not Shown)

4.13 Metallic Objects Requiring Bonding

The goal of bonding metallic objects is to equalize the potential between conductive parts. This ensures personnel safety and prevents arcing between metallic components that could otherwise have different potentials. Bonding conductors **shall** be as short and straight as practicable (see ATIS-0600313.2019(R2024), section 6.3).

Metallic objects within 1.8 m (6 ft) of the external grounding electrode system or a grounded metallic item **shall** be bonded to the external grounding electrode system using 16 mm² csa (#6 AWG) or larger conductors, as described in “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38 (ATIS-0600334.2019(R2024), section 5.3.3). Bonding to the metallic objects **shall** be made as permitted by the manufacturer. In high lightning-prone areas or regions with high soil resistivity, it is recommended to bond all metallic objects within 3 m (10 ft) of the external grounding electrode system or grounded metallic item (ATIS-0600313.2019(R2024), section 10.3.2). See “Bonding to the External Grounding and Bonding System” on page 4-61 for more information.

Exception: Metallic components, such as pipes, raceways, or sleeves that are 5 cm (2 in.) or less in length, **shall not** require bonding (NFPA 780-2026, section 4.4.2.2).

NOTE: Metal objects insulated with non-conductive coatings or covers (such as vinyl fence fabric or bollards) do not require bonding.

NOTE: Refer to “High Lightning Geographic Region Defined” on page 4-6 and “High Soil Resistivity Defined” on page 4-6.

Metallic objects that require bonding include, but are not limited to, the following items (see ATIS-0600313.2019(R2024), section 10.1 and ATIS-0600334.2019(R2024), section 5.3.3).

- Cable Bridge/Ice Bridge (see “Cable Bridge/Ice Bridge Grounding and Bonding” on page 4-117)
- External light fixtures or support masts
- Fences: fabric, gates and posts (see “Fence And Gate Grounding and Bonding” on page 4-109 for specific fence and gate grounding/bonding requirements)
- Fuel storage tanks, above- or below-grade. See “Fuel Tank Bonding” on page 4-121.
- Generator frame. See “Grounding (Earthing) Generators External to the Building” on page 4-99.
- Generator exhaust pipe from an internally-installed generator
- Hand rails
- HVAC units
- Metallic conduits, piping, and raceways. See “Metallic Piping Bonding” on page 4-120.
- Metallic entry ports
- Metallic members of all incoming telecommunications cables, including paired-conductor and optical fiber (ATIS-0600313.2019(R2024), section 8.2)
- Other grounding electrodes or electrode systems at the site (see “Common Grounding” on page 4-7)
- Skid plate, anchor plate, or metal support frame of a prefabricated shelter
- Solar photovoltaic system (and other alternative sources of power) support and conduits. See “Solar Photovoltaic Systems” on page 4-123.
- Telephone service provider ground (if external)
- Vent covers (if not already bonded inside)

IMPORTANT: Avoid bonding electrically continuous items, such as unused entry panels, if they are already bonded internally to the bonding and grounding system. Bonding on both sides may disrupt the single-point ground concept at the site.

NOTE: Bonding conductors installed below-grade **shall** be 35 mm² csa (#2 AWG) or larger. See “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.

4.13.1 Fence And Gate Grounding and Bonding

Fences and gates are grounded and bonded to protect personnel from touch potential and step potential hazards that can occur due to lightning activity or faults in the utility or facility electrical system (see NWSM 30-4106:2017, section 2.7.10). All metallic fences and gates within 6.1 m (20 ft) of a communications shelter/building **shall** be grounded and bonded to the facility’s common grounding electrode system (see FAA-STD-019G, section 5.3.8; and NWSM 30-4106:2017, section 2.7.10, for additional details).

Fences and gates that are more than 6.1 m (20 ft) from the communications shelter or building but are within 1.8 m (6 ft) of the grounding electrode system (such as the building ground ring, tower ground ring, or radial grounding conductors) or other grounded metallic items **shall** be bonded to the facility’s common grounding electrode system. Bonding **shall** be performed using techniques described in this section.

Where fences are located at an electrical power substation, the fence grounding **shall** be performed as required by IEEE C2-2023 (the *National Electrical Safety Code*®), IEEE 80-2020, and the electric utility.

Fences and gates within 1.8 m (6 ft) around tower guy anchor points **shall** be bonded to the guy anchor grounding electrode using techniques as described in this section.

A fence grounding system for a typical communications site is shown in Figure 4-89.

NOTE: If the site has fencing that extends well beyond the communications site, such as when the communications site is inside a large compound, the entire compound fence does not need to be grounded and bonded. Only the portions of the fence within 6.1 m (20 ft) of the communications building and/or tower, or within 1.8 m (6 ft) of a grounded object, are required to be grounded and bonded. See Figure 4-88

NOTE: Only commercial-grade fencing **shall** be used at a communications site. Residential-grade fencing **shall not** be used.

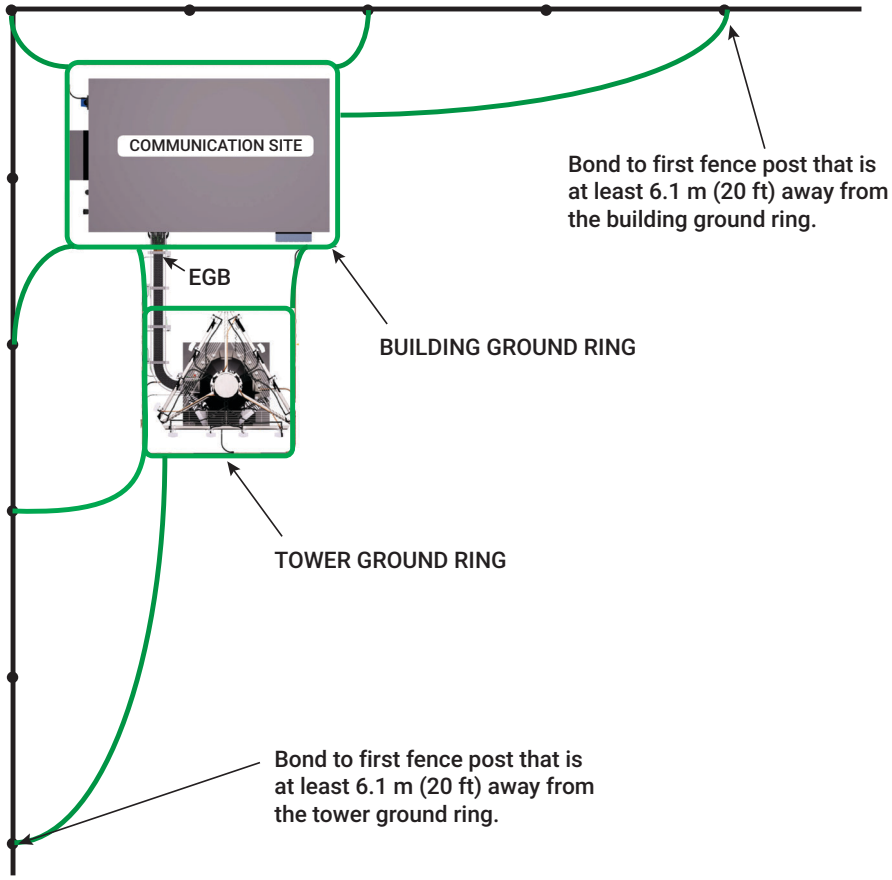


Figure 4-88. Fence Bonding for Communications Sites Within Large Compounds

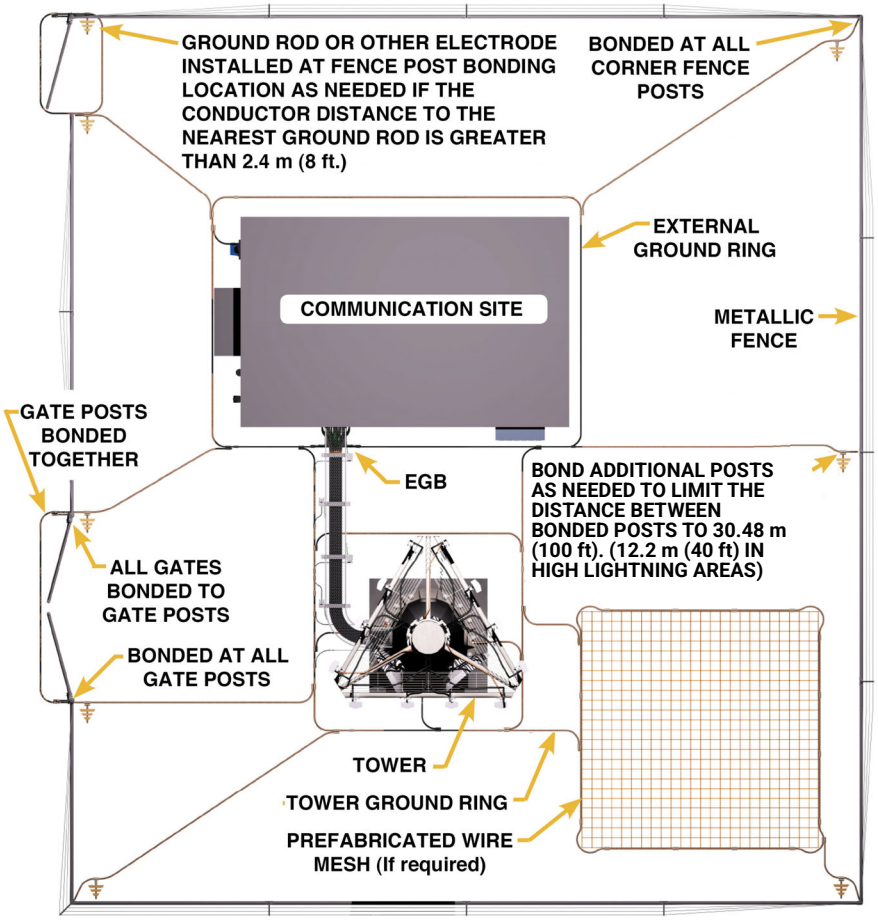


Figure 4-89. Example of Fence Grounding and Bonding

The grounding and bonding requirements for fence systems installed within 6.1 m (20 ft) of the communications building or shelter are as follows:

4.13.1.1 Fence Post Grounding/Bonding

- Each corner fence post **shall** be bonded to the nearest location of the building or tower ground ring using 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper conductors (ATIS-0600313.2019(R2024), Figure 3(a)). If the bonding connection to the fence post uses mechanical hardware, tinned-copper conductors **shall** be used.
  - If the site fencing extends significantly beyond the communications site (for example, if the communications site is within a large compound), the first fence posts that are more than 6.1 m (20 ft) away from the communications building and/or tower should be used instead of the distant corner post. See Figure 4-88 for an example.
- Additional fence posts **shall** be bonded as needed to limit the distance between bonded posts to 30.48 m (100 ft) (FAA-STD-019G, section 5.3.8.1) or 12.2 m (40 ft) in high lightning areas (NWSM 30-4106:2017, section 2.7.10.1). See “High Lightning Geographic Region Defined” on page 4-6 for a definition of high lightning areas.
- Connection to the fence post **shall** use exothermic welding, where practicable; otherwise listed mechanical hardware designed for the purpose may be used. If the bonding connection to the fence post uses mechanical hardware, tinned-copper conductors **shall** be used. See “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63 for more details.

- Connection to the fence post **shall** be made at a height no greater than 305 mm (1 ft) above finished grade (FAA-STD-019G, section 5.3.8.1, and NWSM 30-4106:2017, section 2.7.10.1).
- The grounding conductors **shall** be buried at the same depth as the building ground ring, if practicable. See ATIS-0600313.2019(R2024), Figure 3(a).
- A ground rod (or other electrode) **shall** be installed at the post bonding locations if the conductor distance to the nearest rod (or other electrode) is greater than 2.4 m (8 ft). Refer to NWSM 30-4106:2017 and FAA-STD-019G for additional information.
- See Figure 4-89 and Figure 4-90.

4.13.1.2 Fence Fabric Grounding/Bonding

- The fence fabric near each required post bonding point **shall** be bonded to the nearest location of the building or tower ground ring using 35 mm² csa (#2 AWG) or larger, bare, tinned, copper conductors. This bond should be made using the same grounding conductor used for bonding the fence post. See TIA-607-E, section D.2.8.1, for additional information.
- The fence fabric and entry deterrent wiring on each side of the corner fence posts **shall** be grounded and bonded as shown in Figure 4-90.
- The fence fabric bond **shall** be made near the top, middle, and bottom of the fabric as shown in Figure 4-90. Ensure all fence fabric bonds are to different strands of fence fabric. Depending on the fence fabric construction, this may require the bonding conductor to be installed at a slight angle. See TIA-607-E, Figure 38, for more information.

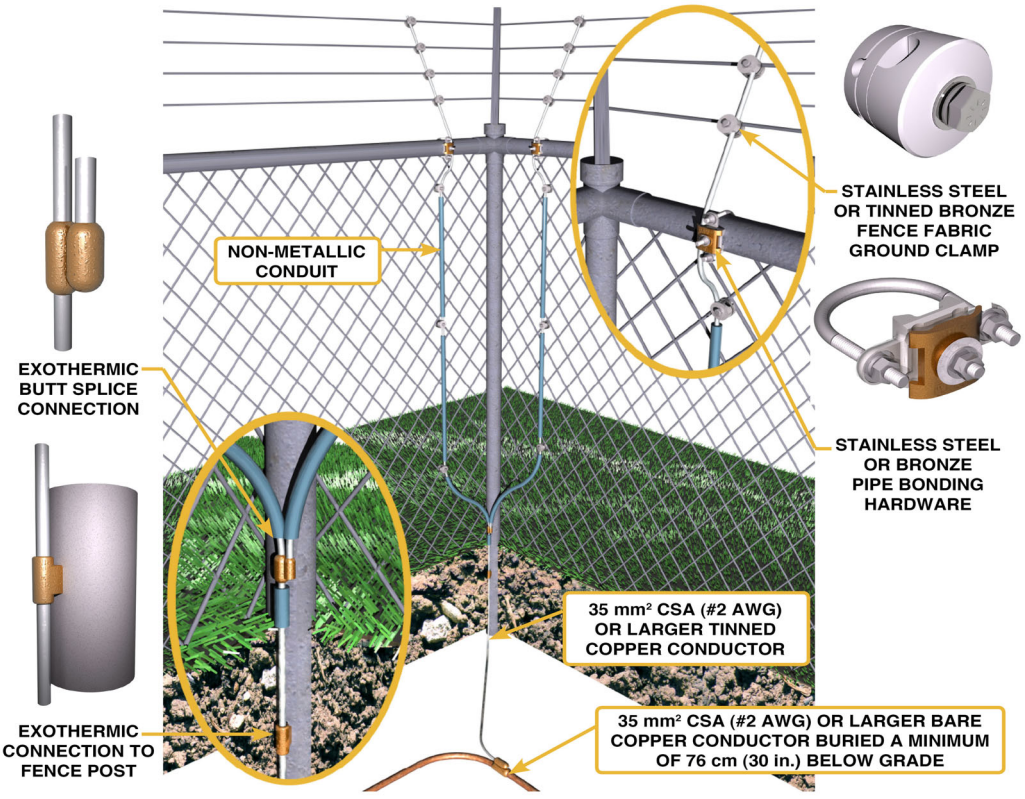


Figure 4-90. Example of Fence Fabric and Deterrent Wiring Bonding

- Clamps used for fence fabric bonding **shall** be designed for the purpose and **shall** be constructed from tinned-copper, tinned-copper alloy, or stainless steel. See “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63 for more details.
- A listed conductive antioxidant compound **shall** be used on the mechanical connections (ATIS-0600334.2019(R2024), section 9). The antioxidant compound **shall** be liberally installed between the two metals. See “Antioxidant Compound” on page 4-68.
- The grounding conductor **shall** be routed so that it does not come into incidental contact with the deterrent wiring, fence post, fence fabric, or support apparatus for the wire. This may require using a non-metallic conduit sleeve to prevent incidental contact. Incidental contact can create an RF interference point.

IMPORTANT: Ensure all fence fabric bonds are to different strands of fence fabric. Depending on the fence fabric construction, this may require the bonding conductor to be installed at a slight angle.

NOTE: Vinyl-coated fence fabric does not require bonding.

4.13.1.3 Entry Deterrent Wiring Grounding/Bonding

See Figure 4-90 and Figure 4-91 for examples.

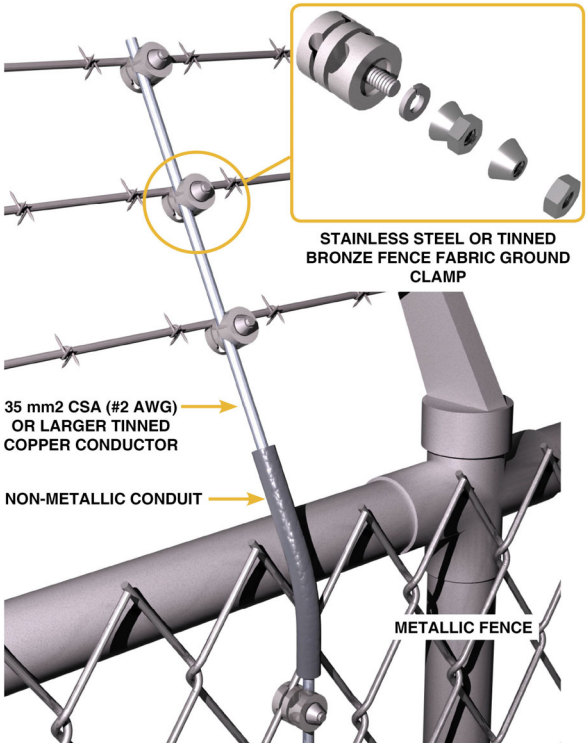


Figure 4-91. Deterrent Wire Bonding

If the site fence has non-electrified entry deterrent wiring (security wire) and the fence is required to be grounded/bonded as described previously, the entry deterrent wiring **shall** be grounded and bonded as follows:

- The deterrent wiring near each fence post bonding point **shall** be bonded to the nearest location of the building or tower ground ring using a 35mm² csa (#2 AWG) or larger, bare, tinned, copper conductor. This bond should be made using the same grounding conductor used for bonding the fence fabric.
- The fence fabric and entry deterrent wiring on each side of the corner fence posts **shall** be grounded and bonded as shown in Figure 4-90.

- Clamps used for security wire bonding **shall** be designed for the purpose and **shall** be constructed from tinned-copper, tinned-copper alloy, or stainless steel. See “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63 for more details.
- A listed conductive antioxidant compound **shall** be used on the mechanical connections (ATIS-0600334.2019(R2024), section 9). The antioxidant compound **shall** be liberally installed between the two metals. See “Antioxidant Compound” on page 4-68.
- The grounding conductor **shall** be routed so that it does not come into incidental contact with the deterrent wiring, fence post, fence fabric, or support apparatus for the wire. This may require using a non-metallic conduit sleeve to prevent incidental contact. Incidental contact can create an RF interference point.
- The grounding conductor **shall** follow the routing methods described in “Bending and Routing Grounding, Bonding, and Down Conductors” on page 4-41.

4.13.1.4 Gate Grounding/Bonding

- Gate posts **shall** be bonded together with a buried 35mm² csa (#2 AWG) or larger, bare copper, or tinned-copper conductor.
- Gate posts (on both sides of the gate) **shall** be bonded to the nearest location of the building or tower ground ring using 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper conductors (ATIS-0600313.2019(R2024), Figure 3(a) and IEEE C2-2023 (the *National Electrical Safety Code*®)).
- Connection to the gate post **shall** use exothermic welding, where practicable; otherwise, listed mechanical hardware designed for the purpose may be used (see “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63 for more details). If the bonding connection to the gate post uses mechanical hardware, tinned-copper conductors **shall** be used.
- Connection to the gate post **shall** be made at a height no greater than 305 mm (1 ft) above finished grade (FAA-STD-019G, section 5.3.8.1, and NWSM 30-4106:2017, section 2.7.10.1).
- The grounding conductors **shall** be buried to the same depth as the building ground ring, where practicable. See ATIS-0600313.2019(R2024), Figure 3(a).
- The fence fabric and entry deterrent wires on each side of the gate **shall** be grounded as shown in Figure 4-92. **Exception:** If the fence fabric and entry deterrent wires are already grounded within 6.1 m (20 ft) of the respective gate post and the fence fabric and entry deterrents wires are continuous from the existing bonding point to the gate post.
- See Figure 4-92 for an example.

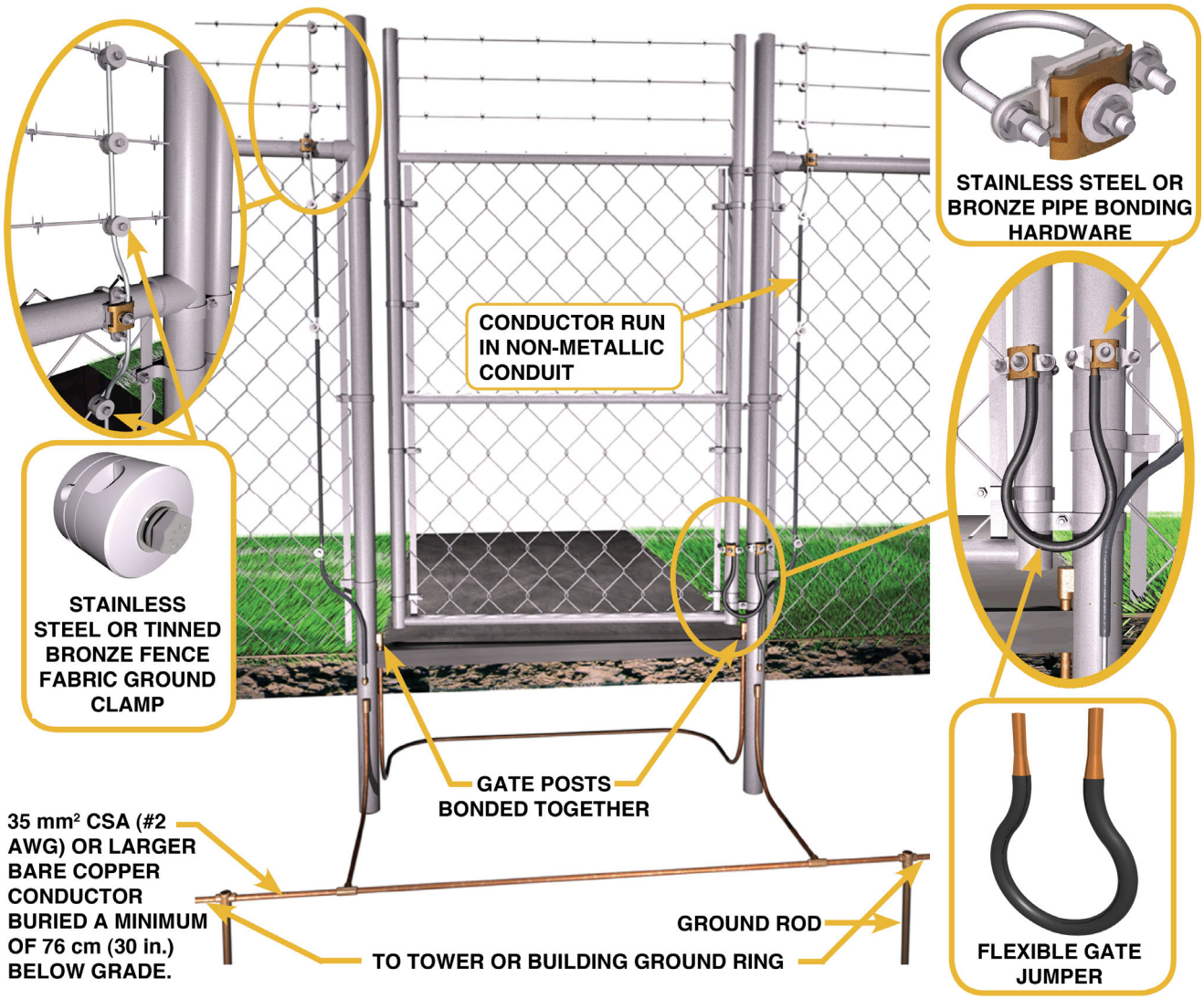


Figure 4-92. Example of Gate Bonding

- The gate **shall** be bonded to the gate supporting post with a 16 mm² csa (#6 AWG) or larger, jacketed, stranded, copper bonding jumper. This jumper wire should be constructed with a highly flexible conductor (ATIS-0600313.2019(R2024), Figure 3(a)), such as 133-strand. The jumper **shall** be installed to allow full motion of the gate (NWSM 30-4106:2017, section 2.7.10.1). The jumper **shall** be installed in an S-shape pattern, unless this would restrict the gate's full range of motion. Otherwise, a U-shaped pattern can be used.
- The gate bonding jumper **shall** be bonded to the gate and post using exothermic welding, where practicable; otherwise, listed mechanical hardware designed for the purpose may be used (see "Above-Grade Mechanical Lugs and Connection Devices" on page 4-63 for more details).

IMPORTANT: Braided straps **shall not** be used because they corrode easily and can cause RF interference.

4.13.1.5 Fences Crossed by Overhead Power Lines

Where overhead power lines (all voltages) cross over a communications site's metallic fence, the following additional grounding and bonding **shall** be completed to ensure that, if the live electrical power lines fall on the fence, the fence remains at ground potential (see FAA-STD-019G, section 5.3.8.2, and NSWM 30-4106:2017, section 2.7.10.2):

- See Figure 4-93 for grounding and bonding requirements.

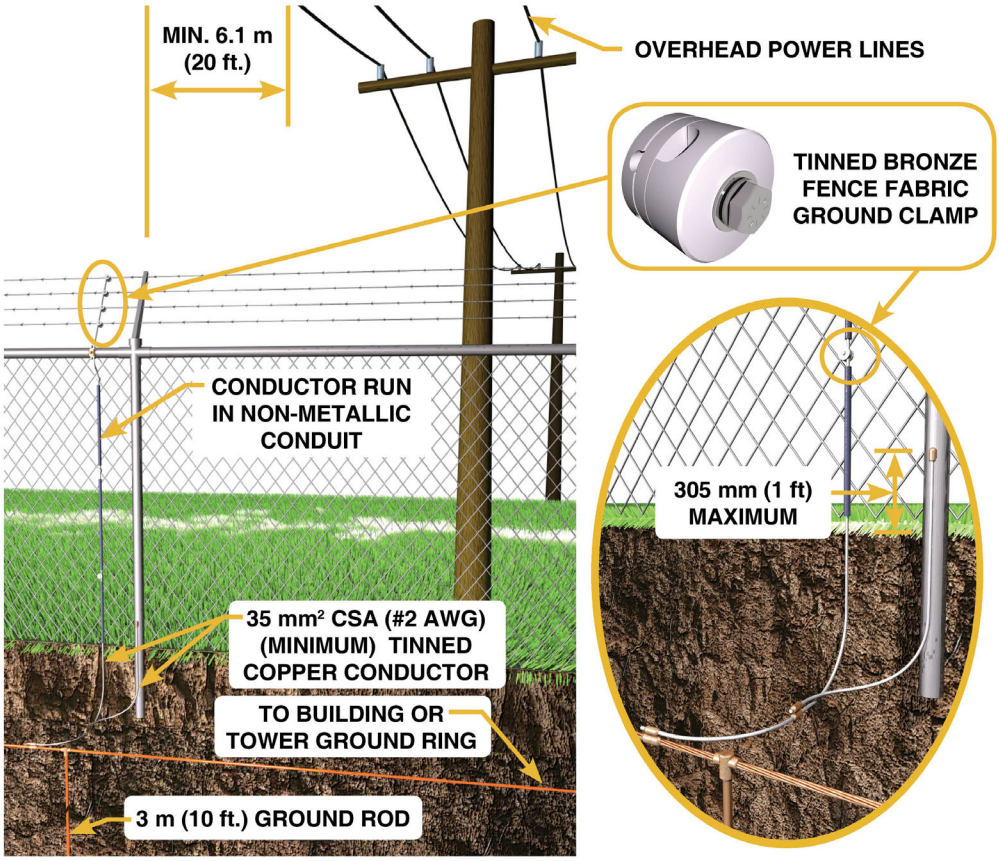


Figure 4-93. Grounding and Bonding for Fences Crossed by Overhead Power Lines (One Side of Overhead Power Lines Shown)

NOTE: The requirements in this subsection are in addition to the previously described fence and gate grounding and bonding requirements.

- A fence post on each side of the overhead wire crossing **shall** be bonded to the grounding electrode system using methods described in "Fence And Gate Grounding and Bonding" on page 4-109.
- The bond to the post **shall** be on each side and at least 6.1 m (20 ft) and no more than 12.2 m (40 ft) from the overhead wire crossing.
- A 3 m (10 ft) ground rod **shall** be installed at each bond location. If soil conditions do not permit driving a vertical ground rod, other electrodes appropriate for the soil conditions may be used, such as a ground plate or a horizontal ground rod.
- The fence fabric at each post bonding location **shall** be bonded at the top, middle and bottom using methods described in "Fence Fabric Grounding/Bonding" on page 4-112.
- The security wire (each strand) at each post bonding location **shall** be bonded using methods described in "Fence And Gate Grounding and Bonding" on page 4-109.

4.13.2 Cable Bridge/Ice Bridge Grounding and Bonding

Cable bridges and ice bridges are used to protect and support RF transmission lines and other communications cables between the tower structure and the equipment building or shelter. Where present, cable bridges and ice bridges **shall** be bonded to the grounding electrode system.

4.13.2.1 Self-Supported Cable Bridge/Ice Bridge

Grounding and bonding of **self-supported** cable bridges/ice bridges **shall** be completed as follows (see Figure 4-94):

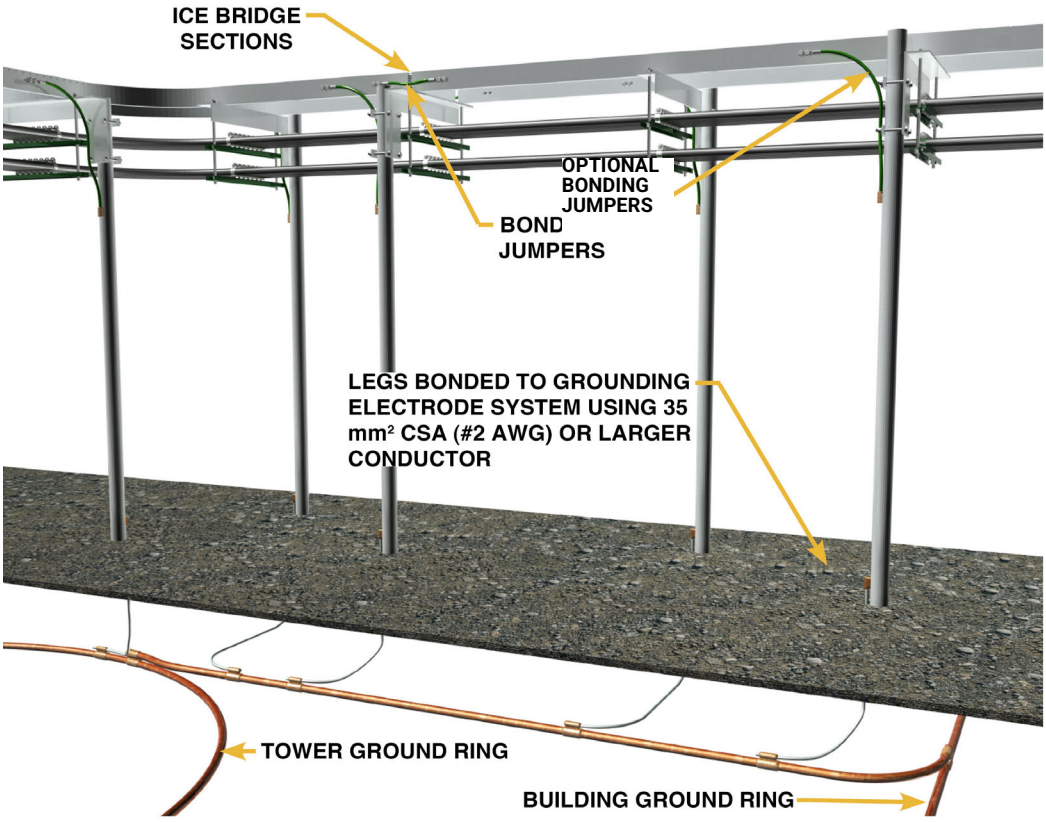


Figure 4-94. Grounding of Self-Supporting Ice Bridge

- Each support post **shall** be bonded to the grounding electrode system using a 35 mm² csa (#2 AWG) or larger, bare copper or tinned-copper conductor.
- Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings. See “Bonding to the External Grounding and Bonding System” on page 4-61.
- Conductor bonding to the support posts **shall** be made using exothermic welding. See “Bonding to the External Grounding and Bonding System” on page 4-61.
- To help ensure effective bonding, the cable bridge/ice bridge should be bonded to each support post using a 16 mm² csa (#6 AWG) or larger, jacketed (ATIS-0600334.2019(R2024), section 5.1), copper conductor (bonding jumper). Conductor bonding to the support post **shall** be made using exothermic welding. Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding or listed two-hole lugs and stainless steel hardware (see “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63 and “Securing Hardware” on page 4-66 for specific requirements).

- If more than one span of cable bridge or ice bridge is installed between the tower and building, bonding jumpers should be placed between the sections to ensure effective bonding. The bonding jumpers **shall** be 16 mm² csa (#6 AWG) or larger, jacketed, copper conductors. The bonding jumpers should use listed two-hole lugs and stainless steel hardware. See “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63 for specific requirements.

4.13.2.2 Tower and/or Building Supported Cable Bridge/Ice Bridge

The cable bridge/ice bridge **shall** be bonded to the grounding electrode system. Grounding and bonding of tower and/or building supported cable bridges/ice bridges **shall** be completed as follows:

4.13.2.2.1 At the Building

- Bonding to the grounding electrode system may be accomplished using a 16 mm² csa (#6 AWG) or larger, copper or tinned-copper conductor bonded to the External Ground Busbar (EGB). Conductor bonding to the cable bridge/ice bridge and EGB **shall** be made using exothermic welding or two-hole lugs and stainless steel hardware. See “Bonding to the External Grounding and Bonding System” on page 4-61.
- Bonding of the cable bridge/ice bridge to the grounding electrode system may also be accomplished using a 35 mm² csa (#2 AWG) or larger, bare, copper or tinned-copper conductor bonded directly to the grounding electrode system.
  - Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings.
  - Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding or listed two-hole lugs and stainless steel hardware. The grounding conductor should be installed in a flexible, non-metallic conduit to help prevent incidental contact with other metals, provide protection for the conductor, and support the conductor. See “Bonding to the External Grounding and Bonding System” on page 4-61.

IMPORTANT: Do not bond the cable bridge/ice bridge directly to the cable entry panel. Doing so could create a discharge path for lightning into the building. See IEEE 1692-2023, section 9.2.

4.13.2.2.2 At the Tower

- Cable bridges and ice bridges may be sufficiently grounded when they are an integral part of the tower construction and are bonded directly to the tower through multiple metallic mechanical connections. The metallic connections **shall** consist of the same metals and **shall** provide direct metal-to-metal contact without non-conductive coatings, such as paint.
- When the cable bridge/ice bridge is not effectively bonded to the tower through multiple metallic connections, additional bonding is necessary to ensure adequate bonding. The extra bonding **shall** be performed using one of the following three options, or as designed by an engineer:
- **Option 1:** Installing a 16 mm² csa (#6 AWG) or larger, copper or tinned-copper conductor (bonding jumper) between the cable bridge/ice bridge and the tower.
  - Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding or listed two-hole lugs and stainless steel hardware.
  - Conductor routing from the cable bridge or ice bridge to the tower **shall** be routed downward, similar to the bonding jumper shown in Figure 4-95 on page 4-119.
  - Conductor bonding to the tower **shall** be performed using exothermic welding at a location approved by the tower manufacturer or by employing appropriate bonding devices and hardware. See “Bonding to the External Grounding and Bonding System” on page 4-61.

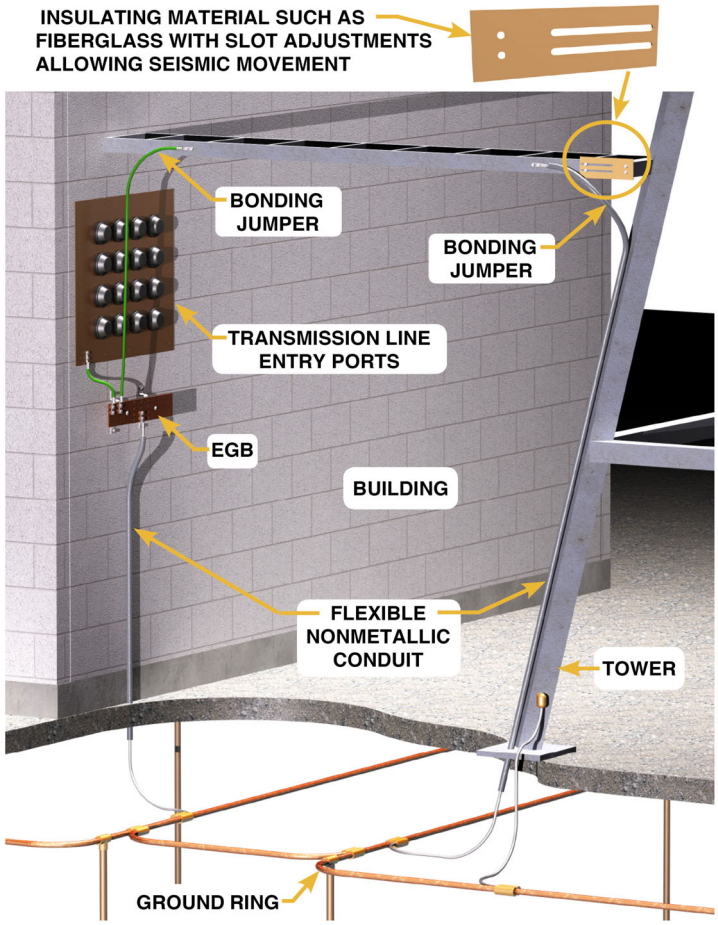


Figure 4-95. Grounding of Non-Self-Supporting Ice Bridge

- **Option 2:** Installing a 16 mm² csa (#6 AWG) or larger, copper or tinned-copper conductor (bonding jumper) between the cable bridge/ice bridge and a nearby Tower Ground Busbar (TGB).
  - Conductor routing from the cable bridge/ice bridge to the TGB **shall** be routed downward, similar to the bonding jumper shown in Figure 4-95.
  - If a downward flow from the cable bridge/ice bridge to the TGB cannot be maintained, Option 1 or 3 should be used.
  - Conductor bonding to the cable bridge/ice bridge and TGB **shall** be made using exothermic welding or listed two-hole lugs and stainless steel hardware. See “Bonding to the External Grounding and Bonding System” on page 4-61.
- **Option 3:** Install a 35 mm² csa (#2 AWG) or larger, bare copper or tinned-copper conductor directly bonded to the grounding electrode system.
  - Bonding to the grounding electrode system **shall** be accomplished using exothermic welding or a listed irreversible high-compression connection fitting.
  - Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding or listed two-hole lugs and stainless steel hardware.
  - The grounding conductor should be installed in a flexible, non-metallic conduit to help prevent incidental contact with other metals and to support and protect the conductor. See Figure 4-95 for an example.
  - See “Bonding to the External Grounding and Bonding System” on page 4-61.

NOTE: To reduce lightning energy diverted toward the equipment building or shelter and to provide seismic isolation between the building and tower, it is recommended to secure the cable bridge or ice bridge to the tower using a non-conductive slip-joint device or support posts near the tower. Where a slip-joint device is used, grounding of the cable bridge/ice bridge at the building **shall** be completed as described previously; grounding at the tower end of the cable bridge/ice bridge **shall** be completed as shown in Figure 4-95. See IEEE 1692-2023, section 9.2.

IMPORTANT: In ice-prone areas, if isolating the cable bridge or ice bridge from the tower creates an unprotected section on the communications cables, an ice shield **shall** be installed above the isolation point to protect the communications cables. The ice shield should be bonded to the tower only.

4.13.3 Metallic Building Siding Bonding

Although metallic building siding is not required to be bonded by this standard, grounding the metallic siding can enhance site safety. It is recommended to bond the metallic building siding in at least one location on the building, preferably near the electrical service entrance or cable entry point.

4.13.4 Metallic Piping Bonding

Lightning energy can enter a communications facility through any available conductive path. To help prevent lightning and other electrical surges from entering the facility, all metallic piping and conduits **shall** be bonded to the grounding electrode system as close as practicable to the entry point of the facility. This is typically achieved using a 35 mm² csa (#2 AWG) grounding conductor that is bonded directly to the grounding electrode system. Refer to Figure 4-96 for examples of bonding.

Where multiple conduits enter a metallic pull box at the building entry point, the conduits are considered sufficiently bonded if the pull box is bonded and the conduits are terminated to the box using threaded or compression fittings.

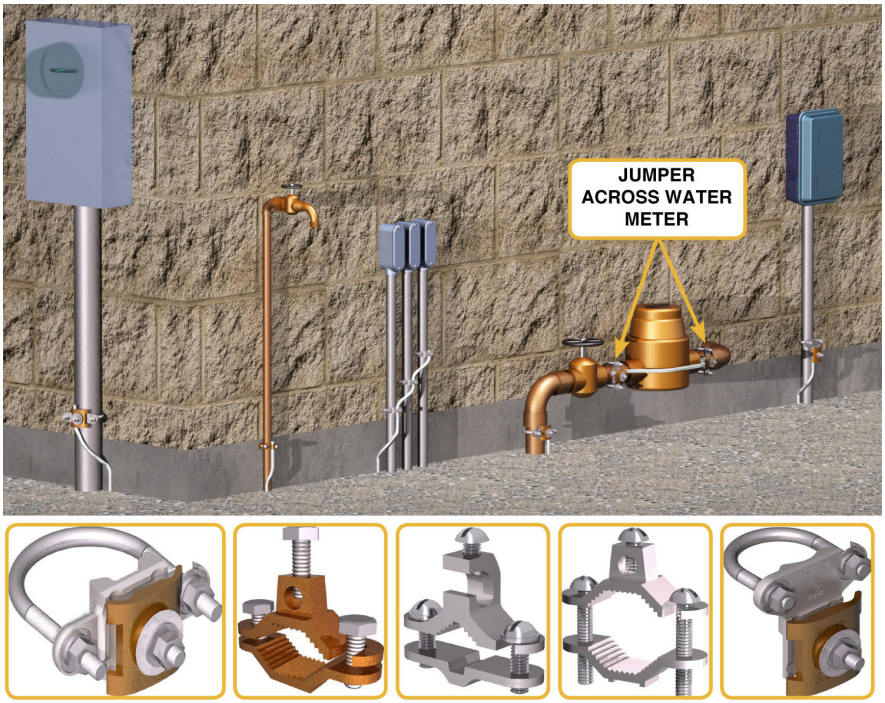


Figure 4-96. Examples of Metallic Pipe Grounding

4.13.5 Fuel Tank Bonding

4.13.5.1 Above-Grade Pressurized Tanks

Above-grade pressurized fuel tanks (for example, propane and compressed natural gas) **shall** be bonded to the grounding electrode system as described in "Metallic Objects Requiring Bonding" on page 4-108 using a 35 mm² csa (#2 AWG) copper or tinned-copper grounding conductor. Attachment to the tank **shall** be at a tank manufacturer approved location (such as a support leg) using a two-hole lug with stainless steel hardware, approved mechanical hardware, (see "Above-Grade Mechanical Lugs and Connection Devices" on page 4-63) or exothermic weld (prior to filling the tank) (see FAA-STD-019G, section 4.3.8.3.2). See Figure 4-97 and Figure 4-98 for examples.

Bond other metallic components associated with the tank, like stairs, ladders, or skids, as described in this chapter.

NOTE: To simplify bonding continuity testing with a clamp-on ohmmeter and to provide a redundant bond, it is recommended to have two separate bonding connections to different locations on the tank. Refer to Appendix D for clamp-on ohmmeter bonding continuity testing.



Figure 4-97. Example of Above-Ground Propane Tank Grounding

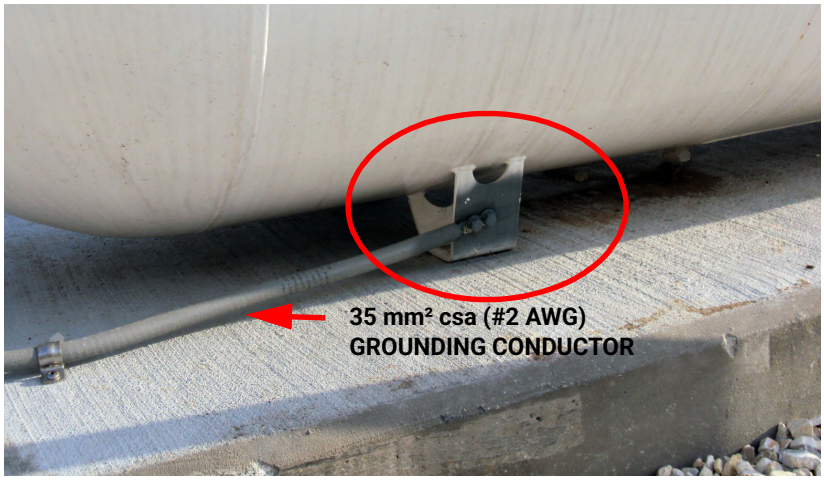


Figure 4-98. Detail From Example of Above-Ground Propane Tank Grounding

4.13.5.2 Above-Grade Non-Pressurized Tanks

Above-grade, non-pressurized metallic fuel tanks, such as those for liquid fuels like diesel, that are electrically continuous, tightly sealed to prevent liquid, vapor, or gas escape, and have a thickness of 4.8 mm (3/16 in.) or more are considered inherently self-protecting and only need to be bonded to the grounding electrode system (see IEEE 142-2007, section 3.3.4.2, and NFPA 780-2026, section 7.2.2).

These tanks **shall** be bonded to the grounding system using at least two easily accessible and widely separated grounding conductors as outlined in “Metallic Objects Requiring Bonding” on page 4-108 (see FAA-STD-019G, section 4.3.8.3.2). Connection to the tank is typically achieved by attaching the bonding conductors to approved locations on the tank (such as support legs) using a two-hole lug with stainless steel hardware, approved mechanical hardware (see “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63) or exothermic weld to dedicated grounding points (before filling the tank).

Vent piping associated with the tank **shall** be bonded to the grounding electrode system (FAA-STD-019G, section 4.3.8.3.2). The bonding connection to the vent pipe is typically established using mechanical hardware designed for this purpose. The connection to the grounding electrode system **shall** use exothermic welding or irreversible high-compression fittings, as described in this chapter.

Tanks that do not meet the above construction requirements **shall** require lightning protection as defined in NFPA 780 or other lightning protection standard in effect and recognized by the authority having jurisdiction. See FAA-STD-019G, section 4.3.8.3.2, for more information.

Bond other metallic components associated with the tank, such as stairs, ladders, or skids, as described in this chapter.

4.13.5.3 Below-Grade Tanks

Below-grade fuel tanks **shall** comply with the construction requirements of applicable codes, such as NFPA 30 and 58, as well as the requirements of the authority having jurisdiction (AHJ). They **shall** also meet the installation requirements of the tank manufacturer, applicable codes, and the AHJ. Additionally, below-grade metallic fuel tanks **shall** be protected from corrosion using a cathodic protection system or another system approved by the tank manufacturer and the AHJ (see NFPA 30-2024, section 23.3.5, and NFPA 58-2024, Annex K, for more details).

In certain applications, a device that offers both DC decoupling and AC continuity for grounding may be necessary for cathodically protected tanks. These devices are commonly known as Polarization Cell Replacements or Solid-State Decouplers. An example of such a device is available at https://www.dairyland.com/product/pcr/.

Below-grade fuel tanks do not need to be bonded to the site's grounding electrode system if no part of the tank is exposed. If any metallic component of the tank, including piping and monitoring systems, is exposed, then the tank **shall** be bonded to the grounding electrode system as described in “Metallic Objects Requiring Bonding” on page 4-108.

Metallic piping systems connected to the tank **shall** be bonded to the site grounding electrode system as close as practicable to where they enter the facility. See “Metallic Piping Bonding” on page 4-120.

Bond other metallic components associated with the tank, such as stairs, ladders, or skids, as described in this chapter.

4.13.6 GPS Antennas and Support Masts

GPS antennas that include a grounding point **shall** be grounded in accordance with both the manufacturer's instructions and the methods outlined in this chapter.

A metallic GPS mast is considered adequately grounded and bonded when it is securely mounted with metallic hardware to an adequately bonded and grounded metallic tower, ice bridge, or similar structure. In such cases, no additional bonding jumpers are necessary. Refer to Figure 4-99 for an example of GPS antennas secured to grounded ice bridge support posts.

If the GPS antenna mast does not meet the above criteria, such as when mounted to the side of a building, it **shall** be bonded with a bonding conductor as described in this chapter.

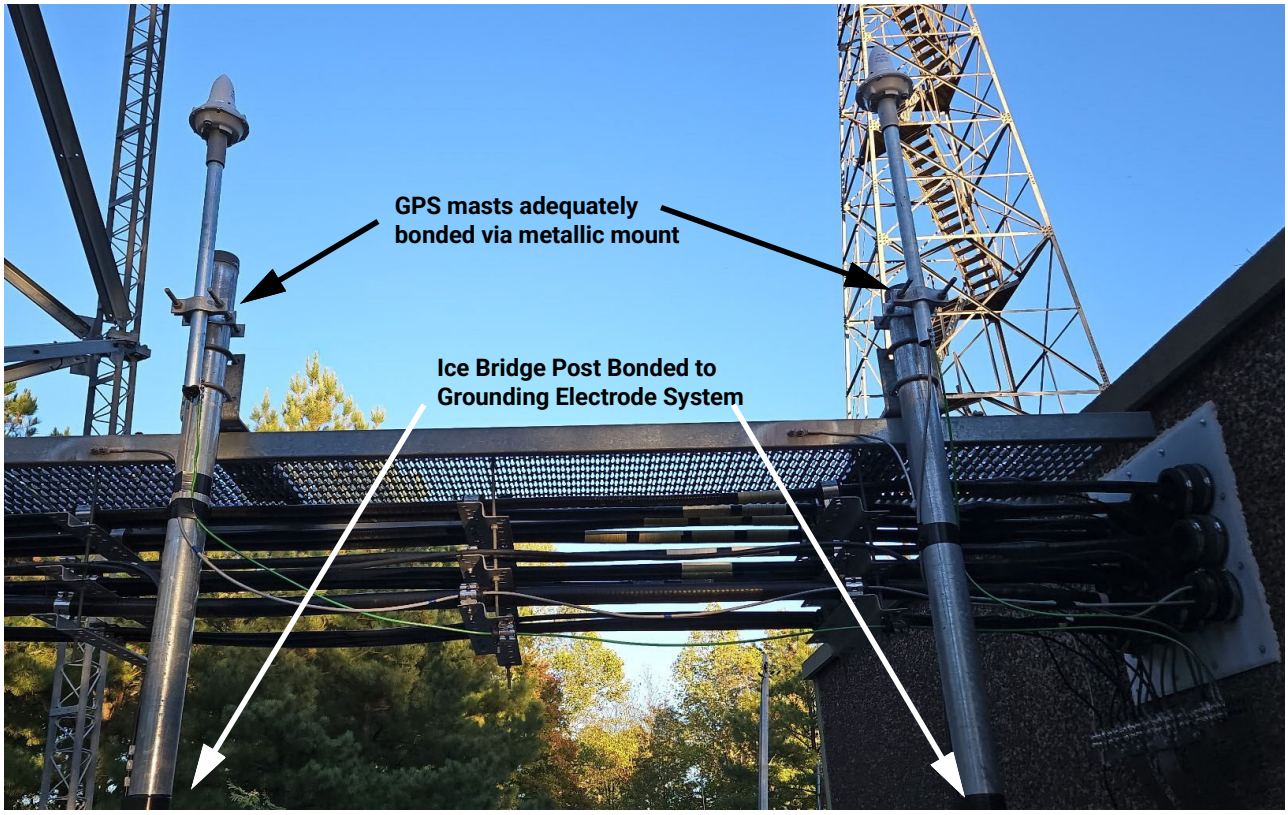


Figure 4-99. Example of GPS Antennas Secured to Grounded Ice Bridge Support Posts

4.13.7 Solar Photovoltaic Systems

Solar photovoltaic (PV) systems **shall** be grounded according to the AHJ (see Chapter 6, "Power Sources", and NFPA 70-2026, Article 690 for grounding requirements).

Exposed non–current carrying metal parts of PV module frames, electrical equipment, and conductor enclosures **shall** be bonded to the site's grounding electrode system (NFPA 70-2026, Article 690.43) using appropriate hardware (see "Above-Grade Mechanical Lugs and Connection Devices" on page 4-63).

Metallic support posts and mounts **shall** be bonded to the common grounding electrode system according to "Metallic Objects Requiring Bonding" on page 4-108 (ATIS-0600334.2019(R2024), section 5.3.3).
See Figure 4-100.

NOTE: Ground other alternative power sources, such as wind generators, in a manner similar to that described in this section for solar photovoltaic systems.

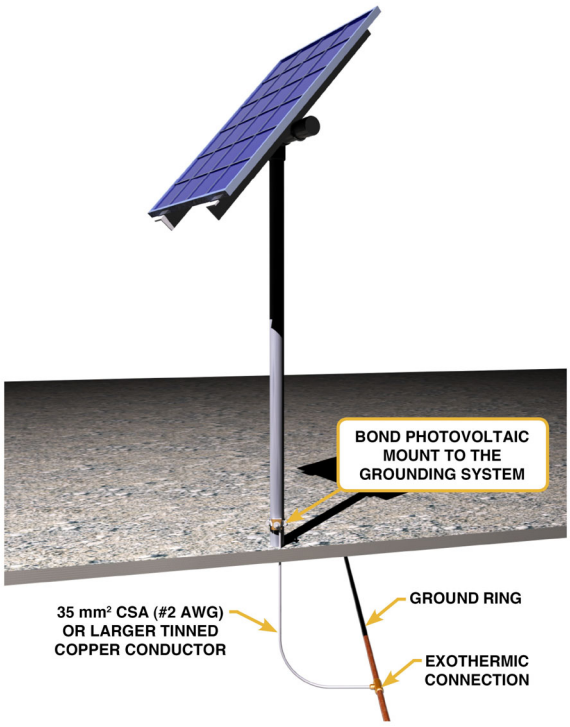


Figure 4-100. Solar Photovoltaic Grounding

4.14 Grounding Roof-Mounted Antenna Masts and Metal Support Structures

All roof-mounted antenna masts and metal support structures **shall** be grounded (NFPA 70-2026, Article 750). See TIA-607-E, section D.2.6, for more information.

NOTE: Rooftop-mounted towers are not covered in this section. See “Grounding (Earthing) Rooftop-Mounted Tower Structures” on page 4-131 for information about rooftop tower grounding requirements.

4.14.1 Rooftop External Ground Busbar (EGB)

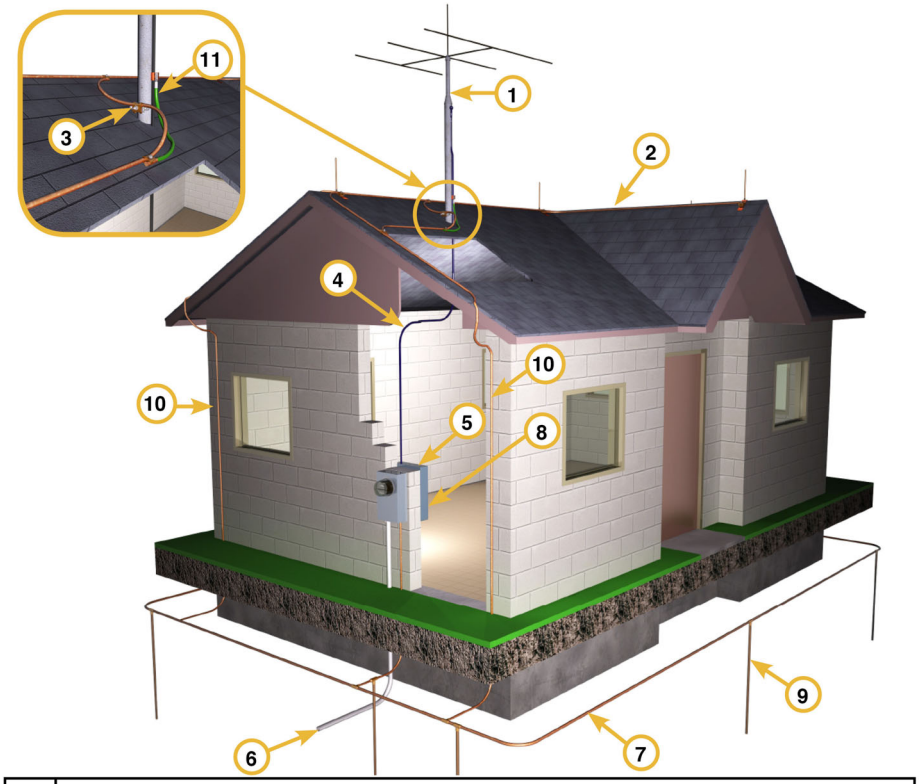
Where communications cables enter the building through a roof-mounted entry point, an EGB **shall** be installed near the entry for bonding the cables before they enter the building. The EGB **shall** be bonded to the rooftop grounding system as described below for the specified grounding type.

4.14.2 New Construction

In new construction, provisions should be integrated into the building design to ensure effective grounding of the roof-mounted antenna mast, support structure, and roof-mounted external ground busbar (EGB). This usually involves a grounding point or multiple points, with at least two direct connections to the building's common grounding electrode system. The direct connection to the grounding system can be made using effectively grounded structural building steel (metal frame/framework) (preferred) and/or down conductors sized according to Table 4-6, or lightning protection system conductors sized according to Table 4-4 and Table 4-5. Other engineered antenna mast and support structure grounding systems may include metallic antenna support structures that are directly and effectively bonded to effectively grounded structural building steel (metal frame/framework).

4.14.3 Existing Rooftop Lightning Protection System

When a lightning protection system (LPS) is installed on the building, roof-mounted antenna masts, support structures, and EGB(s) **shall** be bonded to the lightning protection system (IEC 62305-3:2024, section D.5.2.6.3, and NFPA 780-2026, section 4.16). The conductors **shall** match the size of the Main Roof Perimeter Lightning Protection Ring (FAA-STD-019G, section 4.3.4.3, and NFPA 780-2026, section 4.16). Bonding the conductors to the LPS **shall** be done using approved methods for lightning protection systems, such as exothermic welding, listed irreversible high-compression fittings, or other mechanical bonding devices (NFPA 780-2026, section 4.11.3). Refer to “Bonding to the External Grounding and Bonding System” on page 4-61. No additional grounding is necessary for roof-mounted antenna masts, support structures, and EGBs that are bonded to a LPS. See Figure 4-101.



1	METALLIC MAST
2	LIGHTNING PROTECTION CONDUCTOR RUN ON RIDGE
3	BOND METALLIC MAST TO LIGHTNING PROTECTION SYSTEM
4	ANTENNA CABLE
5	MAIN GROUNDING BUSBAR, METALLIC SHIELD ON THE ANTENNA CABLE IS CONNECTED TO THE BUSBAR
6	ELECTRICAL CABLE
7	GROUND RING CONDUCTOR
8	MAIN ELECTRICAL POWER DISTRIBUTION BOX WITH SPD
9	GROUND ROD
10	LIGHTNING PROTECTION DOWN CONDUCTOR
11	COAX GROUND KIT BONDED TO LIGHTNING PROTECTION CONDUCTOR

Figure 4-101. Antenna Bonding to Lightning Protection System

The EGB(s) **shall** be bonded to the LPS with two conductors. The conductors **shall** be bonded to opposite sides of the EGB and maintain as much separation from each other as practicable. Each conductor from the EGB **shall** be bonded to the LPS near different down conductors and routed so that lightning energy flows toward the down conductors and into the earth. See Figure 4-102.

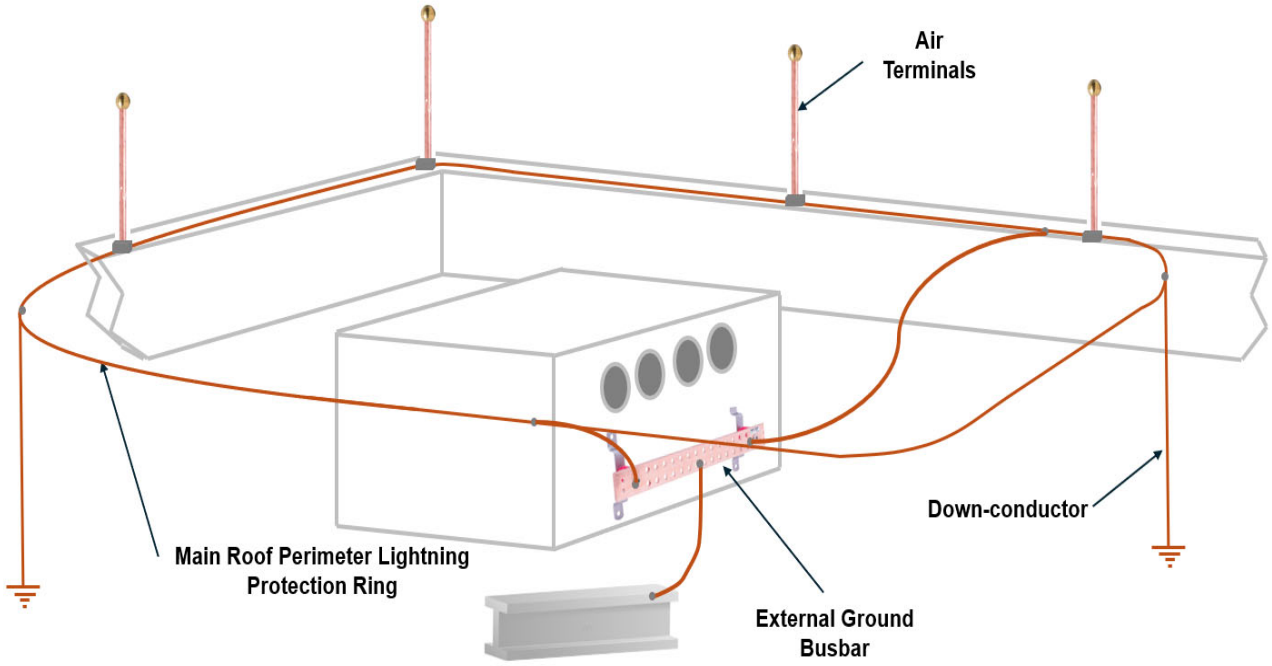


Figure 4-102. Rooftop Grounding Example with Existing Lightning Protection System

4.14.4 No Existing Rooftop Lightning Protection System

Where a lightning protection system is unavailable, roof-mounted antenna masts, metal support structures, and EGBs **shall** be grounded by directly bonding them to the building's grounding electrode system or a supplemental grounding electrode system (FAA-STD-019G, section 4.3.4.3). Bonding to the grounding electrode system should utilize effectively grounded structural building steel (metal frame/framework) where available. If effectively grounded structural building steel is not available, bonding **shall** use at least two down conductors sized according to Table 4-6, or lightning protection system conductors sized according to Table 4-4 and Table 4-5 where practicable (ATIS-0600334.2019(R2024), section 8.2). The down conductors **shall** be physically separated as much as practicable. See Figure 4-103.

The EGB(s) **shall** be bonded to the grounding electrode system using methods similar to those described above for the roof-mounted antenna masts and metal support structures.

- **Building Steel:** Bonded to building steel using at least one conductor sized according to Table 4-6, or lightning protection system conductors sized according to Table 4-4 and Table 4-5.
  - If the connection to building steel does not provide a direct and vertical connection and multiple building steel connection points are available, the EGB(s) **shall** be bonded to two different connection points.
  - The conductors **shall** be bonded to opposite sides of the EGB and maintain as much separation from each other as practicable.
  - The conductors from the EGB **shall** be bonded to the different building steel connection points and routed so that lightning energy flows toward the building steel.
- **Down Conductors:** Bonded to two down conductors sized according to Table 4-6, or lightning protection system conductors sized according to Table 4-4 and Table 4-5.

- The conductors **shall** be bonded to opposite sides of the EGB and maintain as much separation from each other as practicable.
- The conductors from the EGB **shall** be bonded to the different down conductors and routed to ensure lightning energy flows toward the down conductors and earth.

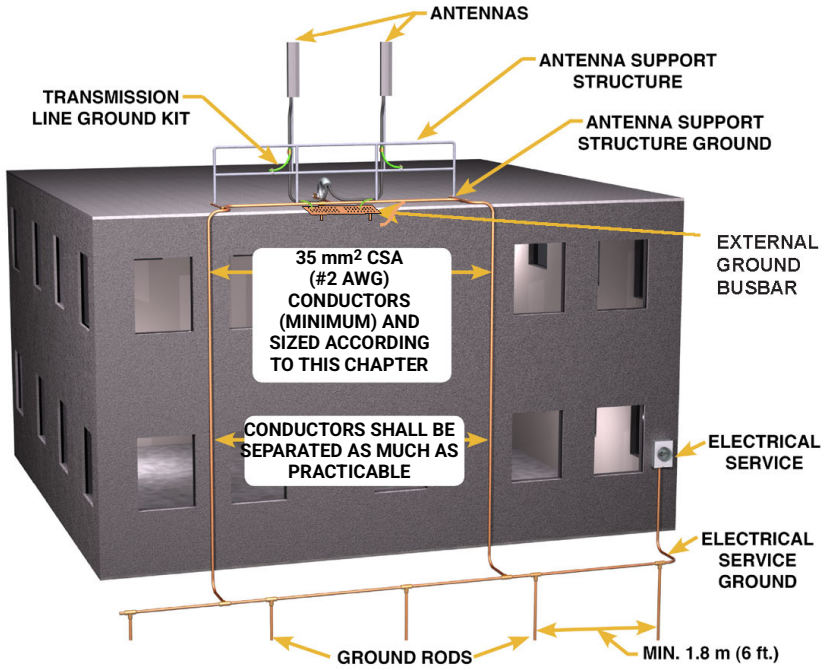


Figure 4-103. Roof Mounted Antenna Mast Grounding with Supplemental Grounding Electrode System

4.14.5 Multiple Down Conductors Not Practicable

Where effectively grounded structural steel (metal frame/framework) is unavailable and using two down conductors is impractical, a single down conductor may be used only if approved by an engineer. In this case, a larger conductor or lightning protection system conductor should be used (see “Down Conductors” on page 4-43). Water piping systems may also serve as a grounding down conductor, but only under the advice and direction of an engineer.

4.14.6 General Requirements for All Grounding Types

Where used, grounding down conductors **shall** meet the following requirements:

- Bonding to the structural building steel (metal frame/framework) **shall** be made using exothermic welding, listed irreversible high-compression fittings, or other fittings listed for use in lightning protection systems (see Figure 4-104).
  - See NFPA 780-2026, section 4.18, for more information regarding the use of structural building steel (metal frame/framework) as a main grounding down conductor.

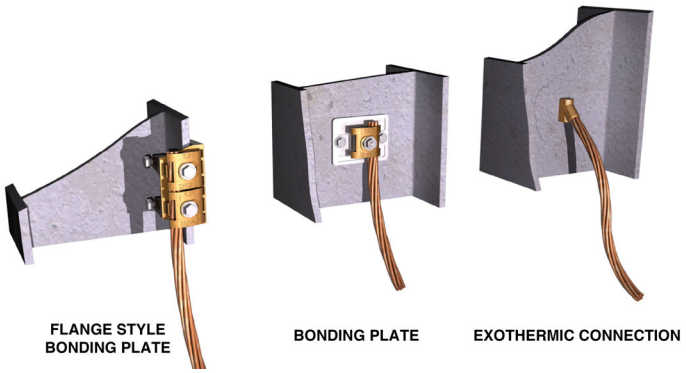


Figure 4-104. Acceptable Structural Building Steel Bonding Connections

- Down conductors **shall** be routed to the grounding electrode system from opposite sides of the roof where practicable (ATIS-0600334.2019(R2024), section 8.2).
- Down conductors **shall** be physically separated from each other as much as is practicable (ATIS-0600334.2019(R2024), section 8.2).
- Grounding down conductors **shall** be sized based on their length as shown in Table 4-6, or lightning protection system conductors may be used according to Table 4-4 and Table 4-5 (see “Down Conductors” on page 4-43 for lightning protection system conductor sizing).
- Grounding down conductors may be run either outside or inside the building or structure (NFPA 70-2026, Article 750.66(G)). Outside the building is the preferred method and should be used when practical.
- Where practicable, grounding down conductors **shall** maintain a separation of at least 1.8 m (6 ft) from communications wires, cables, and equipment (see NFPA 70-2026, Article 750.100(B)(3), for more information).
- Grounding down conductors are not required to be insulated (NFPA 70-2026, Article 750). Insulation is necessary where the grounding conductor might come into incidental contact with other metallic objects. Such contact could be a source of RF interference. Refer to Chapter 8, “Minimizing Site Interference”.
- Grounding down conductor bending and routing **shall** be performed according to “Bending and Routing Grounding, Bonding, and Down Conductors” on page 4-41.
- Grounding down conductors **shall** be protected and secured according to “Protecting and Securing Grounding, Bonding, and Down Conductors” on page 4-42.
- If the building grounding electrode system resistance cannot be verified or fails to provide a low resistance to earth (see “Testing/Verification of Grounding (Earthing) Electrode System and Bonding Continuity” on page D-1), a supplemental grounding electrode system should be installed to meet the site's resistance requirements. The supplemental grounding electrode system **shall** be bonded to the existing grounding system according to “Common Grounding” on page 4-7. Refer to “Supplemental Grounding Techniques to Help Achieve Resistance Design Goal” on page 4-82 for examples of a supplemental grounding electrode system.

IMPORTANT: Where installed, supplemental grounding electrode systems **shall** be effectively bonded to the building grounding electrode system. See “Common Grounding” on page 4-7.

NOTE: Depending on the available locations for grounding down conductors and where the RF transmission lines enter the building, it may be necessary to install a supplemental grounding electrode system. If installed, the supplemental grounding electrode system **shall** be bonded to the building ground.

NOTE: Consult the building engineer or manager for details about existing building grounding electrode systems. Inform the building engineer before attempting to weld or drill on the rooftop

4.15 Grounding Side-Mounted Antennas

Typically, a side-mounted antenna may be grounded with a single grounding conductor. However, using two down conductors and an External Ground Busbar (EGB) is advisable where practical; especially at buildings that are normally occupied, such as dispatch centers (see Figure 4-105). If two grounding down conductors are not installed, it is recommended to use either a copper strap (Figure 4-106) or a larger grounding down conductor, such as 120 mm^2 (#4/0 AWG). Grounding down conductors **shall** be sized according to Table 4-6, or lightning protection system conductors can be used, as outlined in Table 4-4 and Table 4-5. See TIA-607-E, section D.2.6, for further information.

NOTE: An External Ground Busbar (EGB) should be used for side-mounted antenna applications. An EGB simplifies grounding of the antenna support structure and RF cables (see Figure 4-106).

Where multiple side-mounted antennas are installed together, a single horizontal grounding conductor should bond all antenna mounts. This conductor should bond to each side of an EGB as shown in Figure 4-107.

A grounding down conductor **shall** be bonded to the horizontal grounding conductor to the grounding electrode system from each side of the antennas (see NFPA 780-2026, section 4.8.10, and associated subsections for more information). Where a horizontal grounding conductor is used, grounding down conductors **shall** be installed at intervals of at least every 30 m (100 ft) (NFPA 780-2026, section 4.8.10.2); 15 m (50 ft) intervals are recommended for improved protection. Grounding down conductors **shall** be sized according to Table 4-6, or lightning protection system conductors sized according to Table 4-4 and Table 4-5.

NOTE: Ground rods (or other electrodes) should be installed at 3 m to 4.5 m (10 to 15 ft) apart between down conductors (see Figure 4-106 and Figure 4-107).

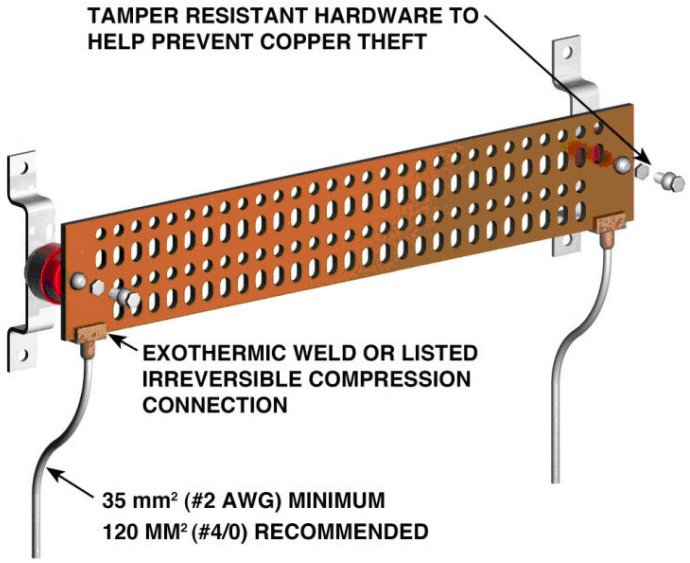


Figure 4-105. Minimum Recommended Busbar Installation for Side Mounted Antenna

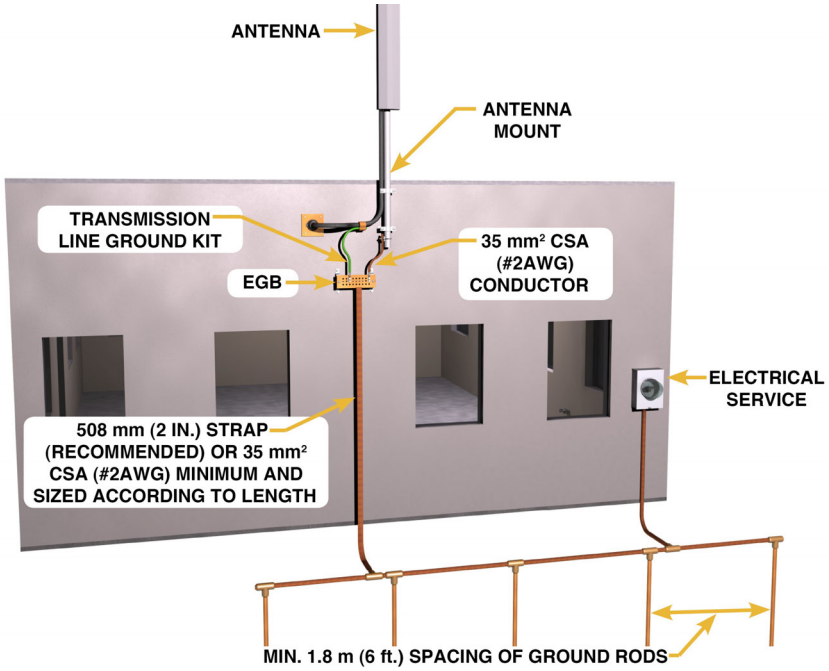


Figure 4-106. Side-Mounted Antenna Grounding Using Copper Strap Down Conductor

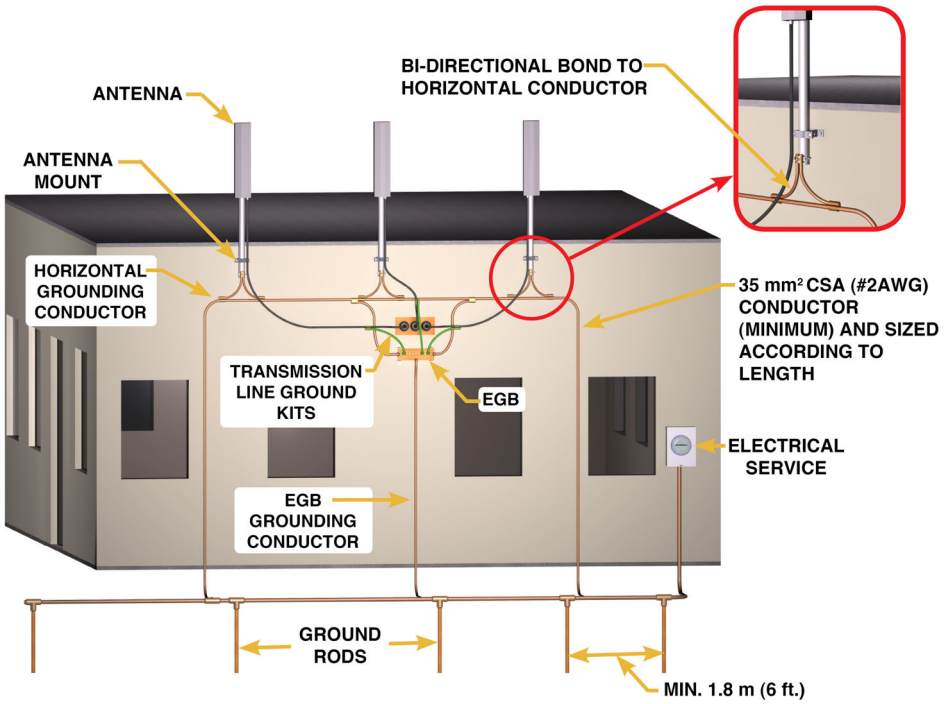


Figure 4-107. Grounding of Multiple Side-Mounted Antennas

4.16 Grounding (Earthing) Rooftop-Mounted Tower Structures

Rooftop-mounted towers and support structures may increase the lightning risk index for the buildings on which they are installed (ATIS-0600313.2019(R2024), section 10.3.3). See ATIS-0600334.2019(R2024), section 8, and TIA-607-E, section D.2.6 for more information.

IMPORTANT: The roof tower grounding system **shall** be coordinated with any existing lightning protection system. A lightning protection system engineering firm should be consulted for grounding rooftop-mounted towers.

IMPORTANT: Consult the building engineer or manager for information about any existing building grounding electrode systems. Notify the building engineer before attempting to weld or drill on the building rooftop.

NOTE: For the purpose of this section, a tower is any metallic structure over 6.1 m (20 ft) above the building roof line that is used to support communications antennas and/or dishes. An engineering firm specializing in lightning protection systems (LPS) may establish a different minimum height.

Where an antenna support structure or tower is installed on a building rooftop, the tower or structure **shall** be grounded as follows (see Figure 4-108):

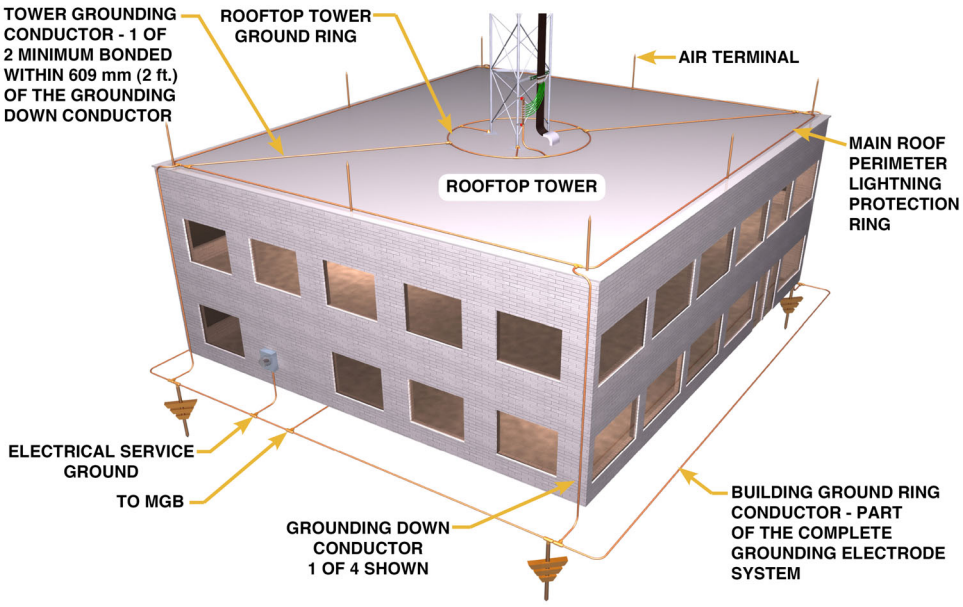


Figure 4-108. Typical Rooftop Tower Grounding

4.16.1 General Requirements

- All bonding connections **shall** be made using exothermic welding, listed mechanical, crimped, or compression fittings.
- All conductors and bonding devices **shall** be listed for use in lightning protection systems according to CAN/CSA-B72, NFPA 780-2026, or IEC 62305, as applicable.
- Metallic objects on the roof **shall** be bonded to the roof grounding system as required by one of the following standards: CAN/CSA-B72:20, IEC 62305-3, NFPA 780, or other code/standard recognized by the authority having jurisdiction.
- All grounding electrode systems at the building **shall** be bonded together to form a single grounding electrode system. See “Common Grounding” on page 4-7.

4.16.2 Main Roof Perimeter Lightning Protection Ring (Roof Ground Ring)

NOTE: These requirements do not apply if the building already has a lightning protection system in place.

- A grounding conductor **shall** be installed around the roof perimeter to form the Main Roof Perimeter Lightning Protection Ring (Roof Ground Ring). The size of the roof ground ring **shall** be determined based on the building height, as specified in NFPA 780-2026, Table 4.1.1.1.1 and 4.1.1.1.2. Refer to “Down Conductors” on page 4-43, Table 4-4, and Table 4-5 for additional details.
  - Class I lightning protection system (LPS) conductors for structures not exceeding 23 m (75 ft) in height. Alternatively, a 35 mm² (#2 AWG) conductor could be used if it meets the requirements in NFPA 780-2026, Table 4.1.1.1.1.
  - Class II LPS conductors for structures equal to or greater than 23 m (75 ft). Alternatively, a 70 mm² (#2/0 AWG) conductor could be used if it meets the requirements in NFPA 780-2026, Table 4.1.1.1.2.
- Strike termination devices, also known as air terminals, **shall** be installed along the main roof perimeter lightning protection ring as required by the authority having jurisdiction, typically every 6.1 m (20 ft).

4.16.3 Down Conductors for the Roof Ground Ring

NOTE: These requirements do not apply if the building already has a lightning protection system in place.

- The roof ground ring **shall** have at least two down conductors, installed diametrically opposed, down the building wall (or equivalent), and connected to a ground ring around the building (preferred), or two or more rods. Down conductors **shall** be minimally sized the same as the roof ground ring as described above.
- Buildings exceeding 76 m (250 ft) in perimeter **shall** have one additional down conductor for each 30 m (100 ft) of building perimeter or fraction thereof. The average distance between all down conductors **shall not** exceed 30 m (100 ft).
- Instead of down conductors, the metal framework of a structure can be used if it is at least 4.8 mm (3/16 in.) thick and electrically continuous, or if it is made electrically continuous by methods specified in NFPA 780-2026, section 4.18.3.

4.16.4 Rooftop Tower Grounding

- A roof tower ground ring **shall** be installed around the tower or support structure using the same type and size of grounding conductors as the roof ground ring.
  - The bottom plate of a guyed tower can serve as a substitute for the tower ground ring.
  - A monopole tower does not require a roof tower ground ring due to its single-leg design. However, the monopole **shall** still be bonded to the roof ground ring, as described in “Main Roof Perimeter Lightning Protection Ring (Roof Ground Ring)” on page 4-132.
- Each tower leg **shall** be bonded to the roof tower ground ring using the same type and size of grounding conductors as the roof ground ring.
  - For non-tower support structures, at least two conductors from opposite sides **shall** be used. If the support structure has multiple legs, each leg **shall** be bonded as described for towers.
- The roof tower ground ring, guyed tower base plate, or monopole **shall** be bonded to the roof ground ring with at least two opposing conductors, positioned within 610 mm (24 in.) of a grounding down conductor or other main grounding conductor, such as effectively grounded structural building steel or metal frame/framework, as defined by CAN/CSA-B72, IEC 62305-3, or NFPA 780-2026.
  - The conductors used **shall** be the same type and size as the roof ground ring.

4.16.5 Tower Ground Busbar (TGB)

- A TGB **shall** be installed near the base of the rooftop tower.
  - The TGB **shall** meet the requirements of this chapter.
  - The TGB **shall** be bonded to either the roof tower ground ring or to one of the grounding conductors that connect the tower ground ring and the roof ground ring. The conductor used for this bonding **shall** be the same size and type as that used for the roof ground ring.
- Coaxes, waveguides, and other shielded communication cables **shall** be bonded to the TGB using appropriate grounding kits.
- Metallic support apparatus for the tower (e.g., cable trays) **shall** be bonded to the TGB or other locations on the roof grounding system.
- If present, metallic conduits for AC branch circuits on the tower (such as warning lights or other powered devices) **shall** be bonded to the TGB using a 16 mm² csa (#6 AWG) or larger conductor.

IMPORTANT: Early Streamer Emission devices and Lightning Elimination devices are not internationally recognized as approved lightning protection components and **shall not** be used for lightning protection systems.

4.16.6 Additional Bonding Requirements for Roof-Mounted Guyed Towers

- Tower guy anchors that are attached directly to the building **shall** be bonded to the roof ground ring (ATIS-0600313.2019(R2024), section 10.3.3).
- Guy anchors that are directly and electrically connected to effectively grounded structural building steel (metal frame/framework) may not require any additional bonding to the roof grounding system.
- Guy wires **shall** be grounded using similar techniques described in “Steel Guy Anchor Point Grounding” on page 4-92 and Figure 4-72.
- The guy wire grounding conductor **shall** be bonded to the roof ground ring or the grounded guy anchor.
- The conductors **shall** be the same size and type as the roof ground ring, where practicable, and **shall** meet the installation requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.

See Figure 4-109 for an example.

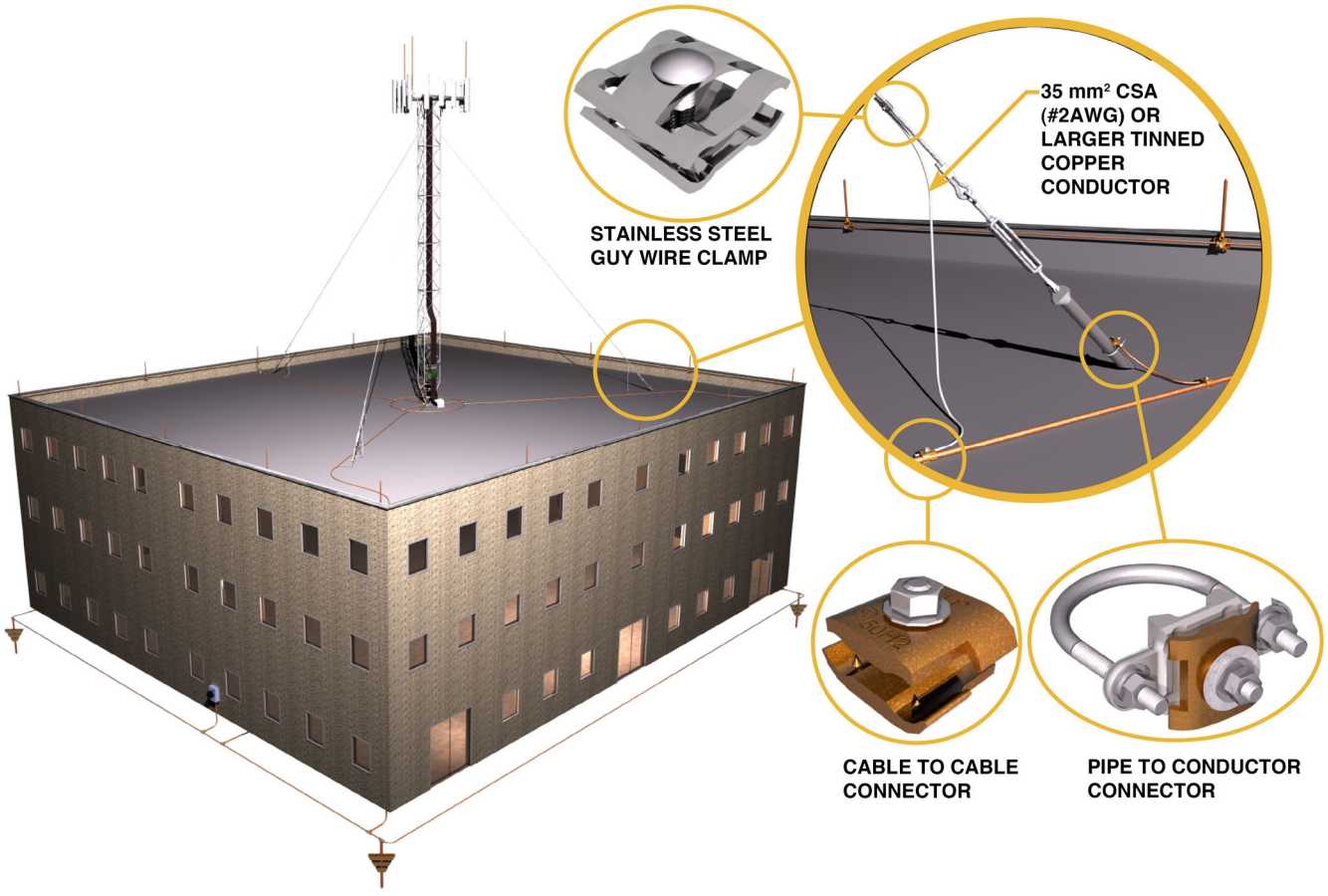


Figure 4-109. Typical Rooftop Tower Guy Anchor Point Grounding

4.17 Special Grounding (Earthing) and Bonding Applications

Some communication site locations and/or applications require special attention for adequate grounding and bonding. The following sections explain techniques for grounding and bonding common communication applications. In some cases, consulting with Motorola Solutions Engineering or another engineering firm might be necessary.

4.17.1 Dispatch Centers Co-Located With Communications Towers

Dispatch centers co-located with communications towers require special protection measures due to their critical operations and the associated lightning risk to personnel. To ensure the best protection of a dispatch center, the following **shall** be considered:

- Site design recommendations given in “Design Considerations to Help Reduce Effects of Lightning” on page 2-16 and Figure 4-110.
  - Cable entry panel within 610 mm (2 ft) of the floor (NWSM 30-4106:2017, Figure 2-2). See Figure 4-110.
  - 9.1 m (30 ft) minimum distance between tower and building (IEEE 1692-2023, section 7; and TIA-607-E, Figure 25). See Figure 4-110.
- Internal bonding and grounding as defined in “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137.
- Surge Protective Devices (SPD) as defined in “Surge Protection for Dispatch Centers and Operator Positions” on page 7-66.
- Electrostatic discharge (ESD) precautions as defined in “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers” on page C-1.
- External grounding and bonding as follows:
  - Grounding electrode system resistance design goal of 5 Ω or less (see IEEE 1692-2023, section 8.1 and TIA-607-E, section 8.1.2). See “Type “B2” Sites: Extra Duty” on page 4-82.
  - Installation of all minimum required grounding electrode system components as described in “Dedicated Communications Building Grounding (Earthing)” on page 4-98.
  - Bonding of all metallic objects as described in “Metallic Objects Requiring Bonding” on page 4-108.
  - Installation of radial grounding conductors as described in “Radial Grounding Conductors” on page 4-29. Radial grounding conductors should be installed regardless of whether the grounding electrode system resistance is 5 Ω or less. A minimum of four radial grounding conductors **shall** be installed, if practicable (IEEE 1692-2023, section 8.2).

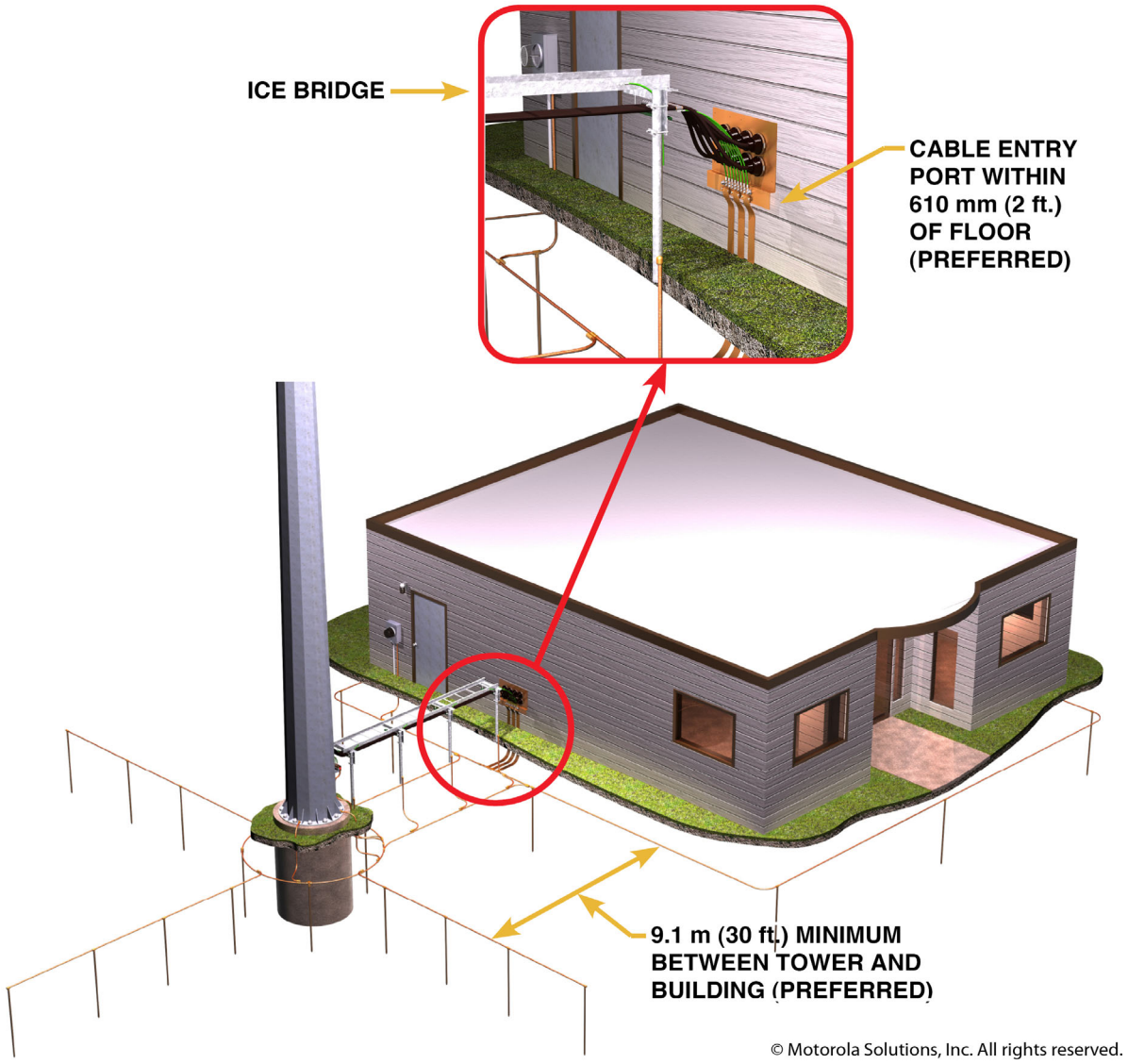


Figure 4-110. Grounding Electrode System for Dispatch Center Co-Located with a Tower

4.17.2 Two or More Separate, Electrically Interconnected Buildings in the Same Area

Where two or more structures or facilities are located in the same general area (less than 61 m (200 ft) apart) and are electrically interconnected with the continuous metallic shield of a cable (for example, signal, control, RF, monitor circuits, or other communications cables), special grounding techniques must be considered. Either a common grounding electrode system **shall** be provided, or the separate grounding electrode systems **shall** be interconnected with two buried grounding conductors. See Telcordia GR-3171-CORE.i02, section 10.5 for more information.

Where installed, the interconnecting grounding conductors **shall** be 50 mm² csa (#1/0 AWG) or larger, bare, copper or tinned copper. The buried grounding conductors **shall** be installed in separate trenches that are separated as much as practicable (at least 1.8 m (6 ft)). The conductors **shall** be buried to a minimum depth of 457 mm (18 in.) below-grade, where practicable. Access to the grounding conductor bonding points should include ground test wells.

For additional information, see Figure 4-111; “Ground Inspection Wells” on page 4-36; and MIL-HDBK-419A Volume II, section 1.2.3.

IMPORTANT: For optimum protection from transient voltage events and ground potential rise, optical fiber links (or other forms of isolation protection) are recommended for all inter-building links. Non-shielded fiber should be used. See IEEE 1692-2023 for more information.

Separate structures spaced closer than 6 meters (20 ft) should have a common grounding electrode system installed that encircles both facilities (MIL-HDBK-419A Volume II, section 1.2.3). See Figure 4-112.

Structures or facilities having no interconnection cables and separated by a distance greater than 61 m (200 ft) generally do not require their grounding electrode systems to be interconnected (MIL-HDBK-419A Volume II, section 1.2.3).

Buildings sharing a common tower require bonding of their respective ground rings to the common tower ground ring. See Figure 4-113.

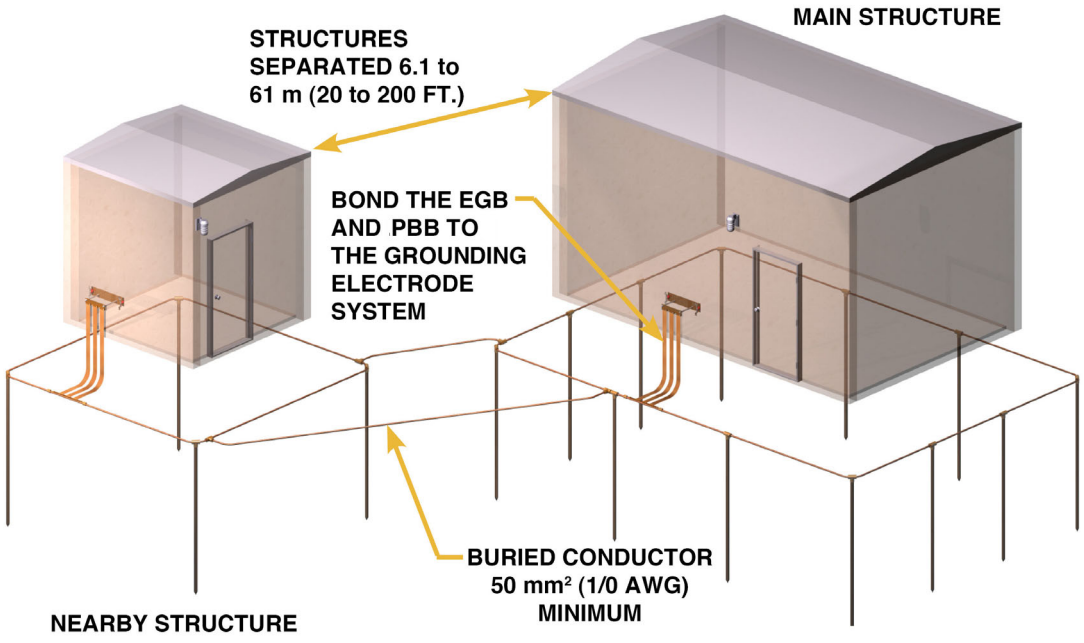


Figure 4-111. Two Electrically Interconnected Buildings Located in the Same Area

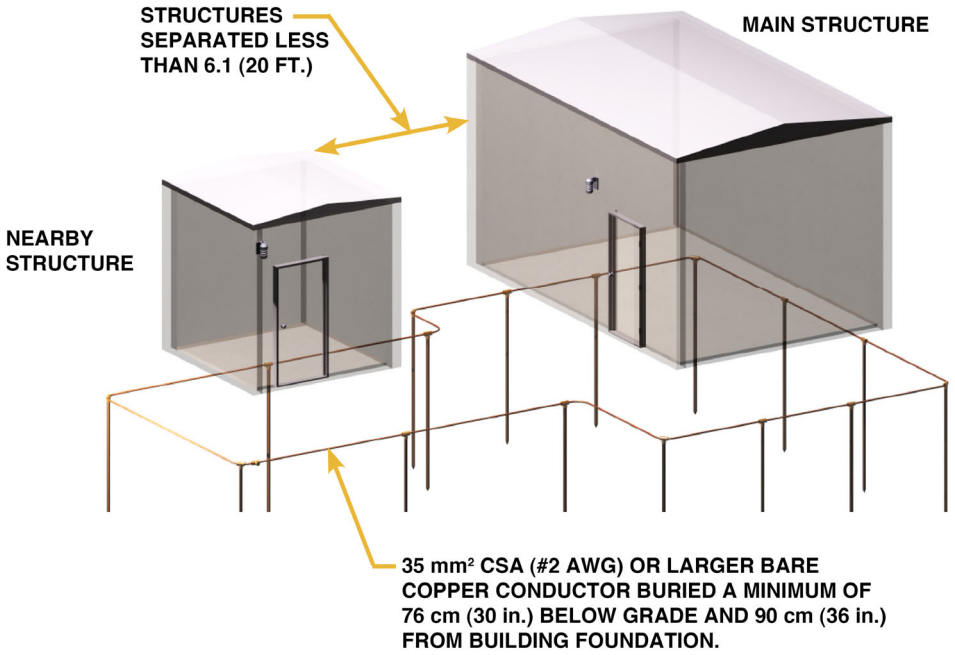


Figure 4-112. Separate Structures with Common Ground Ring

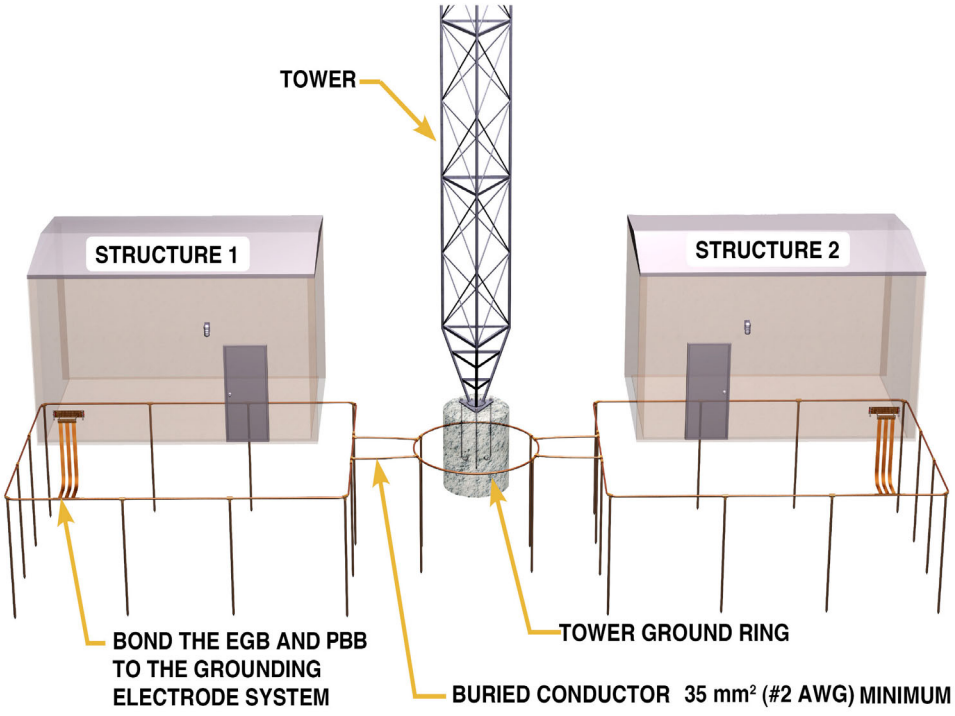


Figure 4-113. Bonding Two Structures Adjacent to Tower

4.17.3 Access Points, Cameras, Wireless Routers, Point-to-Point and Similar Devices

Access points, cameras, wireless routers, point-to-point devices, and similar equipment are typically installed in various locations, such as communications towers, building rooftops, or utility poles. Grounding and bonding requirements for devices installed in typical locations are addressed in this section.

4.17.3.1 Tower-Mounted Devices

Grounding and bonding requirements for tower-mounted devices are provided below.

- Tower-mounted devices **shall** be bonded to the tower using a 16 mm² csa (#6 AWG) or larger, tinned and/or jacketed, copper conductor. Conductors longer than 3.96 m (13 ft) **shall** be 35 mm² csa (#2 AWG) or larger.
- Devices containing internal surge protective devices **shall** be bonded to the tower using a 35 mm² csa (#2 AWG) or larger conductor.
- Grounding conductors **shall** also be sized according to length as shown in Table 4-6.
- The connection to the device **shall** be made to an adequately-sized, dedicated grounding point, as specified by the device manufacturer's requirements.
- Connection to the tower **shall** be made using tower manufacturer-approved methods, typically a mechanical clamp or to an existing tower ground busbar.
- The grounding conductor **shall** comply with the specifications and installation requirements of "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38.
- The tower **shall** be grounded as described in "Tower Grounding (Earthing)" on page 4-84 or "Grounding (Earthing) Rooftop-Mounted Tower Structures" on page 4-131.
- RF transmission lines and other device input/output cables **shall** be grounded and bonded as described in "Grounding and Bonding of RF Transmission Lines and Communications Cables" on page 4-104.

IMPORTANT: For increased protection of the device, it should not be installed on the extreme top of the tower unless protected by a lightning protection system strike termination device (or equivalent).

NOTE: External surge protective devices (SPD) associated with the electronic equipment **shall** be grounded as described previously for tower-mounted devices.

4.17.3.2 Internal Building-Mounted Devices

Devices installed inside the building **shall** be bonded and grounded as required for electronic equipment in Chapter 5, "Internal Bonding and Grounding (Earthing)".

4.17.3.3 External Building Side-Mounted Devices

The grounding and bonding requirements for devices mounted on the side of a building are as follows:

- Devices mounted to the side of a building **shall** be bonded directly to the building's common grounding electrode system using a 16 mm² csa (#6 AWG) or larger, copper or tinned-copper conductor.
  - Conductors longer than 3.96 m (13 ft) **shall** be 35 mm² csa (#2 AWG) or larger.
  - Conductors entering the earth **shall** be 35 mm² csa (#2 AWG) or larger.
- Devices containing internal surge protective devices **shall** be bonded to the grounding electrode system using a 35 mm² csa (#2 AWG) or larger conductor.
- Grounding conductors **shall** also be sized according to length as shown in Table 4-6, or lightning protection system conductors may be used. The lightning protection system conductors may be copper or aluminum, as appropriate for the site-specific conditions (see "Down Conductors" on page 4-43).

- Connection to the device **shall** be made to an adequately-sized dedicated grounding point according to the device manufacturer's specifications.
- The grounding conductor **shall** comply with the specifications and installation requirements of "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38.
- Metallic mounting masts used for supporting access points, cameras, wireless routers, point-to-point, and similar devices **shall** be grounded in the same manner as described in "Grounding Side-Mounted Antennas" on page 4-129.

NOTE: External surge protective devices (SPD) associated with the electronic equipment **shall** be grounded in the same manner as previously described for building side-mounted devices.

4.17.3.4 Roof-Mounted Devices

The grounding and bonding requirements for roof-mounted devices are as follows:

- Devices mounted on the roof of a building **shall** be bonded directly to the building's common grounding electrode system using a 16 mm² csa (#6 AWG) or larger, copper or tinned-copper conductor.
  - Conductors longer than 3.96 m (13 ft) **shall** be 35 mm² csa (#2 AWG) or larger.
  - Conductors entering the earth **shall** be 35 mm² csa (#2 AWG) or larger.
- Devices containing internal surge protective devices **shall** be bonded to the grounding electrode system using a 35 mm² csa (#2 AWG) or larger conductor.
- Grounding conductors **shall** also be sized according to length, as shown in Table 4-6, or lightning protection system conductors may be used. The lightning protection system conductors may be copper or aluminum, as appropriate for the site-specific conditions (see "Down Conductors" on page 4-43).
- The grounding conductor **shall** meet the specifications and installation requirements of "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38.
- Connection to the device **shall** be made to an adequately-sized dedicated grounding point, as specified by the device manufacturer's requirements.
- Metallic mounting masts used to support access points, cameras, wireless routers, point-to-point links, and similar devices **shall** be grounded as described in "Grounding Roof-Mounted Antenna Masts and Metal Support Structures" on page 4-124.

An available bonding location to the building's common grounding electrode system may include the following:

- Effectively grounded structural building steel (metal frame/framework).
- An existing communications grounding system.
- An existing lightning protection system.
- A grounding down conductor sized according to "Down Conductors" on page 4-43 (may include lightning protection system conductors). The lightning protection system conductors may be copper or aluminum, as appropriate for the site-specific conditions (see "Down Conductors" on page 4-43).
- Other connections to earth as designed by Motorola Solutions Engineering or another engineering firm.

IMPORTANT: For increased protection of the device, do not install the device at the extreme top of the metallic mounting mast unless protected by a lightning protection system strike termination device (or equivalent). See Figure 4-114.

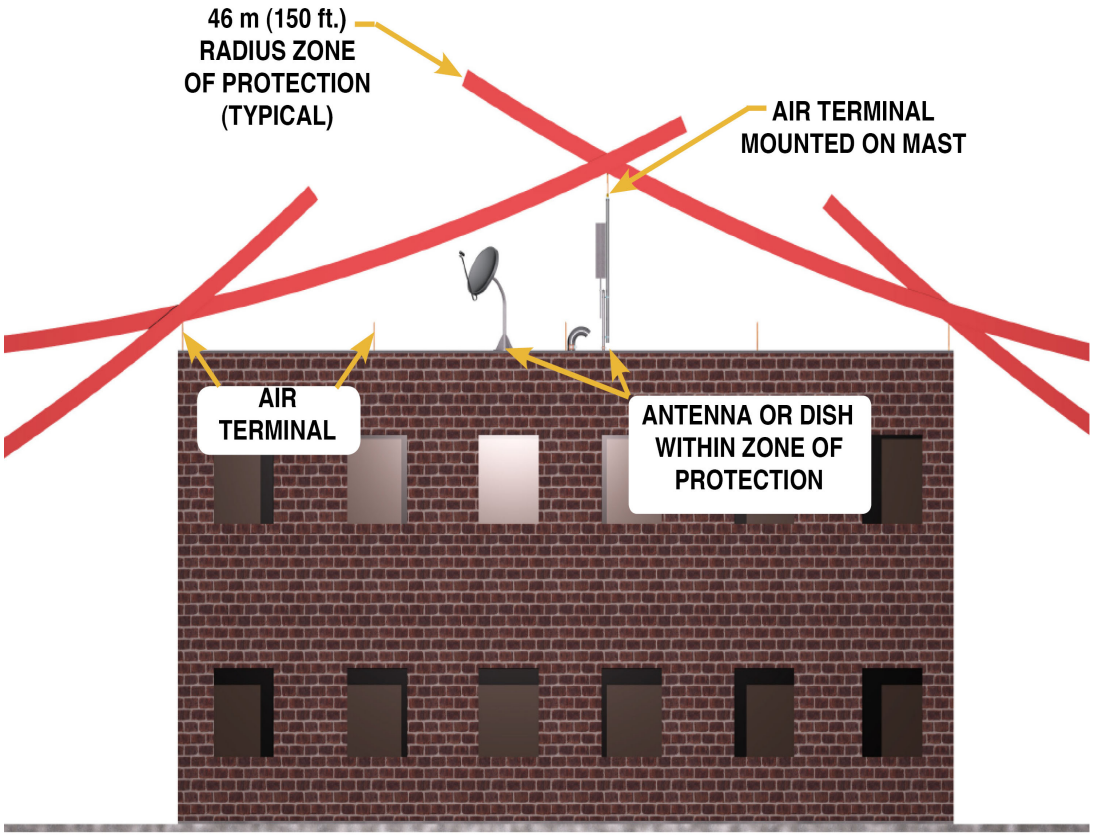


Figure 4-114. Device Installed Within Zone of Protection

NOTE: External surge protective devices (SPD) associated with the electronic equipment **shall** be grounded as described previously for roof-mounted devices.

4.17.4 Site on Wheels

Temporary sites, also called sites on wheels (SOW), are sometimes deployed to quickly provide essential communications for first responders. Sites on wheels are commercially available in several configurations, including sites with crank-up towers (see Figure 4-115). Some typical applications for a site on wheels are as follows:

- To serve as the permanent structure where permanent infrastructure is not practical
- To restore mission-critical communications during disaster recovery efforts
- To facilitate communications during special events
- To temporarily replace a damaged or non-operational site
- To temporarily fill coverage gaps



Figure courtesy of Pepro, LLC

Figure 4-115. Example of Site on Wheels with Crank-up Tower

Internal bonding and grounding for a SOW, as well as surge protection, **shall** be completed as described in this manual according to the requirements for a dedicated communications building or shelter.

4.17.4.1 Site on Wheels Used as a Permanent Site

A SOW used as a permanent site **shall** be grounded and bonded as outlined in this chapter for a dedicated communications site.

4.17.4.2 Site on Wheels Co-located at an Existing Site

A SOW temporarily installed at an existing site **shall** be bonded to the site's grounding electrode system. This is usually done by connecting the SOW's External Ground Busbar to the grounding electrode system using bonding methods described in this chapter (e.g., exothermic welding or irreversible high-compression fittings).

4.17.4.3 Stand-Alone Site on Wheels

A stand-alone SOW **shall** be grounded using at least two ground rods (or other electrodes suitable for the site-specific soil conditions) as described in this chapter. The need for additional grounding electrodes should be evaluated based on the area's lightning activity, soil resistivity, and the anticipated duration of SOW deployment.

If the SOW is powered from another building, the SOW's grounding electrode system **shall** be bonded to that building's grounding electrode system.

4.17.5 Utility/Light Pole-Mounted Devices

The following sections outline grounding and bonding requirements for utility and light pole-mounted access points, cameras, wireless routers, point-to-point links, external surge protective devices associated with electronic equipment, and similar devices.

Before starting work on a utility pole, written approval **shall** be obtained from the utility and/or the authority having jurisdiction (AHJ).

WARNING: High voltage hazards may exist with utility pole installations. Only properly trained and qualified personnel SHALL perform communications equipment installations and maintenance on utility poles and SHALL follow applicable OSHA regulations (or equivalent). Qualification and training SHALL be determined by the utility and/or authority having jurisdiction.

WARNING: Installations on utility poles SHALL meet all installation and clearance requirements of the *National Electrical Safety Code®* (or equivalent), the electric utility (or utility that owns the pole) or other authority having jurisdiction.

4.17.5.1 Metallic Pole-Mounted Devices

Devices **shall** be installed at a utility-approved location with clearances as described in “Utility Pole Required Clearances” on page 9-73. The **Warnings** on page 4-143 **shall** be followed.

Devices mounted on metallic utility poles are grounded and bonded in a manner similar to that described earlier for tower-mounted devices (see Figure 4-116):

- Devices **shall** be bonded to the pole using a 16 mm² csa (#6 AWG) or larger, tinned and/or jacketed, copper conductor. Conductors longer than 3.96 m (13 ft) **shall** be 35 mm² csa (#2 AWG) or larger.
- Devices containing internal surge protective devices **shall** be bonded to the pole using a 35 mm² csa (#2 AWG) or larger conductor.
- Grounding conductors **shall** also be sized according to length as shown in Table 4-6.
- The connection to the device **shall** be made to a correctly-sized dedicated grounding point according to the device manufacturer’s requirements.
- Connection to the pole **shall** be made using appropriate mechanical clamps. See “Above-Grade Mechanical Lugs and Connection Devices” on page 4-63.
- The grounding conductor **shall** meet the specifications and installation requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38.
- The metallic utility pole **shall** be effectively grounded or must be made effectively grounded. If it must be grounded, it **shall** be grounded using at least one ground rod (or another electrode suitable for the soil conditions). See “Grounding System Component and Installation Requirements” on page 4-9.

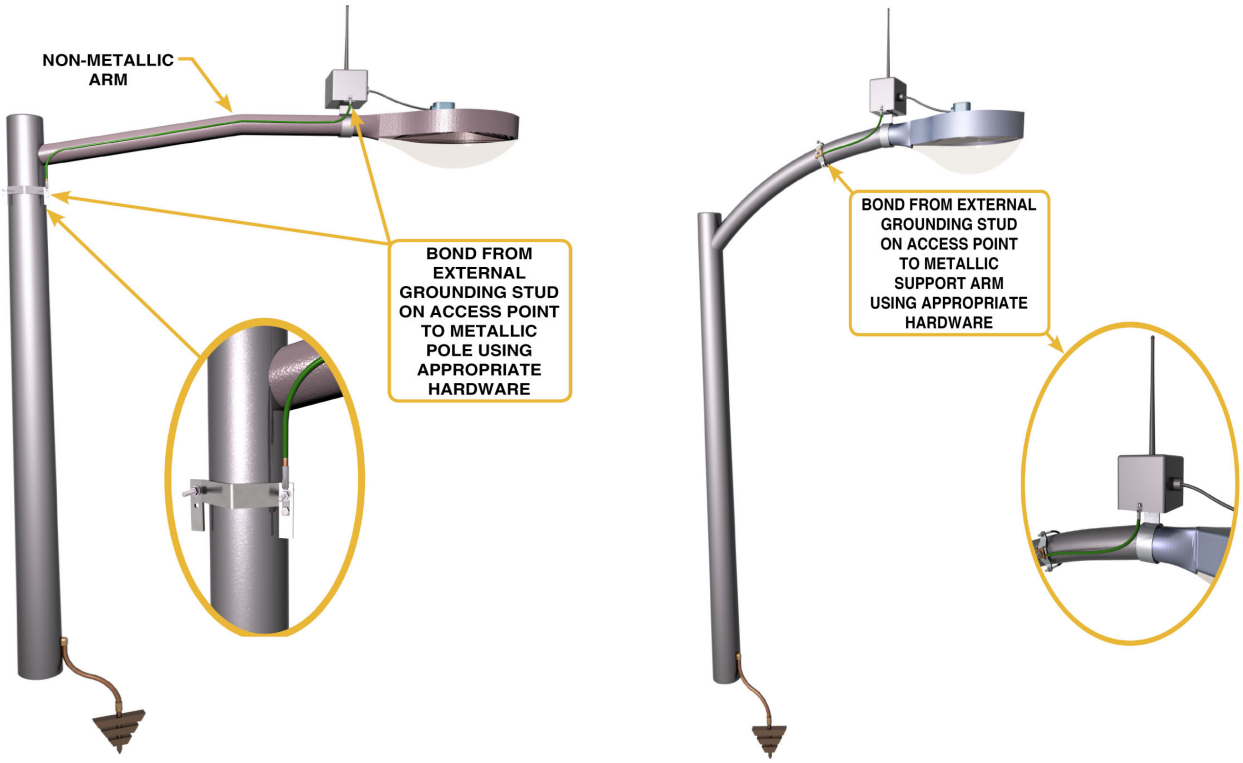


Figure 4-116. Grounding Access Point Mounted on Metal Pole

IMPORTANT: For lightning protection purposes, the metallic utility pole should have a locally-installed grounding electrode, even if it is bonded with an equipment grounding conductor.

NOTE: External surge protective devices (SPD) associated with the electronic equipment **shall** be grounded in the same way as previously described for metallic pole-mounted devices.

NOTE: If the device is mounted on a non-metallic arm attached to a metallic utility pole, the device **shall** be grounded as previously described by bonding it to the metallic part of the pole, as shown in Figure 4-116.

4.17.5.2 Non-Metallic Pole Mounted

Devices **shall** be installed at a utility-approved location with clearances as described in “Utility Pole Required Clearances” on page 9-73. The **Warnings** on page 4-143 **shall** be followed.

Non-metallic utility poles used for supporting access points, cameras, wireless routers, point-to-point links, and similar devices are grounded and bonded in a manner similar to that described in “Non-metallic Poles” on page 4-97. The devices **shall** be grounded and bonded as follows:

- The non-metallic utility pole **shall** have a vertical grounding conductor installed along its length, or at least up to the height of the device. See “Non-metallic Poles” on page 4-97.
- The vertical grounding conductor **shall** be made of 35 mm² csa (#2 AWG) or larger, bare, solid, copper or tinned-copper (ATIS-0600334.2019(R2024), section 6.5).
- Grounding conductors **shall** also be sized based on their length as shown in Table 4-6.
- The vertical grounding conductor **shall** terminate into the earth at a grounding electrode system that includes at least one ground rod or other suitable electrode for the soil. Connection to the grounding electrode system **shall** follow the guidelines in “Below-Grade Bonding Methods” on page 4-69.

- Devices **shall** be bonded to the pole's vertical grounding conductor using a 16 mm² csa (#6 AWG) or larger copper bonding conductor. Conductors longer than 3.96 m (13 ft) **shall** be 35 mm² csa (#2 AWG) or larger.
- Devices with internal surge protective devices **shall** be bonded to the pole's vertical grounding conductor using a 35 mm² csa (#2 AWG) or larger bonding conductor.
- Connection to the device **shall** be made to an adequately sized dedicated grounding point following the manufacturer's requirements.
- Connection to the pole's vertical grounding conductor **shall** be made using appropriate methods, such as exothermic welding or irreversible high-compression fittings. See “Bonding to the External Grounding and Bonding System” on page 4-61.
- The grounding conductor **shall** meet the specifications and installation requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38. If the vertical grounding conductor is exposed to damage, it **shall** be protected for at least 2.44 m (8 ft) above ground or other surface (*National Electrical Safety Code®*).

NOTE: Non-metallic poles with a transformer typically contain a locally-installed ground rod (or other electrode), as specified in the *National Electrical Safety Code (NESC)*. If present, this ground rod can be used for grounding the communication device. The vertical grounding conductor may be connected directly to the ground rod or to the transformer grounding electrode conductor (as close as practicable to the rod). Bonding to the ground rod or grounding electrode conductor **shall** use exothermic welding or listed irreversible high-compression fittings. Refer to “Bonding to the External Grounding and Bonding System” on page 4-61.

NOTE: External surge protective devices (SPD) associated with the electronic equipment **shall** be grounded in the same manner as previously described for non-metallic pole-mounted devices.

IMPORTANT: To prevent a potential difference, any grounding electrode installed for grounding the communications device **shall** be bonded to any other electrode at the pole, which may include a pole butt plate, wire wrap, and/or ground rod. Refer to the *NESC®* for more details on available pole grounding electrodes.

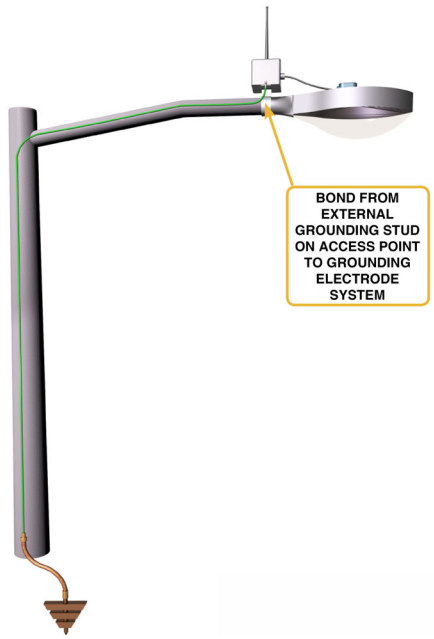


Figure 4-117. Grounding Access Point Mounted on Non-Metallic Pole

NOTE: The *National Electrical Safety Code®* is also known as the American National Standards Institute C2 (ANSI/IEEE C2).

4.17.6 Metal Shipping Containers used as Communications Buildings

Grounding electrode systems for metal shipping containers used as communications buildings **shall** comply with the requirements specified in this chapter for a dedicated communications building (see "Dedicated Communications Building Grounding (Earthing)" on page 4-98). All equipment inside the shipping container **shall** meet the bonding and grounding requirements of Chapter 5, "Internal Bonding and Grounding (Earthing)".

In addition to the previously listed requirements, the exterior of the shipping container **shall** be bonded to the grounding electrode system at all four corners (minimum) using 35 mm² csa (#2 AWG) or larger copper, or tinned copper conductors. The requirements for bonding the metal shipping container to the grounding electrode system are as follows (see Figure 4-118):

- Each corner of the metal container **shall** be directly bonded to the grounding electrode system.
- Conductors **shall** meet the requirements of "Grounding (Earthing), Bonding, and Down Conductors" on page 4-38.
- Conductor bonding to the metal shipping container **shall** be exothermically welded if practicable. See "Exothermic Welding" on page 4-71. If exothermic welding is not practicable, other suitable mechanical connections may be used.
- Conductor bonding to the grounding electrode system **shall** be performed using exothermic welding or listed irreversible high-compression fittings. See "Bonding to the External Grounding and Bonding System" on page 4-61.

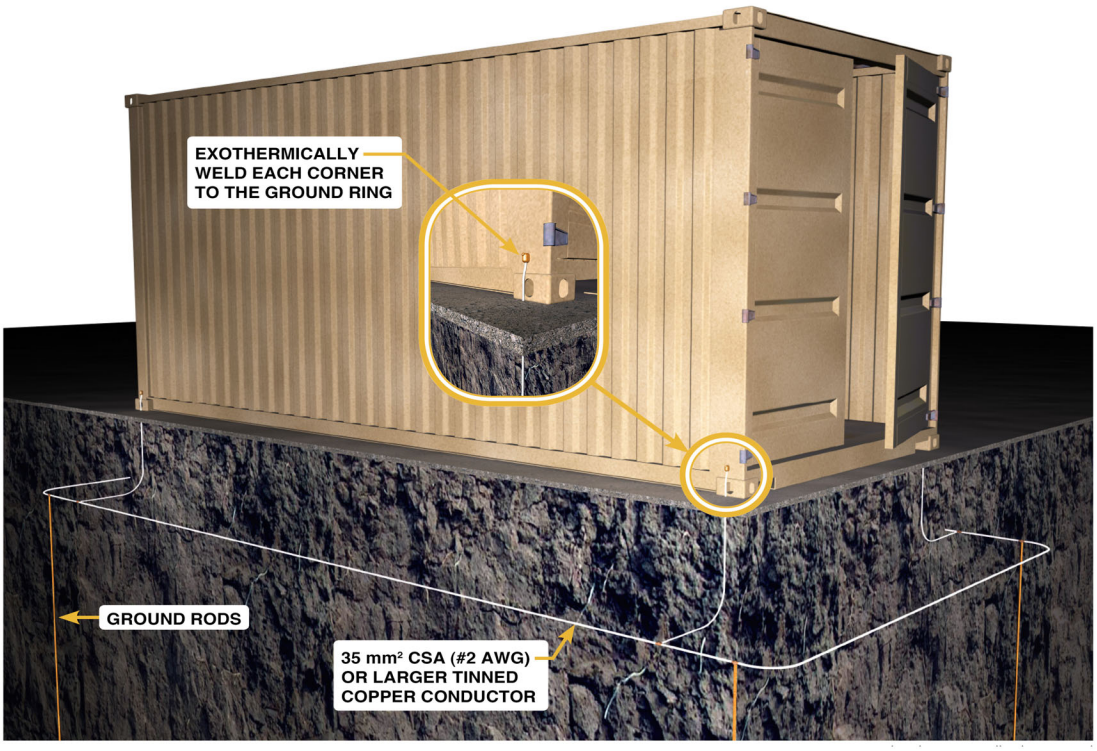


Figure 4-118. Grounding of Metal Shipping Containers

4.17.7 Grounding Electrode Systems Covered by Concrete or Asphalt

When installing a grounding electrode system, every effort should be made to avoid covering the surface above the grounding electrode system with concrete or asphalt. Areas covered with concrete or asphalt will dry out over time, increasing the resistance to earth of the grounding electrode system (see MIL-HDBK-419A and TIA-607-E for additional information). Some alternatives to covering the area with concrete and asphalt are listed below:

- Cover the area with gravel.
- Landscape the area, and choose a water-permeable weed barrier.
- Use electrolytic ground rods where the area must be covered with concrete or asphalt. See “Electrolytic Ground Rods” on page 4-19.

4.17.8 Water Tank and Water Tower Installations

Antennas are commonly mounted on water tanks and water towers for convenience, economic, and RF propagation reasons. Because of the risk of galvanic corrosion on water tank and tower piping systems, grounding at a water tank or tower communications site requires careful planning and should involve an engineering firm or an engineer from the water utility. Any recommendations or requirements in this section **shall** be approved by the water utility before implementation.

IMPORTANT: There are many types of materials used in water tank/tower construction. As a result, there are also many variations in water tank and tower installations. It is recommended to consult with Motorola Solutions Engineering or another engineering firm.

A grounding electrode system is generally not needed at the water tank or tower due to its inherent construction. However, a grounding electrode system is required at the communications building or shelter and **shall** be bonded to the water tank or tower at a location approved by the tank or tower manufacturer. Such locations may include, but are not limited to, one of the following:

- Exothermic weld to the base of the tank/tower.
- Grounding stud attached to the tank/tower using capacitive discharge welding.
- Existing grounding electrode system connections to the tank/tower (other than cathodic protection systems).
- Other locations approved by the tank/tower manufacturer and/or water utility.

A grounding electrode system installed at a water tank or tower, communications site building, or shelter **shall not** cause corrosion of the water tank, tower, or piping system. Corrosion is usually avoided by using grounding electrode system components that are compatible with the water tank, tower, and piping systems. Such components may include, but are not limited to, the following:

- Tinned-copper grounding conductors
- Galvanized steel ground rods
- Stainless steel ground rods
- Stainless steel electrolytic ground rods

IMPORTANT: Any grounding electrode system that directly or indirectly bonds to the water tank or tower **shall** be approved by the water utility.

NOTE: The water utility or corrosion specialist may require additional cathodic protection.

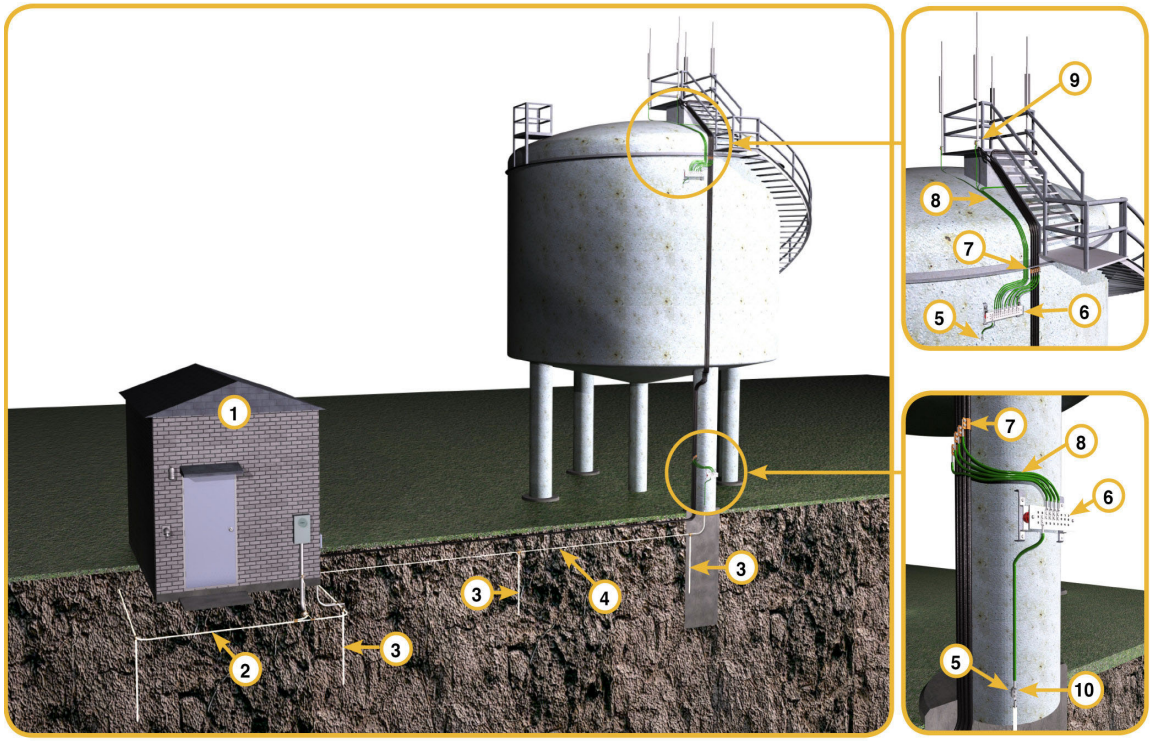
Antenna mounts and mounting structures on water tanks and towers **shall** be grounded. This can be achieved by directly bonding the mount or mounting structure to the water tank or tower at a location approved by the manufacturer. Such locations may include, but are not limited to, one of the following:

- Grounding stud or busbar attached to the tank or tower using capacitive discharge welding (or other techniques approved by the tank manufacturer).
- Exothermic weld to a tank or tower manufacturer-supplied tab.
- Other location approved by the tank or tower manufacturer and/or water utility.

Antenna transmission lines and other communications cables with an outer metallic shield **shall** be bonded to the tank or tower at both the top and the bottom. Bonding at the top of the tank or tower can be made directly to the antenna mounting structure or to the previously described bonding point. Bonding at the bottom of the tank or tower can be made at the same location as the communications building or shelter grounding electrode system's bond to the tank or tower, or using similar techniques.

Figure 4-119 shows a typical water tank/tower installation.

IMPORTANT: Before performing any type of welding on a water tank or tower, appropriate permissions **shall** be obtained from the water utility and/or tank/tower manufacturer.



1	COMMUNICATIONS SHELTER
2	TINNED COPPER GROUND RING
3	STAINLESS STEEL OR GALVANIZED GROUND RODS
4	TINNED COPPER CONDUCTOR BONDING WATER TOWER
5	EXOTHERMIC WELD OR GROUNDING STUD ATTACHED USING CAPACITIVE DISCHARGE WELDING AS APPROVED BY TANK MANUFACTURER.
6	TINNED COPPER BUSBAR
7	COAX CABLE GROUNDING KIT
8	GREEN JACKETED BONDING CONDUCTOR
9	BOND ANTENNA MASTS TO THE GROUNDING BUSBAR
10	BOND BUSBAR AT SAME POINT / STUD AS THE BOND FROM BUILDING GROUND LOOP

Figure 4-119. Typical Water Tank/Tower Installation

4.18 Special Situations

Site conditions, such as limited space and high (poor) soil resistivity, may require special considerations for effective grounding and bonding. Methods for achieving effective grounding and bonding in some specific situations are outlined in the following sections. Consulting with Motorola Solutions Engineering or another engineering firm may be necessary in some cases.

4.18.1 Rooftop Communications Sites

A rooftop communications site is a shelter or building installed on a rooftop or a rooftop penthouse that serves as a communications equipment room. The rooftop communications shelter, building, or penthouse equipment room **shall** contain an internal bonding and grounding system, with all equipment bonded and grounded as described in Chapter 5, "Internal Bonding and Grounding (Earthing)". The internal bonding and grounding system of the rooftop communications site, along with the External Ground Busbar (EGB) where applicable, **shall** be bonded to earth using methods outlined in this section.

Rooftop communications sites are usually grounded and bonded using effectively grounded structural building steel (metal frame/framework). Where effectively grounded structural building steel (metal frame/framework) is unavailable, alternative effective grounding and bonding methods **shall** be employed. See TIA-607-E, section D.2.6, for details.

IMPORTANT: Consultation with Motorola Solutions Engineering or another engineering firm might be necessary for rooftop communication site grounding and bonding. The building owner and/or authority having jurisdiction **shall** approve the communication site grounding and bonding system.

Some options for grounding and bonding a rooftop communications site include the following:

- Bonding to at least two down conductors of an existing lightning protection system using conductors of the same size as the lightning protection system. Ensure a downward sloping path to the earth.
- Bonding to at least two down conductors of an existing rooftop tower grounding system using conductors sized according to Table 4-6. See "Grounding (Earthing) Rooftop-Mounted Tower Structures" on page 4-131 for rooftop tower grounding details.
- Installing at least two down conductors and bonding to the building's common grounding electrode system. When installing down conductors, the following **shall** be observed:
  - The down conductors **shall** be sized according to Table 4-6, or lightning protection system conductors may be used (preferred method). Where used, the lightning protection system conductors **shall** be sized according to building height as shown in Table 4-4 and Table 4-5. The lightning protection system conductors may be made of copper, tinned-copper, or aluminum, as appropriate for the site-specific conditions (see "Down Conductors" on page 4-43).
  - Each down conductor **shall** terminate at a grounding electrode or a grounding electrode system, such as a small ground ring (see Figure 4-120) or multiple parallel ground rods in a straight line, as needed to achieve the grounding electrode system resistance design goal. See "Grounding (Earthing) Electrode System Resistance Requirements" on page 4-81.
  - The grounding electrodes **shall** be bonded to the building's common grounding electrode system. See "Common Grounding" on page 4-7.
- Bond all nearby metallic piping systems, conduits, and other metallic objects within 2 m (6 ft) of any metallic part of the rooftop communications site or down conductors. In areas with high lightning activity, bonding should also include any metallic objects within 3 m (10 ft). See "Metallic Objects Requiring Bonding" on page 4-108. Bonding of the objects can be made to a nearby busbar that is bonded to the down conductor(s) or can be made directly to the down conductor(s).

IMPORTANT: If a supplemental grounding electrode system is installed, it **shall** be bonded to the existing building grounding electrode system. See “Common Grounding” on page 4-7.

IMPORTANT: Where an existing lightning protection system is used for grounding and bonding a rooftop communications site, ensure that the down conductors maintain a downward-sloping path and are effectively connected to earth.

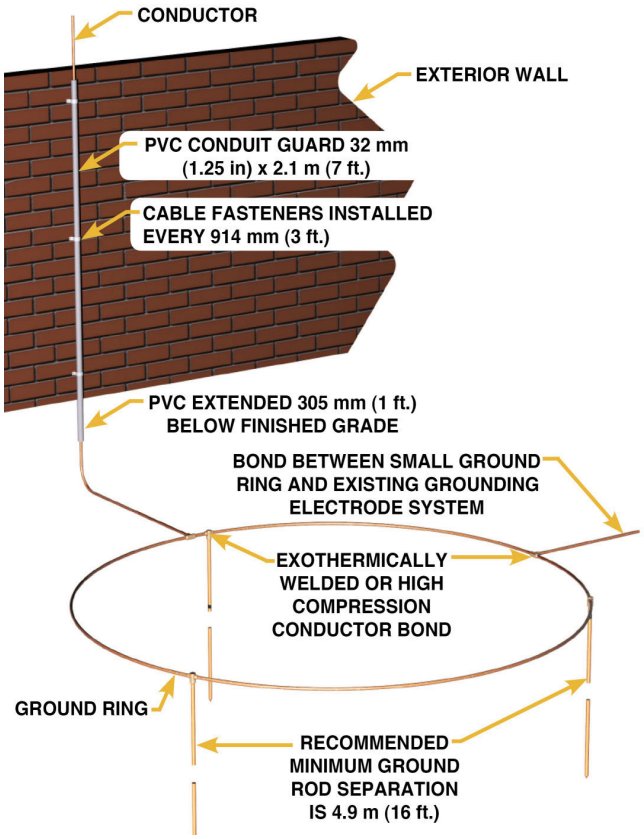


Figure 4-120. Small Ground Ring Installation

NOTE: To ensure maximum efficiency of parallel ground rods in a small ground ring installation, the ground rods **shall** be spaced as far apart as practical, ideally by twice the length of the rod. See Figure 4-7 on page 4-11. This requirement applies only to small ground rings installed under this section. It does not apply to building and tower ground rings, where a ground rod is required every 3 m to 4.5 m (10 ft to 15 ft).

4.18.2 Sites With Limited Space for the Grounding Electrode System

Some sites, such as those in metropolitan areas or near adjacent buildings or property lines, have very limited space available for installing a grounding electrode system. One solution for achieving an effective grounding electrode system that meets the resistance design goal requirements outlined in this chapter may be to install a grounding electrode grid system using all available space on the property.

A grounding electrode grid system consists of grounding electrodes, typically rods, arranged in a grid pattern. The electrodes are evenly spaced and connected underground with a grounding conductor. See MIL-HDBK-419A for additional information. Requirements for a grounding electrode grid system are as follows:

- The grounding electrodes **shall** meet the specifications and installation requirements of “Grounding (Earthing) Electrodes” on page 4-10.
- Grounding conductors used to connect the grounding electrode **shall** meet the specifications and installation requirements of “Grounding (Earthing), Bonding, and Down Conductors” on page 4-38. Where practicable, the grounding conductors **shall** be buried at least 762 mm (30 in.) deep or below the frost line, whichever is deeper.
- Grounding conductors **shall** be bonded together where they intersect, usually at a ground rod or other grounding electrode.
- All component bonding **shall** use exothermic welding or listed irreversible high-compression fittings. See “Bonding to the External Grounding and Bonding System” on page 4-61.

See Figure 4-121 for an example of a grounding electrode grid system for an available area of 9.1 × 9.1 m (30 × 30 ft), with all ground rods separated by 3 m (10 ft).

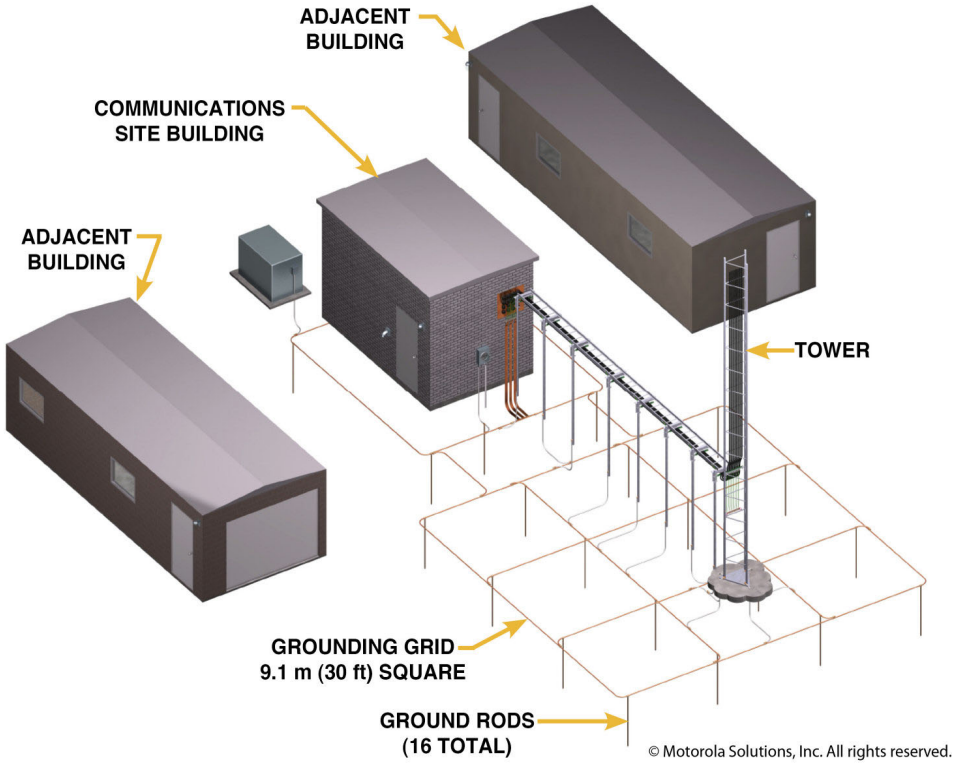


Figure 4-121. Typical Grounding Grid

See “Interpreting Test Results” on page B-12 to determine if the desired resistance to earth can be achieved using different rod lengths and/or spacing. If the resistance to earth cannot be achieved with conventional rods, consider using electrolytic rods instead. Burying the grounding conductors in at least 152 mm (6 in.) of grounding electrode encasement material should also be considered as a way to improve the resistance to earth (see “Grounding (Earthing) Electrode Encasement Materials” on page 4-36).

NOTE: In shallow topsoil conditions, the grounding electrode grid system described earlier may use ground plates instead of ground rods. Wire mesh could be another option (see “Wire Mesh” on page 4-33).

In some metropolitan areas where access to the ground is limited due to exterior coverings such as sidewalks, pavement, or concrete, cutting or coring through those coverings might be necessary to install the grounding electrode system components. Consulting with Motorola Solutions Engineering or another engineering firm may be required for these situations.

4.18.3 Towers with Limited Space for a Ground Ring

Towers installed close to a building may lack enough space for a complete tower ground ring or adequately spaced ground rods to meet the site's resistance requirements. Depending on the available space, the tower can be grounded with multiple parallel rods and/or ground radials. See “Radial Grounding Conductors” on page 4-29 and Figure 4-122.

See “Interpreting Test Results” on page B-12 to determine the number of rods and rod spacing needed to meet the resistance requirements of the site.

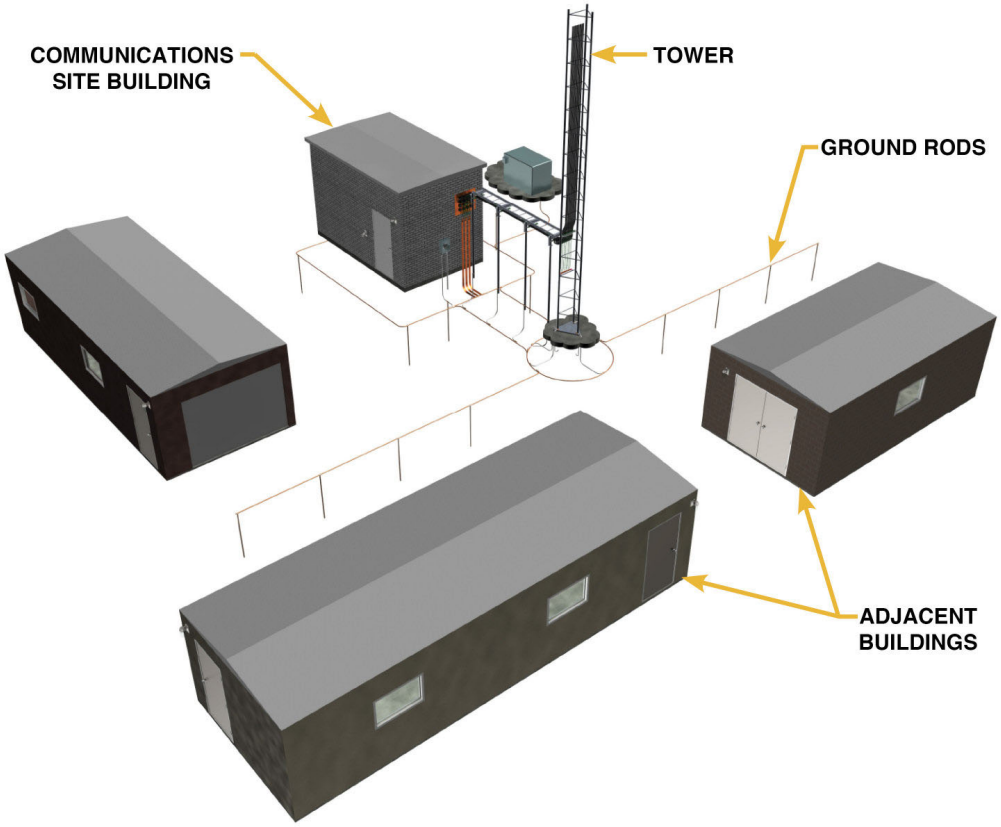


Figure 4-122. Typical Linear Grounding Electrode System

4.18.4 Stone Mountaintops

Some sites are located on mountaintops due to RF propagation characteristics. Special designs are necessary for sites with little or no topsoil. Consultation with Motorola Solutions Engineering or another engineering firm may be required for such sites. Reasonable efforts should be made to use as many options as needed to meet the grounding electrode system resistance requirements and to ensure adequate equal potential bonding at the site. Some options for achieving an effectively grounded and bonded site are as follows:

- Installation of concrete-encased electrodes during new construction. See “Concrete-Encased Electrodes” on page 4-23.
- Installation of wire mesh around the building and tower. The wire mesh and installation **shall** meet the requirements of “Wire Mesh” on page 4-33. See Figure 4-123.
- Installation of ground rings around the building and tower. The ground rings **shall** be secured to the rock surface at intervals no greater than 91 cm (3 ft), using suitable fasteners. Conductive-type concrete can also be used to protect and secure the ground rings. Refer to “External Building and Tower Ground Ring” on page 4-25 and “Grounding (Earthing) Electrode Encasement Materials” on page 4-36. Additional electrodes, such as wire mesh, are recommended in this case. See “Wire Mesh” on page 4-33 and Figure 4-123.

- Installation of radial grounding conductors radiating away from the tower and building. The radial grounding conductors **shall** be secured to the rock surface at intervals not exceeding 91 cm (3 ft), using appropriate fasteners. Conductive-type concrete may also be used to protect and secure the radial grounding conductors (see IEEE 1692-2023, section 8.3). See “Radial Grounding Conductors” on page 4-29.
- Install radial conductors as described earlier, extending down to an area with suitable soil for installing vertical ground rods or other effective grounding electrodes. Size the radial conductors based on their length as shown in Table 4-6, or use a listed Class II lightning protection system conductor (see “Down Conductor Sizing” on page 4-43). If a lightning protection system grounding conductor is used on a mountaintop site, only copper or tinned-copper conductors **shall** be used. See “General Ground Rod Requirements” on page 4-12 and Figure 4-124.
- Installation of radial conductors as previously described, extending down to a lower area with suitable soil for installing vertical ground plates. The radial conductors **shall** be sized based on their length as shown in Table 4-6, or a listed Class II lightning protection system conductor may be used (see “Down Conductor Sizing” on page 4-43). If a lightning protection system grounding conductor is used on a mountaintop site, only copper or tinned-copper conductors **shall** be used. See “Ground Plate Electrodes” on page 4-21 and Figure 4-125.
- Installation of copper strap radials on the surface of the rocks, radiating outward in all directions from the building and tower. The copper straps may be covered with topsoil (native or imported) and/or a grounding electrode encasement material, such as conductive concrete, or securely attached to the rock surface. Each copper strap radial should vary in length (± 5%) to help prevent ringing of the tower during a lightning strike.

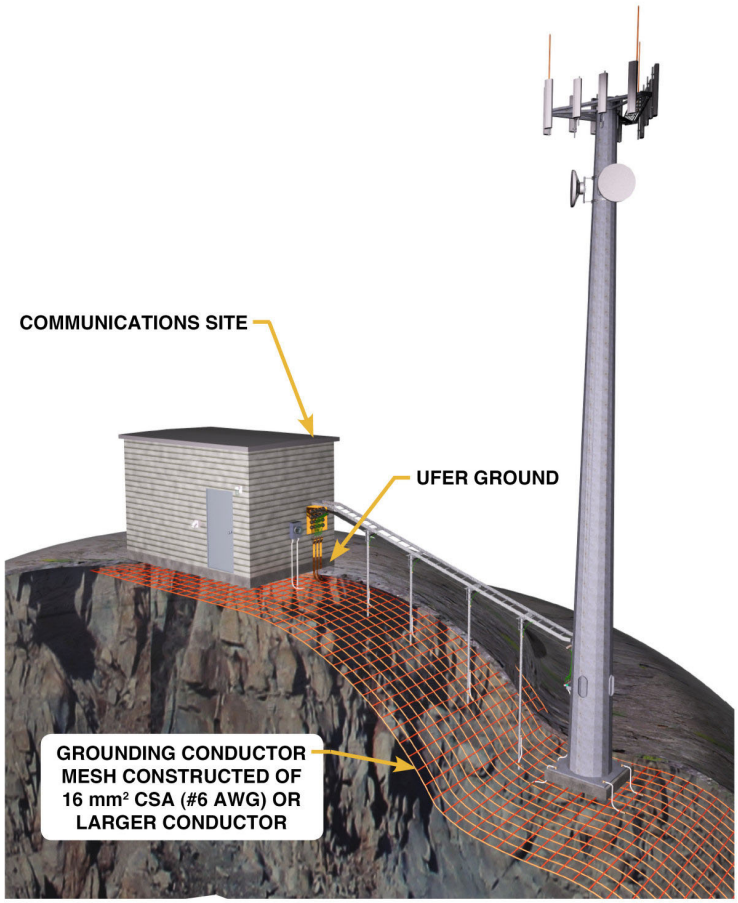


Figure 4-123. Installation of Wire Mesh on Stone Mountaintop Site or Site with Shallow Topsoil

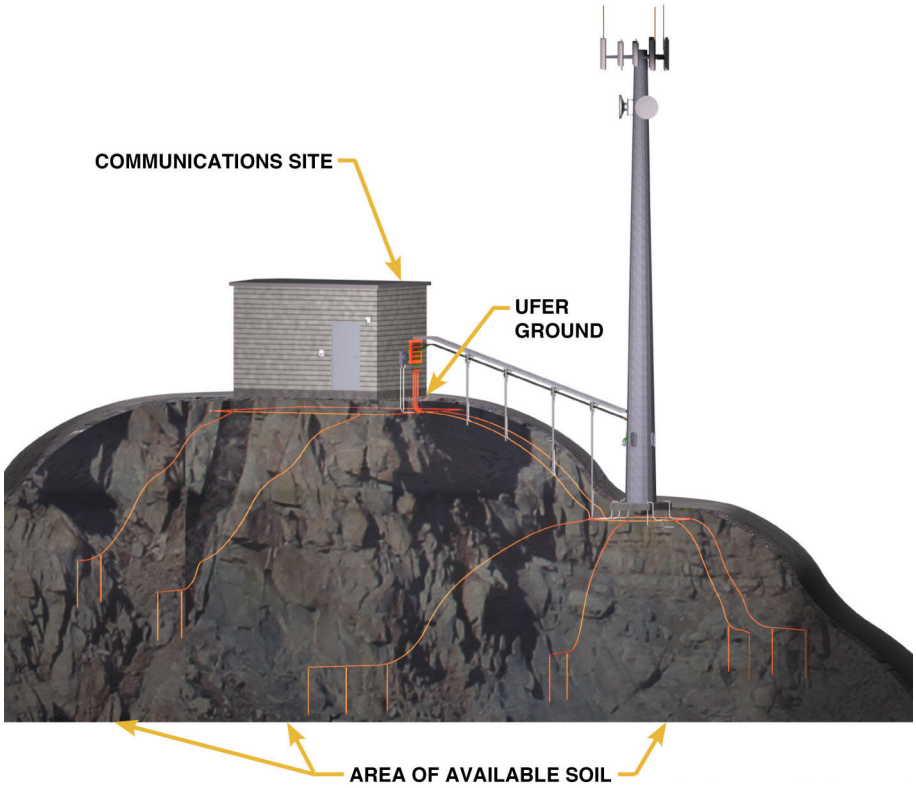


Figure 4-124. Installation of Radials and Ground Rods on Stone Mountaintop Site

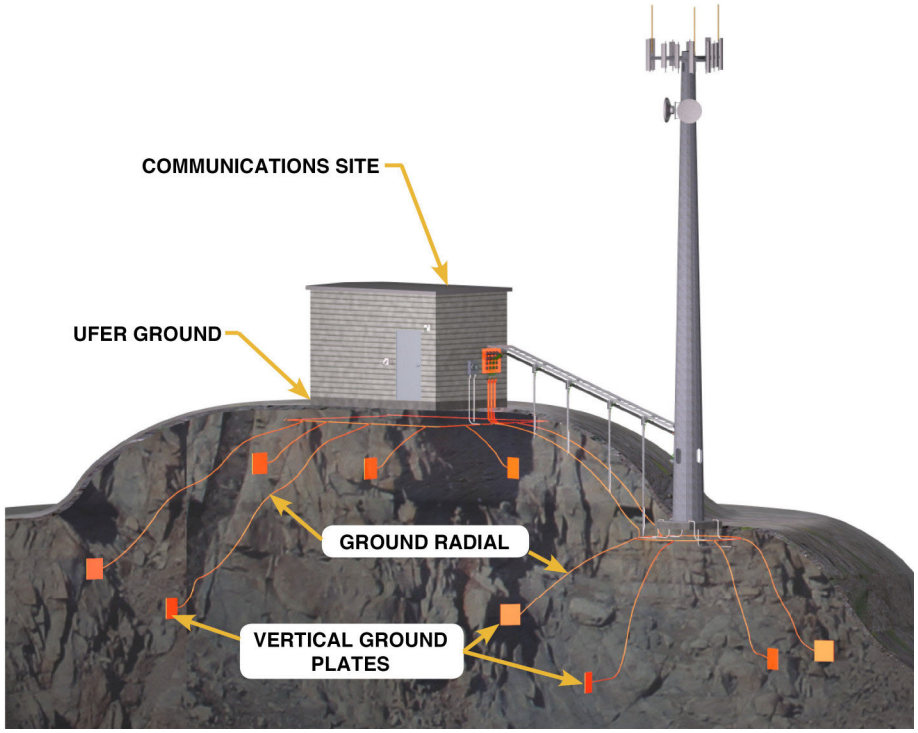


Figure 4-125. Installation of Radials and Ground Plates on Stone Mountaintop Site or Site with Shallow Topsoil

4.18.5 Shallow Topsoil Environments

IMPORTANT: At sites such as stone mountaintops, where establishing an effective grounding electrode system is difficult, the importance of single-point grounding, equal potential bonding of all equipment (both internal and external), and surge protective devices on all input/outputs is paramount.

IMPORTANT: Radial conductors alone should not be relied on as the sole grounding electrode system and equipotential bonding method. Other options listed in this section, such as building and tower ground rings, wire mesh, and concrete-encased electrodes, should also be employed to help establish an effective grounding system.

NOTE: Drilling holes in solid rock to insert a ground rod surrounded by grounding electrode encasement material is generally ineffective and should not be done without additional grounding system components. Solid rock is no more conductive in a borehole than on the surface. Radial grounding conductors encased in a grounding electrode material, such as conductive concrete, would be more effective and economical.

Some sites are located in areas where bedrock is close to the surface or where the topsoil is less than 305 mm (1 ft) deep. These areas require the installation of specialized grounding electrode systems and may need the assistance of Motorola Solutions Engineering or another engineering firm.

Requirements and recommendations for grounding electrode systems in areas with shallow topsoil are provided in this section. Reasonable efforts should be made to use as many options as necessary to meet the grounding electrode system resistance design goals for the site. See NFPA 780-2026, section 4.12.8.1, and related subsections for additional information. Some options to help achieve an effectively grounded and bonded site are:

- Installing concrete-encased electrodes during new construction. See “Concrete-Encased Electrodes” on page 4-23.
- Installing ground rings around the building and tower, burying them as deep as the soil allows. The ground rings should be covered in a grounding electrode encasement material. Conductive concrete may be the best choice for this purpose in shallow topsoil environments because it does not require a topsoil covering for protection. See “External Building and Tower Ground Ring” on page 4-25.
- Installation of a grounding electrode grid system, using ground plates instead of vertical ground rods. The grounding conductors and ground plates **shall** be buried as deep as the soil allows. The grounding conductors should be encased in a grounding electrode encasement material. Conductive concrete may be the best material for grounding electrode encasement in shallow topsoil environments, as it does not require a covering of topsoil for protection. See “Sites With Limited Space for the Grounding Electrode System” on page 4-150 and Figure 4-121 for additional information on grounding electrode grid systems. See “Ground Plate Electrodes” on page 4-21 for additional ground plate installation requirements.
- Installation of wire mesh throughout the site, in addition to the building and tower grounding rings. See “Wire Mesh” on page 4-33. See Figure 4-123 for an example of wire mesh installation.
- In addition to the building and tower ground rings, the installation of horizontal ground rods radiating away from the building and tower. See Figure 4-126.

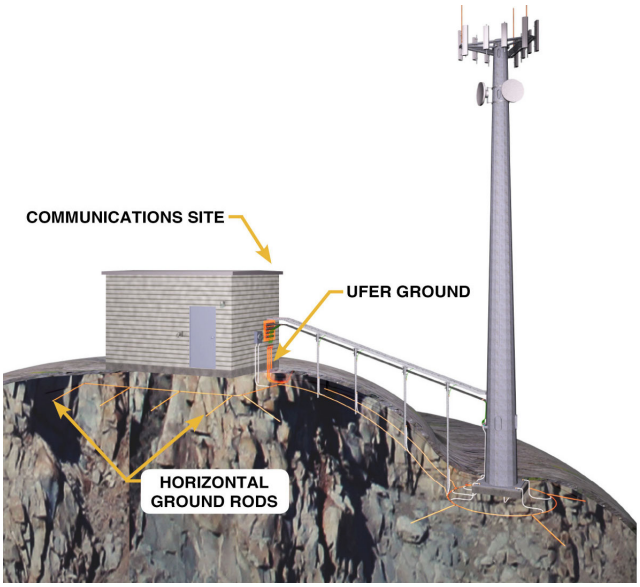


Figure 4-126. Installation of Horizontal Ground Rods in Shallow Topsoil Conditions

- Installing ground plates along the length of the ground rings instead of vertical ground rods. The ground plates should be encased in a grounding electrode encasement material. See “Ground Plate Electrodes” on page 4-21, “Grounding (Earthing) Electrode Encasement Materials” on page 4-36 and Figure 4-127.

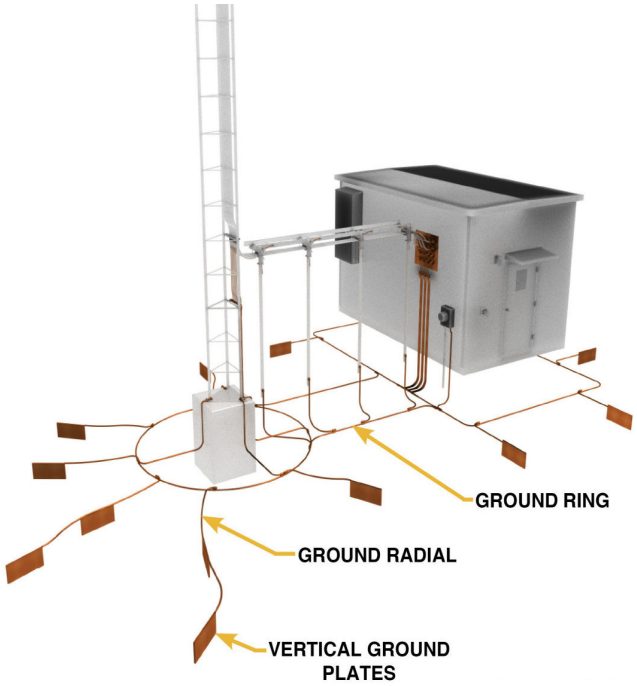


Figure 4-127. Installation of Ground Plates in Shallow Topsoil Conditions

- Installation of electrolytic ground rod systems. See “Electrolytic Ground Rods” on page 4-19.
- Installing building and tower radial grounding conductors in a trench extending away from the building and tower. The radial grounding conductors **shall** be buried as deep as the soil allows. The radial grounding conductors **shall** be bonded to the ground rings using exothermic welding or listed irreversible high-compression fittings.

- The radial grounding conductors should be encased in a grounding electrode encasement material. Conductive concrete may be the best choice for grounding electrode encasement in shallow topsoil environments because it does not need a covering of topsoil for protection (see IEEE 1692-2023, section 8.3). Each radial grounding conductor can have ground plates installed at intervals of 1.8 to 4.9 m (6 to 16 ft) along its length. See Figure 4-128.

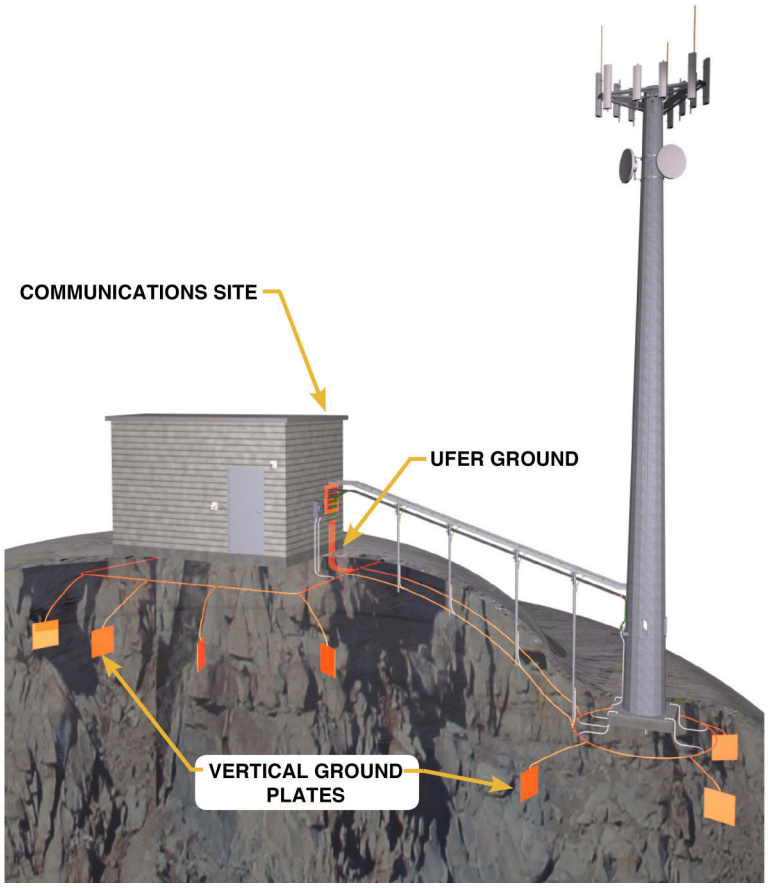


Figure 4-128. Installation of Radials and Ground Plates in Shallow Topsoil Conditions

4.18.6 Sand, Coral or Limestone Environments

Sites with very high soil resistivity, such as those composed of sand, coral and limestone, may require specialized techniques to achieve an effectively grounded and bonded site. Consultation with Motorola Solutions Engineering or another engineering firm may be necessary for these types of sites. Some options to help achieve an effectively grounded and bonded site are as follows:

- Installation of concrete-encased electrodes during new construction. See “Concrete-Encased Electrodes” on page 4-23.
- In addition to building and tower ground rings, installing radial grounding conductors with vertical ground rods throughout the available property. See “Radial Grounding Conductors” on page 4-29 and “General Ground Rod Requirements” on page 4-12.
- Encasing all components in a grounding electrode encasement material can further improve the effectiveness of the grounding electrode system. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-36.
- Installing electrolytic ground rod systems instead of traditional ground rods. See “Electrolytic Ground Rods” on page 4-19.

- In addition to the building and tower ground rings, installing a grounding electrode grid system throughout the site. See “Sites With Limited Space for the Grounding Electrode System” on page 4-150.
- In addition to the building and tower grounding rings, installing wire mesh throughout the site. See “Wire Mesh” on page 4-33.
- Using multiple large copper plates (0.93 to 1.8 m^2 (10 to 20 ft^2) buried at an optimal depth of 1.5 m to 2.4 m (5 to 8 ft). The plates are positioned vertically on edge and bonded to the grounding electrode system using exothermically welded 35 mm^2 csa (#2 AWG) solid copper conductors. Placing the plates on their vertical edges minimizes excavation and can enhance soil contact area when backfilling. It is preferable to use several well-placed ground plates in parallel rather than longer rows of ground plates (IEEE 142-2007, section 4.2.4). Encasing the ground plates in a grounding electrode encasement material can further improve the effectiveness of the grounding electrode system.

4.18.7 Arctic Environments

Achieving an effective low-resistance grounding electrode system in arctic regions or similar cold climates can be challenging. In such cases, consulting with Motorola Solutions Engineering or another engineering firm is advised. The main challenge in these environments is establishing good contact with frozen, high-resistivity soils. To optimize grounding in areas with frozen soils, careful attention to both surface and subsurface terrain is essential. The resistivity of frozen soils can be 10 to 100 times higher than when unfrozen, meaning seasonal changes in temperature and moisture significantly impact the grounding electrode system's resistance to earth. Refer to Appendix B for more information on soil resistivity changes related to temperature and moisture. Additionally, see MIL-HDBK-419-A Volume I, section 2.11.1, for further details.

Seasonal freezing causes an increase in grounding electrode system resistance. Because frozen soil has high resistivity, using larger electrodes decreases the resistance to earth. In Arctic regions with very shallow surface thaw layers, horizontal rods or conductors offer an equivalent resistance to earth and may be easier to install than driven rods. Soil conditions at the site and the cost of installation determine whether to use multiple electrodes, a single deep-driven rod, or horizontal conductors. See MIL-HDBK-419-A Volume I, section 2.11.1, for more information.

One option for an effective grounding electrode system is to install electrolytic ground rods encased in a grounding electrode encasement material. See “Electrolytic Ground Rods” on page 4-19 and “Grounding (Earthing) Electrode Encasement Materials” on page 4-36. Refer to MIL-HDBK-419-A Volume I, section 2.11.2, for additional information.

CHAPTER 5

Internal Bonding and Grounding (Earthing)

This chapter provides requirements for bonding and grounding (earthing) communications site equipment within a facility. The following topics are included:

- “Introduction to Internal Bonding and Grounding (Earthing)” on page 5-1
- “General Application” on page 5-3
- “Common Grounding (Earthing)” on page 5-6
- “Single-Point Grounding (Earthing) and the Single-Point Entry Window” on page 5-7
- “Electrical Service Grounding and Entrance Point” on page 5-8
- “Internal Bonding System Components and Installation Requirements” on page 5-9
- “Bonding and Grounding Infrastructure Subsystems” on page 5-51
- “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69
- “Bonding Equipment to Internal Bonding and Grounding (Earthing) System” on page 5-84
- “Bonding and Grounding (Earthing) for Specific Site Types” on page 5-129
- “Testing the Internal Bonding and Grounding (Earthing) System” on page 5-144

NOTE: Throughout this chapter, the terms “grounding” and “earthing” are used interchangeably.

5.1 Introduction to Internal Bonding and Grounding (Earthing)

Effective bonding and grounding of communications equipment are essential for both personnel safety and system reliability and availability. As circuit density increases and lower-voltage integrated circuit devices become more prevalent, communications equipment becomes increasingly vulnerable to damage from lightning, power line disturbances, and electrostatic discharge. Inadequate bonding and grounding can create a potential difference between system components, leading to injuries to personnel, system failures, or equipment damage.

The requirements and guidelines in this chapter are based on a compilation of national codes, accepted industry standards, and good engineering practices. These codes and standards include those from the following organizations:

- Alliance for Telecommunications Industry Solutions (ATIS)
- American National Standards Institute (ANSI)
- Building Industry Consulting Service International (BICSI®)
- Canadian Standards Association (CSA)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Electrotechnical Commission (IEC)
- International Organization for Standardization (ISO)
- International Telecommunication Union (ITU)
- National Fire Protection Association (NFPA)
- Telcordia
- Telecommunications Industry Association (TIA)

- Underwriters Laboratories (UL)
- United States Department of Defense (DoD)
- United States Federal Aviation Administration (FAA)
- United States National Weather Service (NWS)

References to the specific industry codes and standards on which this chapter is based are included throughout. The requirements and guidelines in this chapter aim to improve personnel safety and equipment reliability.

The safety of personnel and the protection of sensitive electronic equipment from ground faults, lightning, ground potential rise, electrical surges, power quality issues, and electrostatic discharge are critically important at any communications site. Although unexpected electrical events, such as lightning strikes and power surges, cannot be entirely prevented, this chapter provides design and installation guidance on internal bonding systems for communications sites to help reduce damage from such events.

CAUTION: Grounding and bonding alone are insufficient to adequately protect a communications site. Surge Protective Devices (SPD) must be included at a communications site to ensure sufficient protection. See Chapter 7, "Surge Protective Devices," for details and requirements.

WARNING: The AC power system ground SHALL be sized adequately for the electrical service and SHALL be approved by the authority having jurisdiction (AHJ).

An internal bonding and grounding system **shall** feature low electrical impedance and conductors adequately sized to withstand high fault currents. Lowering the impedance of the internal bonding and grounding network ensures robust potential equalization across all equipment enclosures, mitigates the effects of electromagnetic interference (EMI) and electrical noise on signal circuits, and prevents electrostatic discharge (ESD) accumulation by providing a continuous, low-impedance path to the facility's grounding infrastructure.

All site development and equipment installation work **shall** comply with all applicable codes enforced by the AHJ. Grounding systems **shall** be installed neatly and professionally (ATIS-0600313.2019(R2024), section 11.1; IEC 60364-1:2005, section 131; NFPA 70-2026, Article 110.12; NECA 1-2023; and NFPA 780-2026, section 1.5.1). In the event of a conflict, the more stringent standard **shall** be followed. Government and local codes **shall** take precedence over the requirements of this manual.

IMPORTANT: Local codes and other codes enforced by the authority having jurisdiction (AHJ) **shall** take precedence over the requirements of this manual. The stricter requirement **shall** be followed.

Unusual site conditions might require extra effort to ensure effective bonding and grounding. In such cases, it is recommended to consult with Motorola Solutions Engineering or another engineering firm.

This section outlines the benefits of a correctly designed and installed low-impedance grounding and bonding system. See ATIS-0600333.2013(S2023), section 4; IEEE 1100-2005, section 3.3.1; and NFPA 70-2026, Article 250.4 for further details. Benefits include the following:

- Helps dissipate the overvoltages caused by lightning.
- Limits potential differences between conductive surfaces caused by electrical disturbances such as electrical power faults, lightning strikes, and electrostatic discharges.
- Provides fault current paths with sufficient current-carrying capacity and low impedance, allowing overcurrent protection devices to clear the circuit quickly.
- Limits the voltage resulting from accidental contact between the site's AC supply conductors and conductors of higher voltage.
- Enhances the immunity of the communications equipment installation to noise, electromagnetic interference, and electrostatic discharges.
- Reduces noise and electromagnetic interferences produced by communications equipment.
- Contributes to reliable equipment operation.

- Provides a common signal reference ground.

NOTE: Grounding communication equipment through the Alternating Current (AC) power cord does not align with the intent of this installation standard or other related industry standards. While the AC power cord usually includes an Equipment Grounding Conductor (EGC), the integrity of the electrical distribution system's EGC ground path to the electrical service (power) ground cannot be easily verified (see TIA-607-E and IEEE 1100-2005 for more information).

5.2 General Application

The basic design, principles and components of an internal bonding and grounding system outlined in this chapter apply to buildings of various designs, structures, and sizes. These buildings may include, but are not limited to, the following:

- Outdoor equipment cabinet
- Dedicated communications building or shelter (see Figure 5-1)
- Single-story, smaller building (see Figure 5-2)
- Single-story large building (see Figure 5-3)
- Multi-story large building and high-rise building (see Figure 5-4)

NOTE: Each Secondary Bonding Busbar (SBB) shown in Figure 5-3 and Figure 5-4 effectively serves as a Primary Bonding Busbar (PBB) for the room in which it is installed.

Within a building or structure, the bonding and grounding system infrastructure originates at the electrical service ground and extends throughout the building as required. The internal bonding and grounding system for an RF site generally includes, but is not limited to, the following main components (see Figure 5-1 for an example):

- Primary Bonding Busbar (PBB) formerly known as Master Ground Busbar (MGB)
- Secondary Bonding Busbar (SBB)
- Rack Bonding Busbar (RBB)
- Network-Equipment Bonding Busbar (NBB)
- Internal Perimeter Bonding Bus Conductor (IPBB)
- Halo Ground Ring

These telecommunications bonding and grounding components are designed to work in conjunction with a building's telecommunications pathways, spaces, installed cabling, and administration systems.
See BICSI N3-20, CSA ISO/IEC 30129:20, and TIA-607-E for more information.

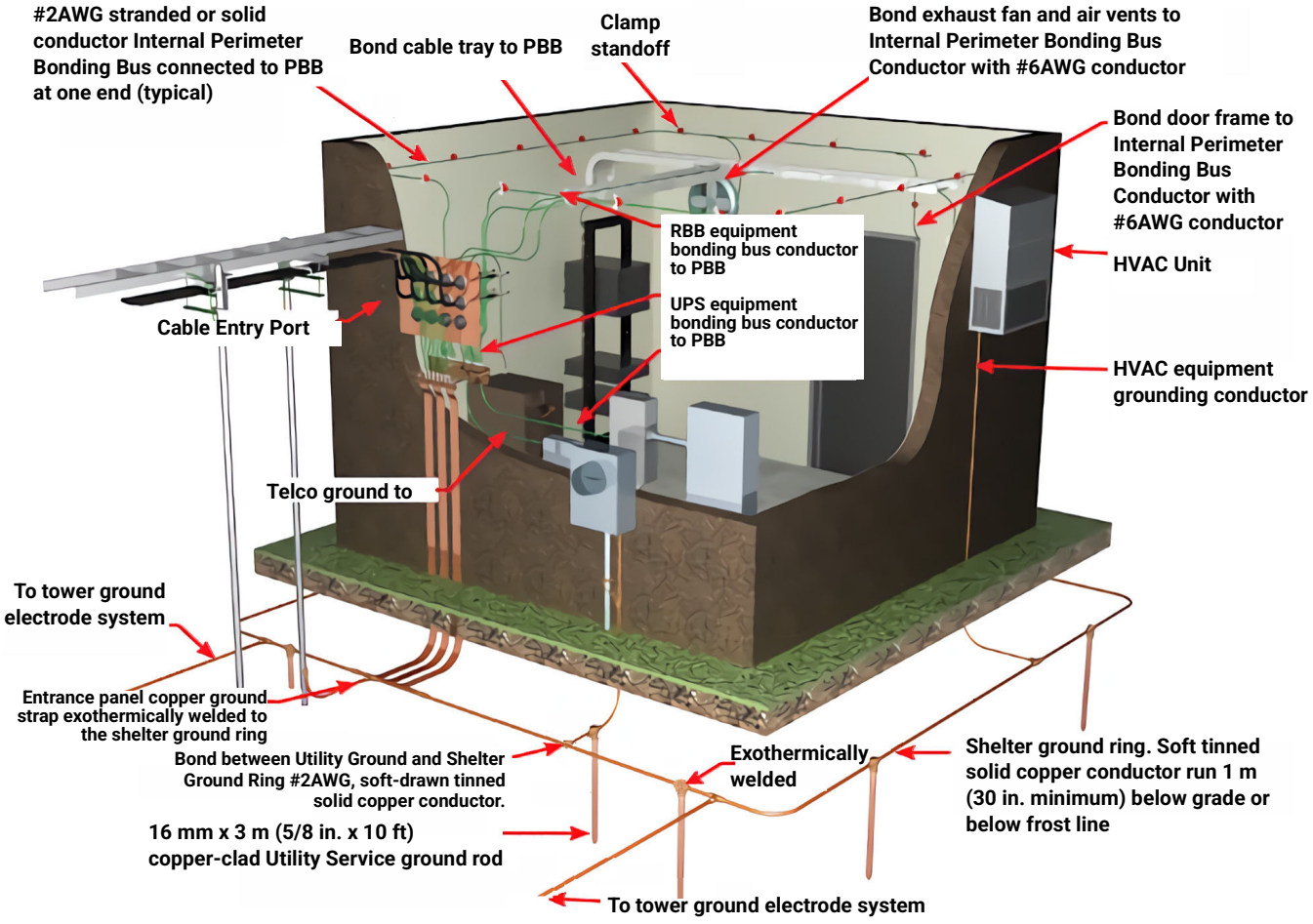


Figure 5-1. Example of Internal Bonding and Grounding System for Typical Dedicated Communications Shelter

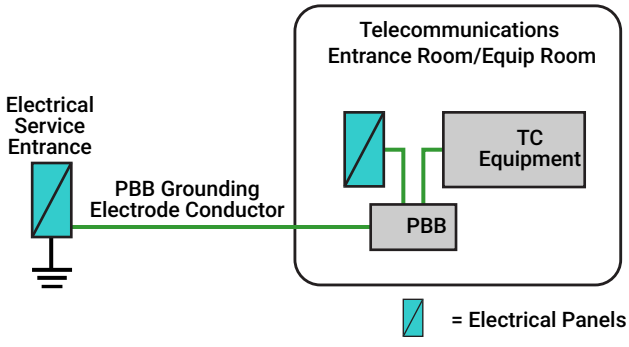


Figure 5-2. Example of Internal Bonding and Grounding System for a Single-Story Smaller Commercial Building

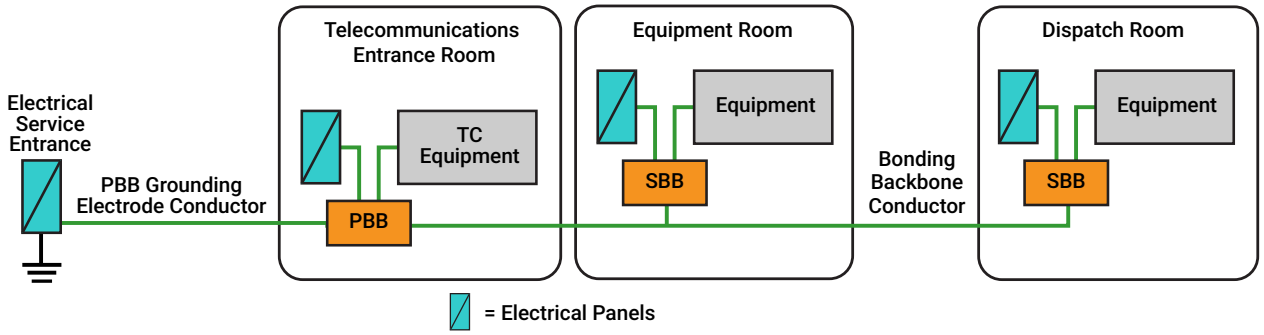


Figure 5-3. Example of Internal Bonding and Grounding System for Single-Story Large Commercial Building

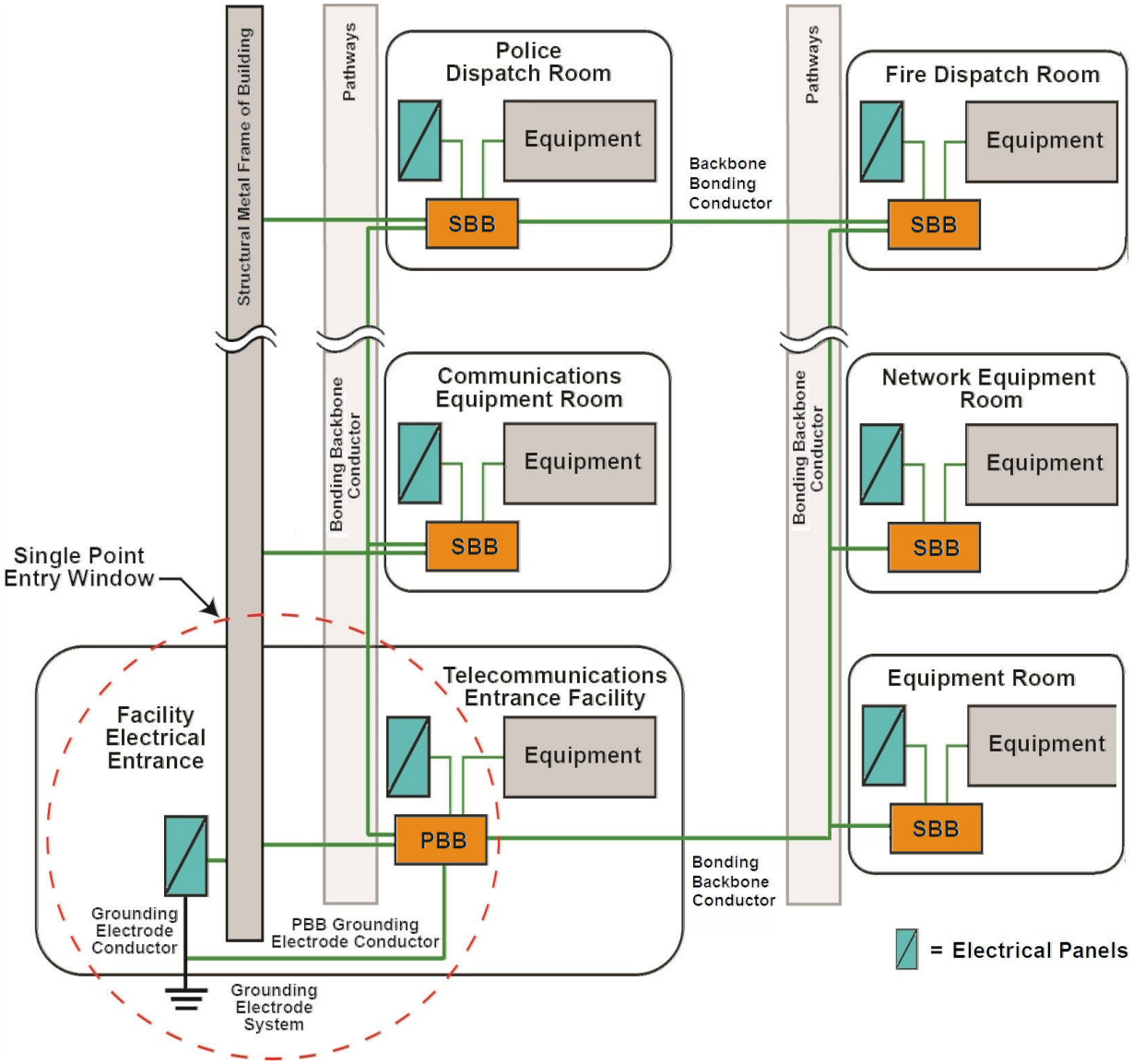


Figure 5-4. Example of Internal Bonding and Grounding System for Multi-Story Large Commercial Building

5.3 Common Grounding (Earthing)

At a communications site, all grounding electrodes **shall** be bonded together to form a single grounding electrode system (see Figure 5-5). All grounding electrodes used for the power system, communications systems, and lightning protection system **shall** be effectively and permanently bonded together (IEEE 1100-2005, section 8.5). The AC power system ground, communications tower ground, lightning protection system ground, telephone system ground, exposed structural building metal, underground metallic piping entering the facility, and any other existing grounding systems **shall** be bonded to form a single grounding electrode system (ATIS-0600313.2019(R2024), section 7; ATIS-0600333.2013(S2023), section 5.1; ATIS-0600334.2019(R2024), section 5.3; IEC 62305-3:2024, section 6.2; ITU Earthing and Bonding Handbook, section 3.1; IEEE 1100-2005; NFPA 70-2026, Articles 250.58, 250.104, 250.106, and 750; NFPA 780-2026, section 4.13.6.1; and Telcordia GR-3171-CORE.i02).

Underground metallic piping systems typically include water service, well castings located within 7.6 m (25 ft) of the structure, gas piping, underground conduits, and underground liquefied petroleum gas piping systems. Connection to a gas line **shall** be made on the customer's side of the meter (IEC 60364-5-54:2011, section 542.2.6 and Annex B; and NFPA 780-2026, section 4.14.6). Refer to Chapter 6, “Power Sources” for additional information on grounding the electrical utility service to the facility grounding electrode system.

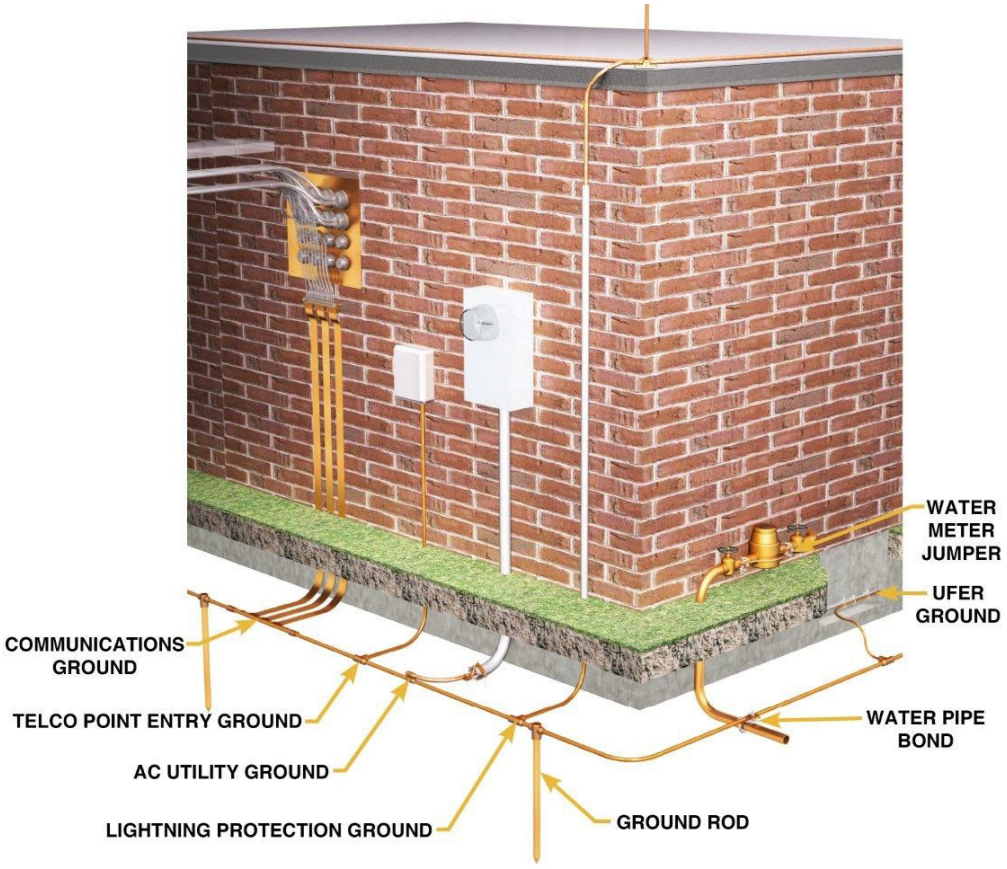


Figure 5-5. Example of Common Grounding

The goal of bonding and grounding system components to a single point is to reduce any potential difference that may develop between individual components within the system and within the equipment site or area. To achieve this, a low-impedance internal single-point bonding system is required for all communications equipment, support equipment, power systems, and other items or materials located within the same facility.

5.4 Single-Point Grounding (Earthing) and the Single-Point Entry Window

IMPORTANT: To achieve true single-point grounding, all utilities and communications cables must enter the facility through the same general area.

Single-point grounding involves bonding all equipment in a communications building or shelter—such as communications equipment, support apparatus, antenna cables, surge protective devices, and other components—to a common point, typically the Primary Bonding Busbar. This common point is then bonded to the grounding electrode system at a single location. The single point or location doesn't necessarily imply just one grounding electrode conductor; multiple conductors may be used for grounding various system components or utilities, such as the Primary Bonding Busbar, AC power, telephone, and others.

The main requirement for single-point grounding is that all grounding electrode conductors enter and exit the building at approximately the same location, creating a single-point entry window. Where feasible, the area of this entry point should fit within a sphere with a diameter of 2 m (6 ft) (see ATIS-0600333.2013(S2023), section 3.1.23). Refer to Figure 5-6 for an example of the single-point entry window.

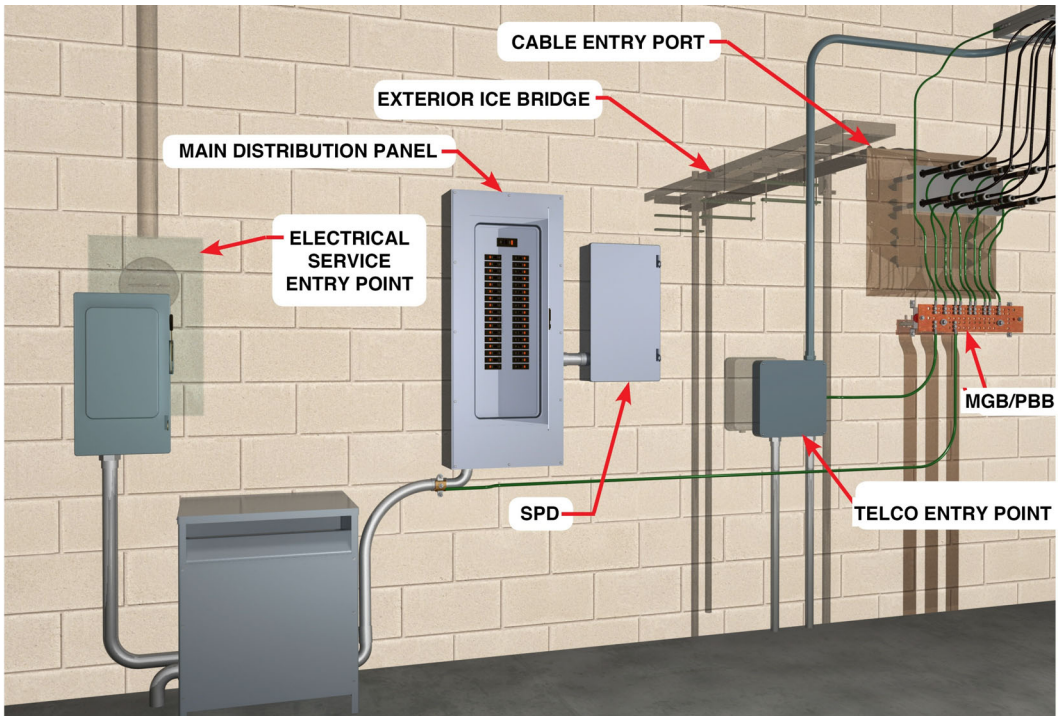


Figure 5-6. Single-Point Entry Window Example

The theory behind single-point grounding is that the electrical potential of all equipment in the building or shelter will rise and fall together during a lightning strike (either direct or nearby) or during other electrical faults or disturbances. Single-point grounding also helps reduce the current flow in the building or shelter during a lightning event or fault condition.

Single-point grounding is easily established at a dedicated communications shelter or small commercial building, such as a small dispatch center, but may not always be feasible in larger or multi-story buildings. If single-point grounding is not practical for the entire building, the same principle is applied to each equipment room or area (see “Bonding and Grounding for Large and Multi-Story Commercial Building Installations” on page 5-133).

If practicable, a single-point grounding system **shall** be established at all communications buildings and shelters. In large, multi-story buildings where it is not feasible to establish a single-point grounding system for the entire structure, a single-point grounding system **shall** be installed in each communications equipment room or area.

5.5 Electrical Service Grounding and Entrance Point

The electrical service entrance is a crucial component of the single-point grounding system and should be located at the single-point entry window. For optimal grounding and AC surge protection, the neutral-ground bond should be located within the single-point entry window. See Chapter 6, “Power Sources”, for more information.

WARNING: The AC power system ground SHALL be adequately sized for the electrical service and SHALL be approved by the authority having jurisdiction (AHJ).

IMPORTANT: All bonding and grounding systems at a site **shall** be bonded to the electrical service ground.

The grounding electrode conductor for the electrical service **shall** be installed in the main disconnect and bonded to the common grounding electrode system, as described in Chapter 4, “External Grounding (Earthing) and Bonding” and Chapter 6, “Power Sources”. The main disconnect grounding electrode conductor **shall** comply with all installation requirements of applicable electrical codes (NFPA 70-2026, Article 250.64). Figure 5-7 and Figure 5-8 provide examples of the grounding electrode conductor routing and bonding to the common grounding system.

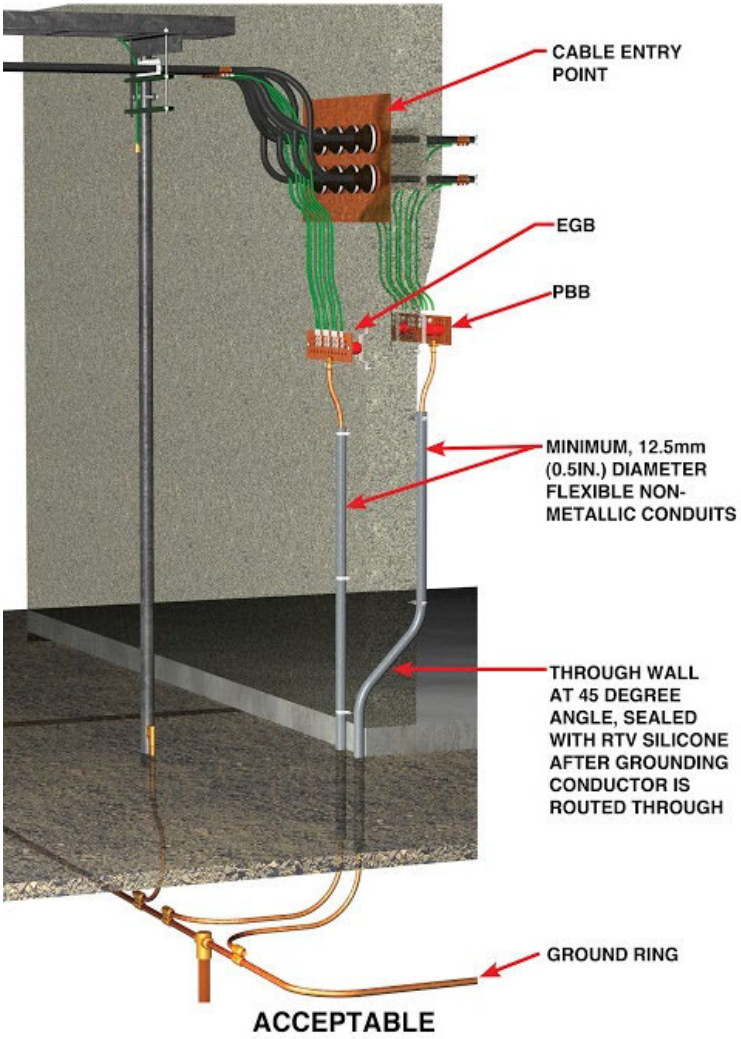


Figure 5-7. Routing and Protecting of PBB Grounding Electrode Conductor

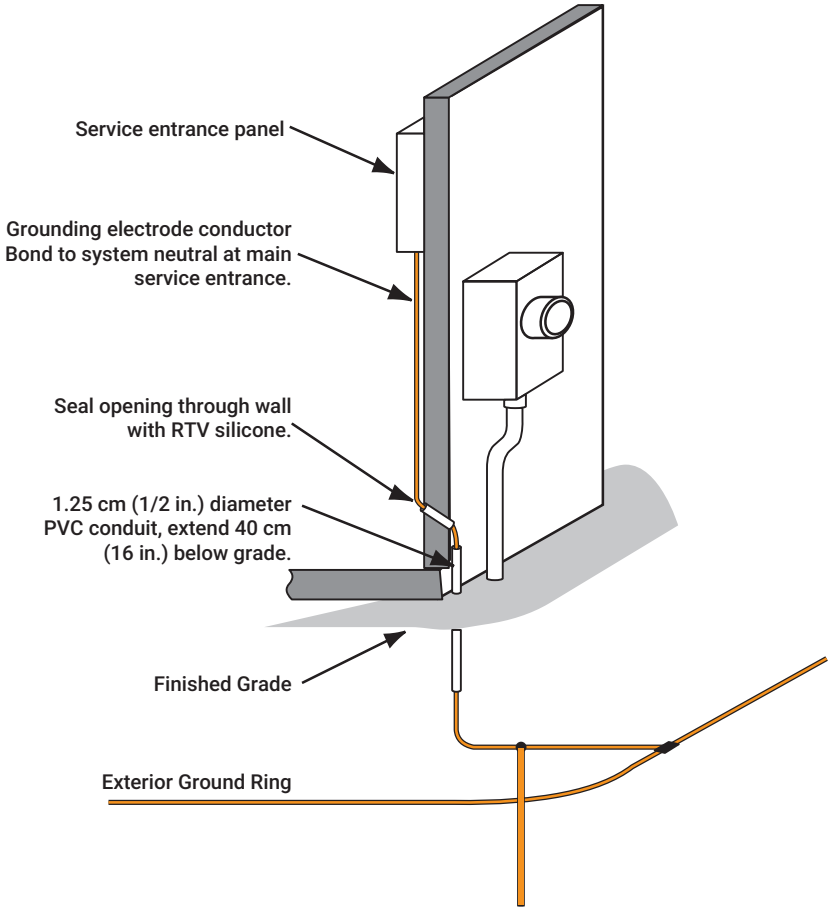


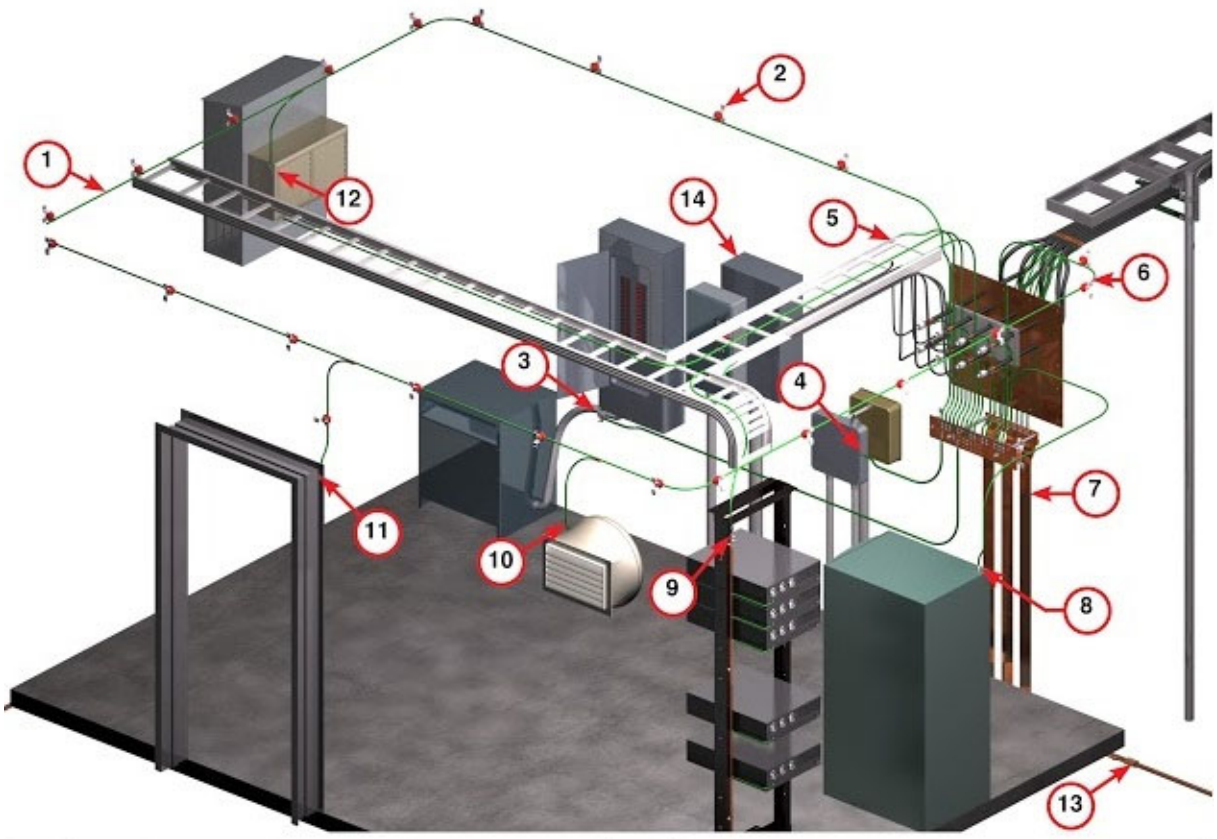
Figure 5-8. Routing of Electrical Grounding Electrode Conductor

5.6 Internal Bonding System Components and Installation Requirements

A low-impedance internal bonding and grounding system can be effectively established using the components listed in this section, all of which must be bonded together to ensure minimal potential difference among them.

Figure 5-9 illustrates the main components of a typical internal single-point bonding and grounding system, which are explained in the following subsections:

- “Primary Bonding Busbar” on page 5-10
- “Integrated Cable Entry Grounding Systems and Cable Entry Panels” on page 5-15
- “Secondary Bonding Busbar” on page 5-17
- “Rack Bonding Busbar” on page 5-28
- “Network-Equipment Bonding Busbar” on page 5-33
- “Bonding and Grounding (Earthing) Conductors” on page 5-41



1	#2 AWG INTERNAL PERIMETER BONDING BUS CONNECTED TO THE PBB AT ONE END	8	UPS EQUIPMENT GROUND CONDUCTOR TO THE PBB
2	STANDOFF CLAMP WITH INSULATOR	9	EQUIPMENT BONDING BUS TO THE PBB
3	BOND AC ELECTRICAL SERVICE TO THE PBB	10	BOND EXHAUST FANS AND AIR VENTS TO THE INTERNAL PERIMETER BONDING BUS
4	BOND TELCO GROUND TO THE PBB	11	BOND DOOR FRAME TO THE INTERNAL PERIMETER BONDING BUS
5	BOND CABLE TRAY TO THE PBB	12	BOND HVAC TO THE IPBB
6	BOND IPBB TO THE PBB	13	SHELTER GROUND RING
7	ENTRANCE PANEL GROUND STRAPS EXOTHERMICALLY WELDED TO THE SHELTER	14	AC ELECTRICAL METER BOX

Figure 5-9. Typical Internal Bonding and Grounding System in a Standalone Shelter

5.6.1 Primary Bonding Busbar

The Primary Bonding Busbar (PBB), formerly known as the Master Ground Busbar (MGB), functions as the primary ground (earth) reference point within the facility. The PBB connects the interior bonding system to the exterior grounding electrode system. It provides a convenient internal bonding termination point and connection to the grounding electrode system. In other standards, the PBB may also be called a Building Principal Ground (BPG) or a Telecommunications Main Grounding Busbar (TMGB). See ATIS-0600313.2019(R2024); ATIS-0600333.2013(S2023); ATIS-0600334.2019(R2024), section 7.3; BICSI-N3-20, ISO/IEC 30129:2015; and TIA-607-E for more information.

NOTE: Throughout this chapter, the terms Master Ground Busbar (MGB) and Primary Bonding Busbar (PBB) are used interchangeably. To better align with national and international standards, Primary Bonding Busbar (PBB) is the preferred naming convention in this publication.

The PBB functions as the primary internal earth reference point and central attachment point for all equipment bonding conductors, bus conductors, bonding backbone conductors, and communications/electronic equipment within the facility (see TIA-607-E). The PBB also serves as the central attachment point for Secondary Bonding Busbars (see TIA-607-E). Typically, there should be only one PBB per building (ATIS-0600334.2019(R2024) and TIA-607-E).

- A typical PBB installation in a small commercial building is shown in Figure 5-6.
- A typical stand-alone equipment shelter internal bonding and grounding system is shown in Figure 5-9.
- A typical PBB with insulated mounting hardware is shown in Figure 5-10.

The PBB **shall** be installed as close as practicable to the single-point entry window of the facility (see “Single-Point Grounding (Earthing) and the Single-Point Entry Window” on page 5-7). The PBB **shall** be bonded to the common grounding electrode system of the site as described in this chapter. A single PBB **shall** be installed for the communications system within a shelter, building, room, or equipment area as specified in this chapter. In facilities where RF transmission lines, electrical service, and telecommunication cables enter at different locations, the PBB **shall** be positioned as described in this chapter. In all cases, transmission lines, telecommunication cables, and electrical service **shall** be effectively bonded to the PBB, and the PBB **shall** be effectively bonded to the grounding electrode system as detailed in this chapter.

NOTE: Large buildings or campuses with multiple power feeds may require special design considerations that are beyond the scope of this document. Consulting Motorola Solutions Engineering or another engineering firm is advised in these instances.

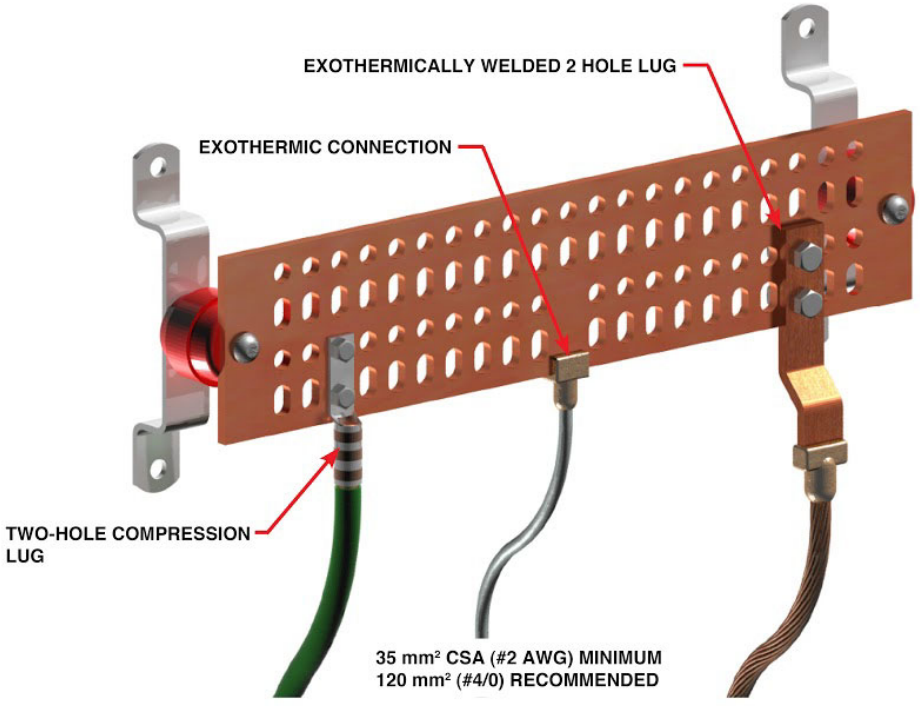


Figure 5-10. Typical Primary Bonding Busbar with Acceptable Connection Methods

5.6.1.1 Primary Bonding Busbar Specifications

Specifications for the PBB are as follows:

- The PBB **shall** be constructed and minimally sized according to Table 5-1.
- The PBB **shall** be designed for grounding and **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL) (see TIA-607-E, section 6.2.1).
- The PBB **shall** be sized based on the current application, and future site growth should also be considered (TIA-607-E, section D.2.2).

Table 5-1. Primary Bonding Busbar Specifications

Item	Specification
Listing Requirement (TIA-607-E)	**Shall** be listed by a Nationally Recognized Testing Laboratory (NRTL)
Material (ISO/IEC 30129:2015)	Solid Copper or copper alloys having a minimum of 95% conductivity when annealed. May also be tinned-copper.
Minimum Dimensions (BICSI-N3-20, ISO/IEC 30129:2015, and TIA-607-E)	**Height**: 100 mm (4 in.) **Thickness**: 6.35 mm (0.25 in.) **Length**: Variable to meet the application requirements and allow for future growth. 305 mm (12 in.) is recommended as the minimum length.
Mounting brackets	Suitable for the application and should provide a minimum 50.8 mm (2 in.) separation from the supporting surface
Insulators	Should be polyester fiberglass 2 kV minimum voltage rating
Conductor mounting hole number and dimensions	Dependent on the number of conductors to be attached Holes should be 11 mm (7/16 in.) on 19 mm (3/4 in.) or 24.5 mm (1 in.) centers to permit the convenient use of two-hole lugs. Slotted hole patterns may be used if sized to minimum dimensions listed in this table.
Method of attachment of the grounding electrode conductor or bonding conductors	• Exothermic welding • Two-hole exothermic lug • Listed two-hole irreversible compression lug • Irreversible high-compression connection

5.6.1.2 Primary Bonding Busbar Location

The Primary Bonding Busbar (PBB) mounting location requirements are as follows:

- Where practicable, the PBB **shall** be located within the single-point entry window. See “Single-Point Grounding (Earthing) and the Single-Point Entry Window” on page 5-7.
- The PBB **shall** be installed as close as practicable to the electrical service entrance panel and **shall** be installed to maintain clearances required by applicable electrical codes (TIA-607-E, section 7.2.1).
- Where practicable, the PBB **shall** be located within 610 mm (24 in.) of the RF transmission line entry point into the facility.
- The PBB **shall** be installed below the RF transmission line entry point and the RF surge protective devices to enable a continuous downward discharge path.
- In buildings or shelters where RF transmission lines enter at floor level or through conduits within the floor, the PBB should be installed on the wall or floor immediately beside the RF transmission line entry point.
- In buildings or shelters where RF transmission lines enter at ceiling level or through ceiling conduits, the PBB should be placed immediately next to the RF transmission line entry point. See Figure 5-11 for an example.

- In all cases, the PBB **shall** be installed to allow the shortest and most direct downward routing of bonding conductors to the grounding electrode system.

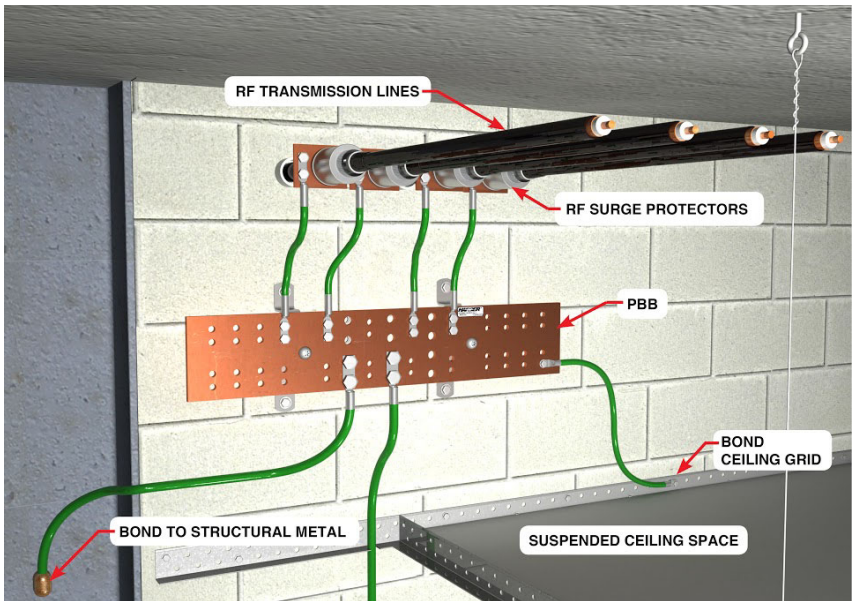


Figure 5-11. RF Transmission Lines Entry Entering Equipment Room Above Suspended Ceiling

5.6.1.3 Primary Bonding Busbar Support

The requirements for supporting the PBB are as follows:

- The PBB **shall** be secured to the structure using brackets suitable for the application.
- The PBB **shall** be insulated from its support structure using listed insulators. See Table 5-1 and TIA-607-E for additional information.
- A minimum 51 mm (2 in.) separation from the supporting surface is recommended to allow access to the rear of the busbar (TIA-607-E, section 7.2.1).

5.6.1.4 Primary Bonding Busbar Grounding Electrode Conductor

The PBB grounding electrode conductor connects the internal bonding system PBB to the electrical system ground and/or directly to the grounding (earthing) electrode system, which is the common grounding electrode system at the site. In a dedicated communications shelter, the grounding electrode conductor usually bonds the PBB directly to the grounding electrode system. In a larger commercial building, such as a communications center, the grounding electrode conductor typically bonds the PBB to the electrical service equipment ground and/or directly to the grounding electrode system. Refer to Figures 5-1 through 5-4, starting on page 5-4, for examples.

The grounding electrode conductor **shall** meet the following specifications:

- The PBB grounding electrode conductor **shall** meet the requirements of “Bonding and Grounding (Earthing) Conductors” on page 5-41.
- The PBB grounding electrode conductor **shall** be 35 mm^2 csa (#2 AWG) or larger (ATIS-0600334.2019(R2024), section 7.3).
  - If the PBB grounding electrode conductor is longer than 10 m (33 ft), it **shall** be sized based on its length as shown in Table 5-3.
  - In larger buildings containing a bonding backbone, the PBB **shall** be bonded to the electrical service equipment (power) ground using a conductor that is the same size or larger than the bonding backbone conductor (TIA-607-E, section 6.3.4).

- If the building has a DC power plant, the PBB **shall** be connected to the electrical service equipment (power) ground, as described in "DC Power Systems" on page 5-94 and related subsections.
- In areas prone to high lightning activity, it is recommended to use a larger conductor, such as 120 mm^2 csa (#4/0 AWG) (NWSM 30-4106:2017, section 2.6.7.2).

- The PBB grounding electrode conductor **shall** be free of splices (TIA-607-E, section C.10). **Exception:** If a splice becomes necessary, splicing **shall** be permitted only by exothermic weld or listed irreversible compression-type connection (NFPA 70-2026, Article 250.64(C)).

IMPORTANT: Where structural metal is accessible and in the same room as the PBB, the PBB **shall** be bonded to structural metal using a conductor as described in this section (see TIA-607-E, section 7.1.6).

5.6.1.5 Primary Bonding Busbar Grounding Electrode Conductor Routing

In addition to the requirements described in "Bonding and Grounding (Earthing) Conductor Routing and Installation Requirements" on page 5-45, the PBB grounding electrode conductor **shall** meet the following routing requirements:

- The grounding electrode conductor **shall** be routed to the grounding electrode system without sharp bends or narrow loops, following the shortest and straightest downward path practicable.
- Where routing the grounding electrode conductor through a perimeter wall to the external grounding electrode system, the conductor should pass through the wall in a flexible, non-metallic conduit sleeve at a 45-degree angle toward the earth. See Figure 5-12 for an example.

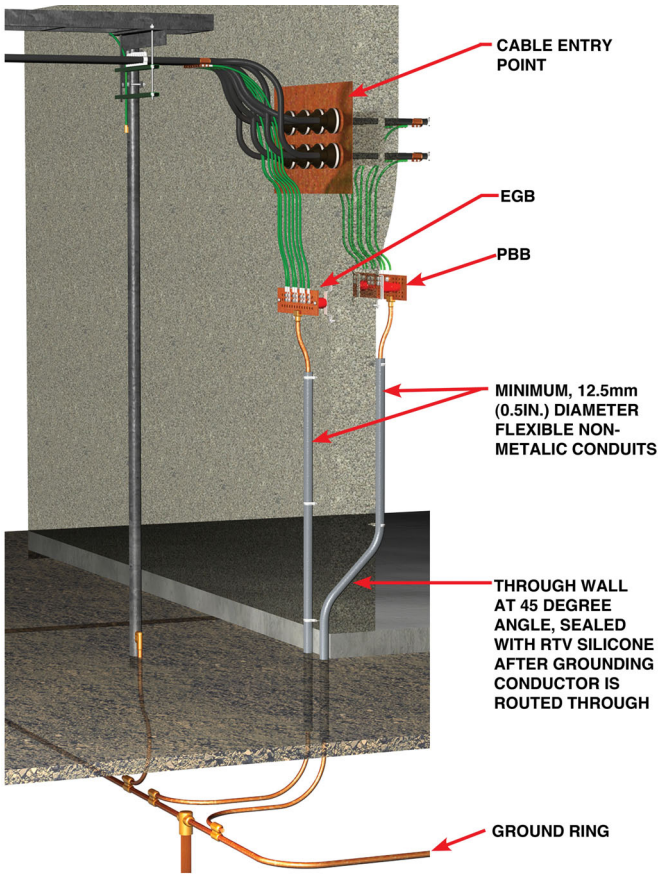


Figure 5-12. Routing and Protecting of PBB Grounding Electrode Conductor

5.6.1.6 Primary Bonding Busbar Conductor Connection Methods

Conductor attachment to the PBB **shall** be made according to “Bonding to the Primary Bonding Busbar, Secondary Bonding Busbar and Rack Bonding Busbar” on page 5-79 and “Connection to the Primary Bonding Busbar” on page 5-80.

- The PBB grounding electrode conductor **shall** be bonded to the PBB by exothermic weld, a listed irreversible compression two-hole lug, a two-hole exothermic lug, or an irreversible high compression-type connection (ATIS-0600334.2019(R2024), section 7.3; BICSI-N3-20; and TIA-607-E, section 7.2.3).
- The PBB grounding electrode conductor **shall** be bonded to the grounding electrode system using methods described in “Bonding to the External Grounding and Bonding System” on page 4-61.

5.6.1.7 Primary Bonding Busbar Grounding Electrode Conductor Identification

The specifications for identifying the PBB grounding electrode conductor are as follows:

- Where the grounding electrode conductor is insulated, the jacket **shall** be identified with a green coloring as described in “Bonding and Grounding (Earthing) Conductor General Specifications” on page 5-41.
- The grounding electrode conductor **shall** be labeled at the PBB (see TIA-607-E, section 7.9).
- Where the PBB grounding electrode conductor terminates in the electrical service panel, such as in a commercial building, the grounding electrode conductor **shall** also be labeled as close as practicable to its point of termination to the electrical service (power) ground (TIA-607-E, section 7.9).
- The labels **shall** be made of a nonmetallic material and placed in visible locations.
- See Figure 5-13 and TIA-607-E, section 6.5.2, for labeling requirements.



Figure 5-13. PBB Grounding Electrode Conductor Identification

5.6.2 Integrated Cable Entry Grounding Systems and Cable Entry Panels

Integrated cable entry grounding systems may be used in place of the Primary Bonding Busbar (PBB) and External Ground Busbar (EGB). The specifications and installation requirements for integrated cable entry grounding systems are as follows:

- **Shall** be factory-assembled and designed for grounding.
- **Shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- **Shall** be installed according to the manufacturer's instructions.
- The interconnecting devices (such as brass rods) should be routed through the structure wall in rigid non-metallic conduits. The wall penetrations **shall** be sealed with suitable weather-proofing material.
- Should be sized to allow for future growth.
- See Figure 5-14 for an example of an integrated cable entry grounding system.

NOTE: Integrated cable entry grounding systems eliminate the need for a PBB grounding electrode conductor. The connection to earth is made by the feed-through mounting bolts and the External Ground Busbar (EGB) grounding electrode conductor (or copper straps).

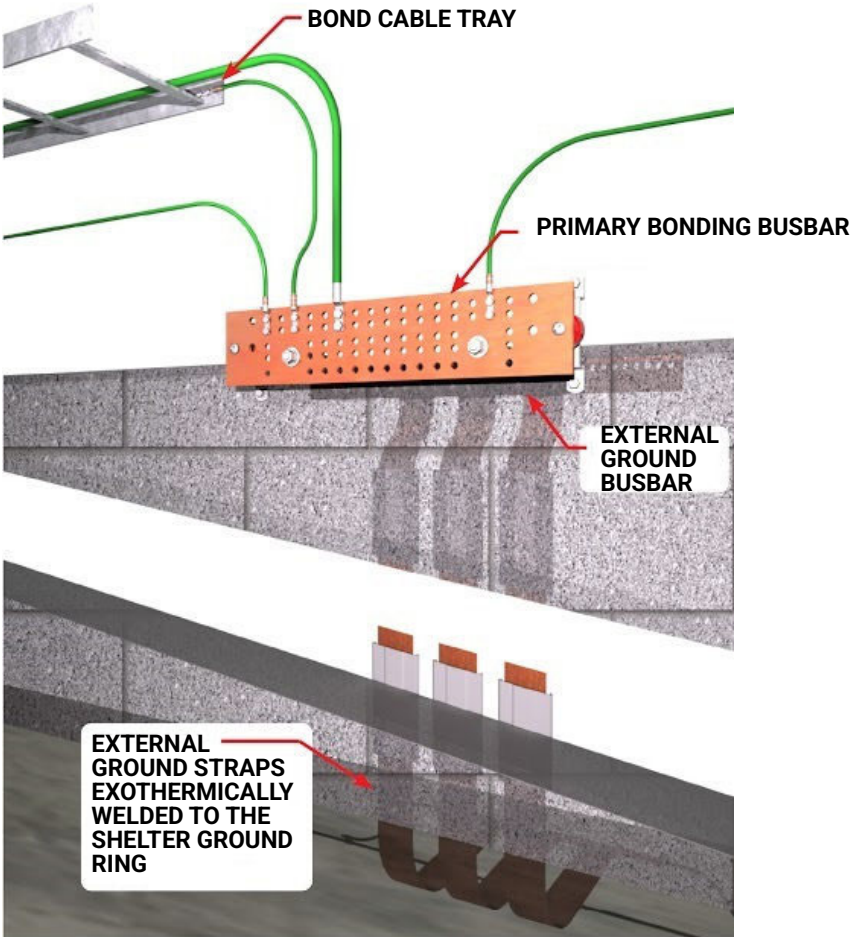


Figure 5-14. Integrated Cable Entry Grounding System with Ground Straps

Integrated cable entry panels can replace the PBB. The specifications and installation requirements for integrated cable entry panels are as follows:

- Integrated cable entry panels can be used instead of the PBB if they provide sufficient surface area for termination of the internal bonding conductors.
- Integrated cable entry panels **shall** be made of solid copper construction and be electrically continuous between the interior and exterior of the structure.
- Integrated cable entry panels **shall** be factory-assembled and designed for grounding.
- Integrated cable entry panels **shall** be installed according to the manufacturer's instructions.
- Integrated cable entry panels should be adequately sized for future expansion.
- See Figure 5-15 for examples of integrated cable entry panels.

NOTE: Integrated cable entry panels eliminate the need for a PBB grounding electrode conductor. The connection to earth is made via the solid copper construction and the External Ground Busbar (EGB) grounding electrode conductor.

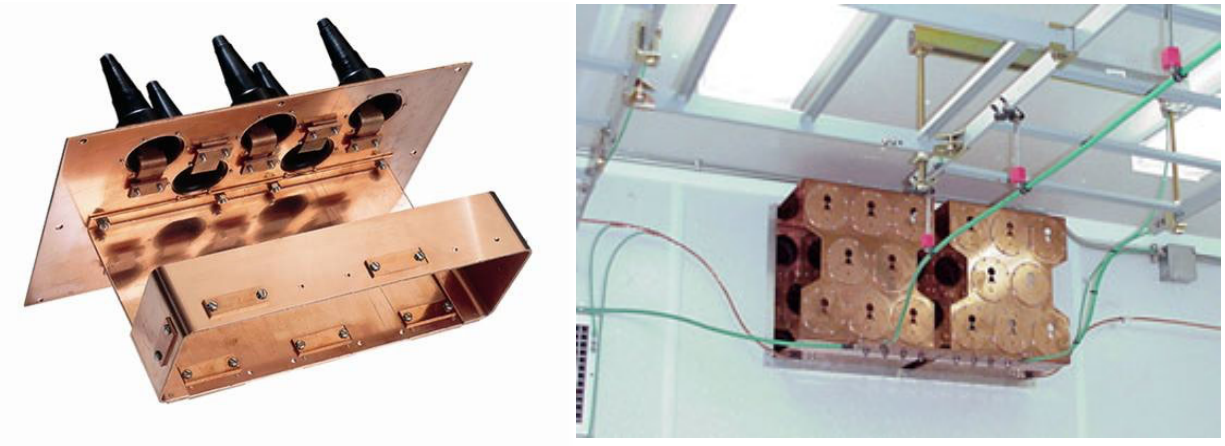


Figure 5-15. Integrated Cable Entry Panel Examples

5.6.3 Secondary Bonding Busbar

A Secondary Bonding Busbar (SBB) is used as a convenient extension of the Primary Bonding Busbar (PBB). In other standards, it may be referred to as a Floor Ground Bar (FGB), Telecommunications Grounding Busbar (TGB), or Position Bonding Terminal (PBT) (see ATIS-0600313.2019(R2024), ATIS-0600333.2013(S2023), ATIS-0600321.2020, and TIA-607-E for more information). More than one SBB can be installed in a building, shelter, room, or area. See Figure 5-16 for an example.

The purpose of an SBB is to serve as a convenient internal bonding termination point for communications equipment, bonding conductors, internal perimeter bonding bus conductors, surge protective devices, or ancillary support equipment. An SBB can act as a single point bonding busbar for a separate room in a building or shelter, as a common bonding busbar for a communications cable entry panel, in assemblies of communications equipment cabinets, or at a group of network operator positions, as referenced in this chapter.

See Figures 5-17 through 5-20, starting on page 5-18, for typical SBB installations.

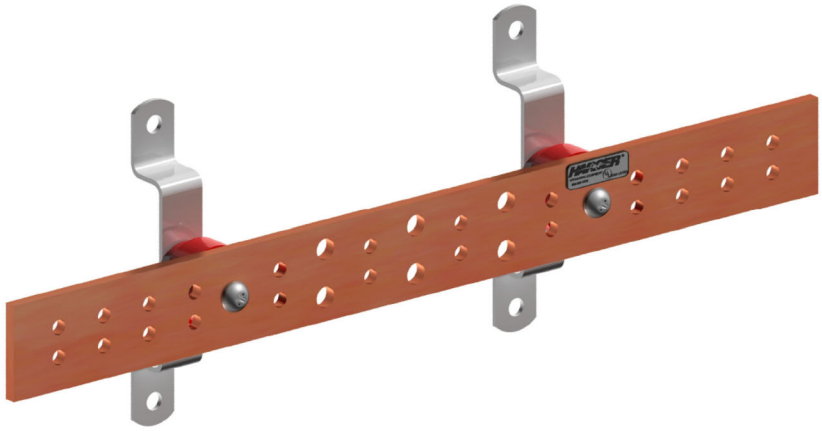


Figure 5-16. Typical Secondary Bonding Busbar with Insulated Mounting Hardware

IMPORTANT: Where an SBB is installed in a separate area of a building, or where an SBB must feed another SBB, the requirements of “Bonding Backbone and Bonding Backbone Conductor” on page 5-55 **shall** be followed.

IMPORTANT: An SBB **shall not** be extended to another building/shelter. In these cases, a separate internal bonding and grounding system **shall** be installed in each building.

IMPORTANT: Where structural metal is accessible and in the same room as the SBB, the SBB **shall** be bonded to the structural metal using a conductor as described in this section (see TIA-607-E, section 7.1.6).

NOTE: In the example shown in Figure 5-17, the SBB in each equipment room can be considered a Primary Bonding Busbar (PBB) for that room.

NOTE: In the example in Figure 5-18, the SBB in each dispatch position area can be considered a PBB for that area.

NOTE: Not all communications sites will need an SBB.

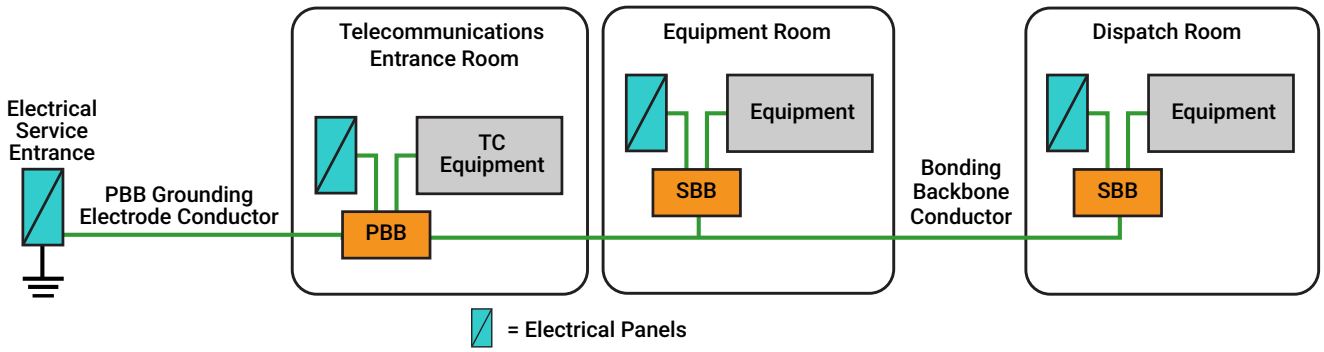


Figure 5-17. Example of Secondary Bonding Busbar Configuration for a Commercial Building

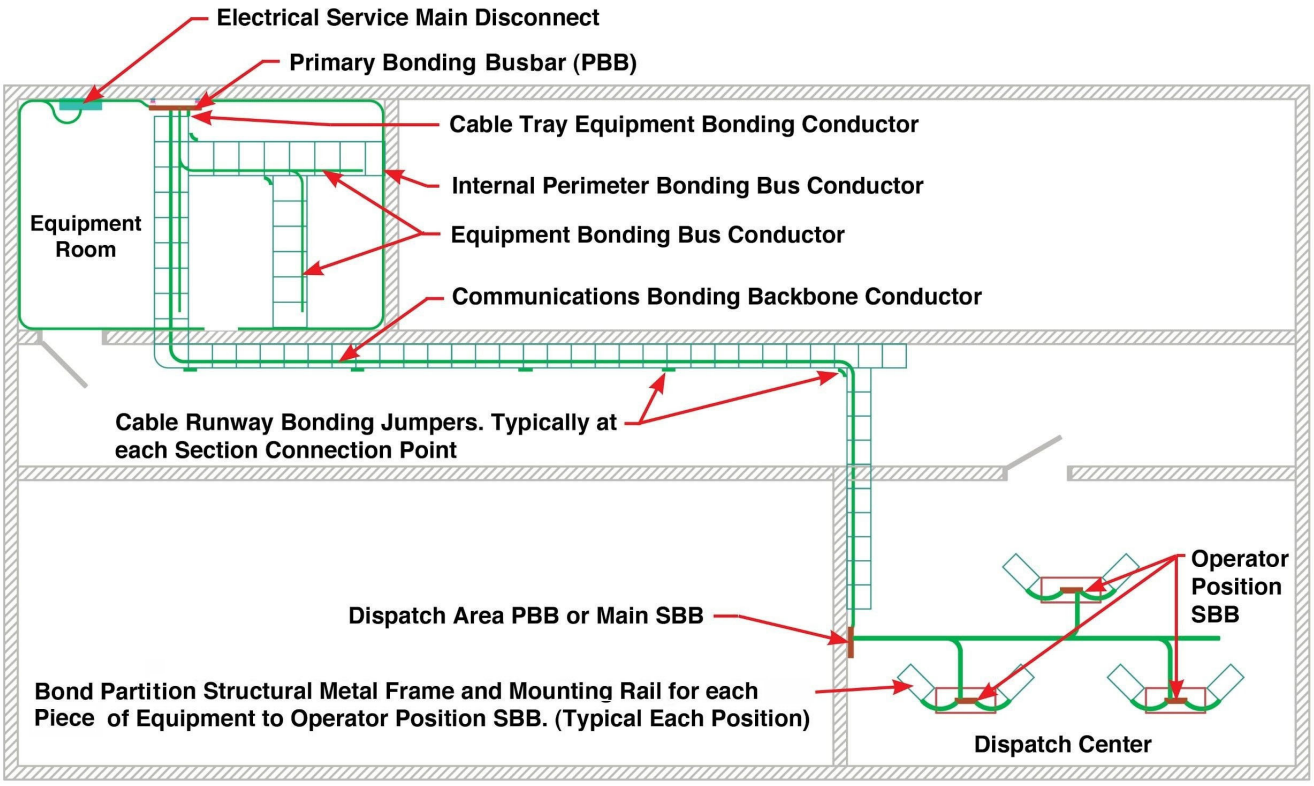


Figure 5-18. Example of a Main Secondary Bonding Busbar Configuration for a Dispatch Center

NOTE: In the example in Figure 5-19, the SBB in each equipment room can be considered a PBB for that room.

NOTE: For multi-story or commercial buildings, structural metal may be the best option for the grounding electrode conductor.

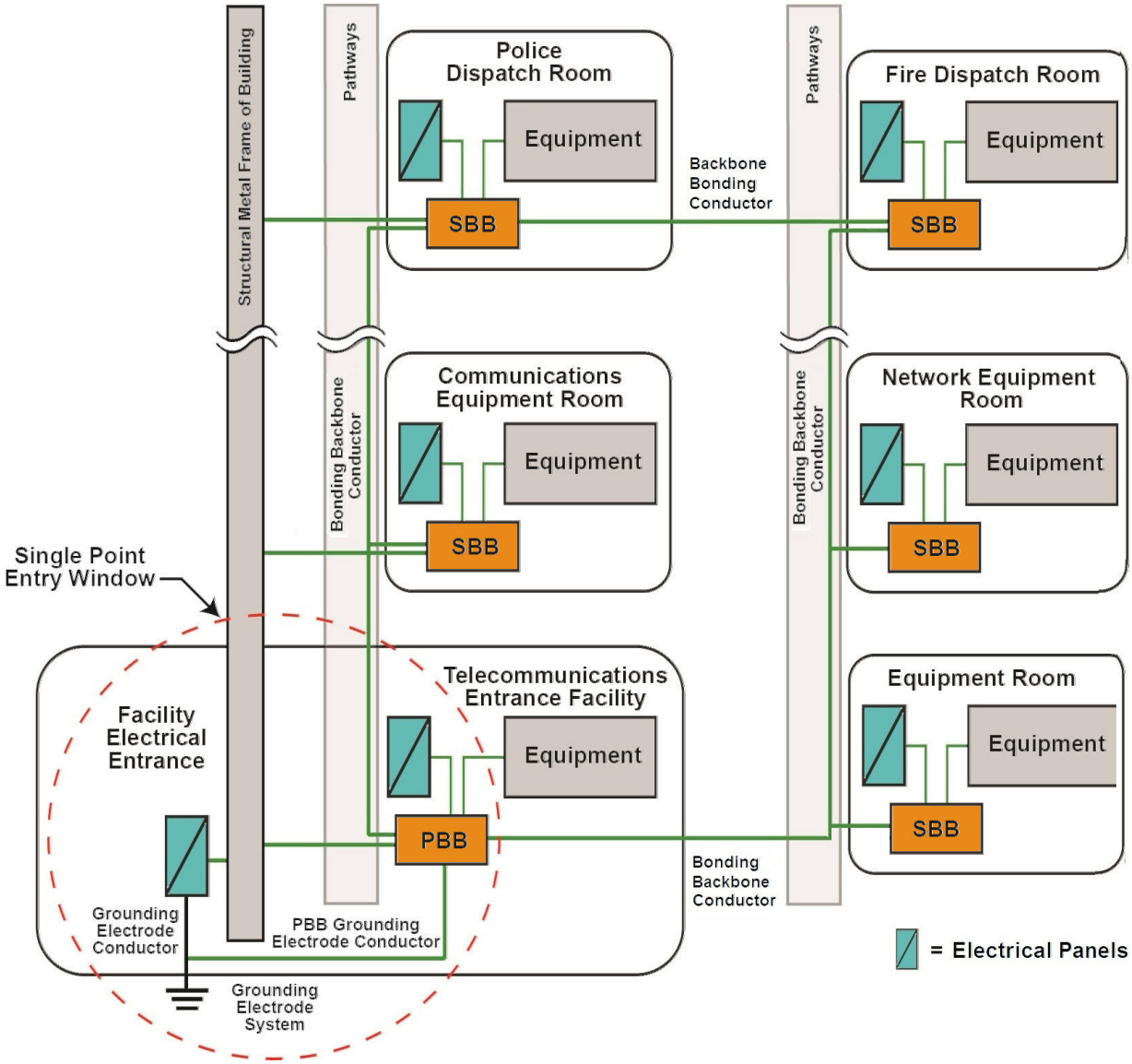


Figure 5-19. Example of Secondary Bonding Busbar Configuration for Multi-Story Building

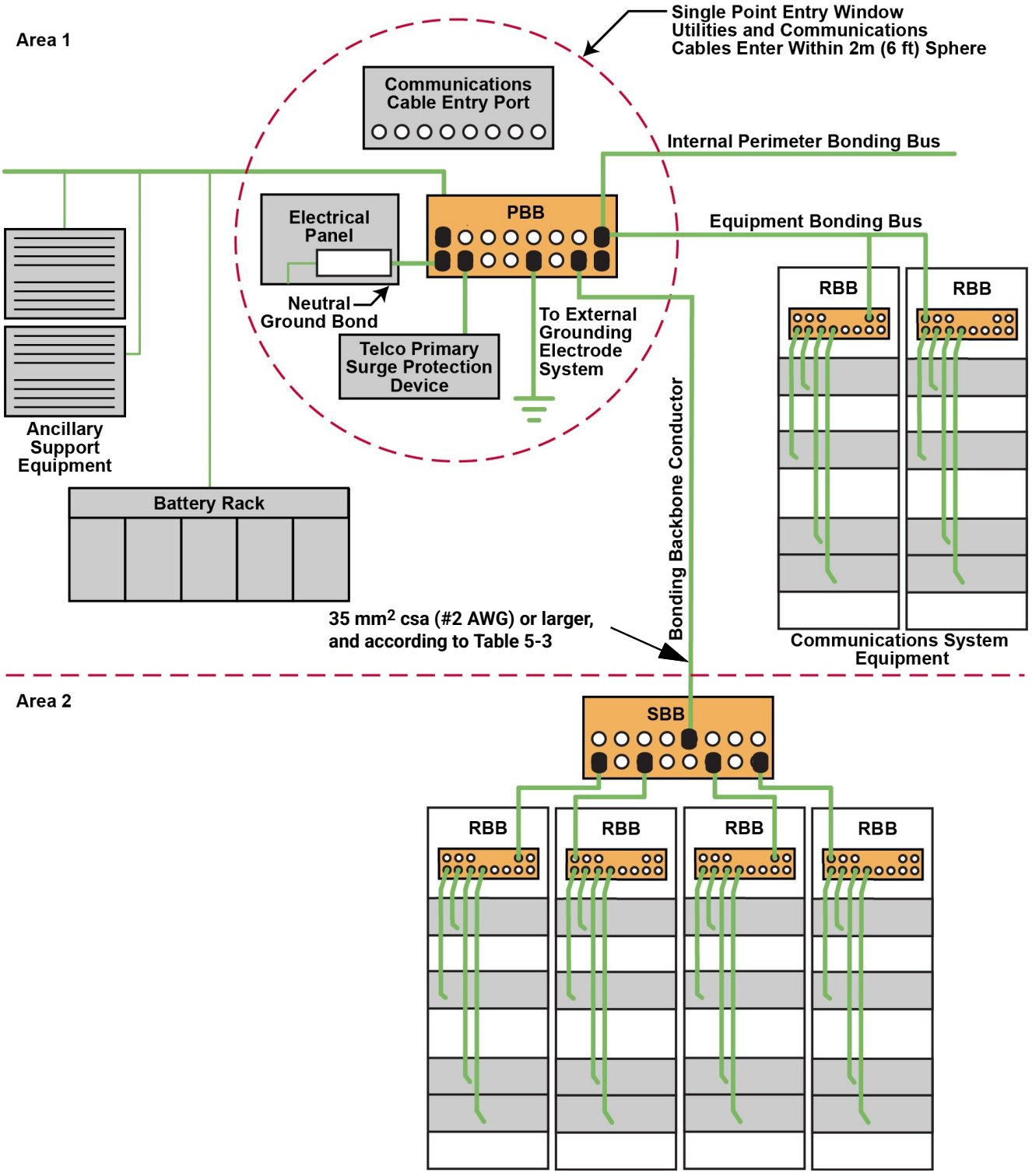


Figure 5-20. Typical Secondary Bonding Busbar Configuration for Separate Equipment Area

5.6.3.1 Secondary Bonding Busbar Specifications

Specifications for a Secondary Bonding Busbar (SBB) are as follows:

IMPORTANT: Only an SBB serving an entry point **shall** have a direct connection to earth using a grounding electrode conductor, in addition to the bonding conductor to the PBB.

NOTE: If the SBB serves an entry point (such as a secondary cable entry port), the SBB **shall** be sized the same as a Primary Bonding Busbar (see “Primary Bonding Busbar Specifications” on page 5-12).

- The SBB **shall** be constructed and minimally sized as specified in Table 5-2.
- Where the SBB is used at an entry point, the SBB **shall** be sized the same as a PBB.
- The SBB **shall** be designed for grounding and **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL) (TIA-607-E, section 6.2.2).
- The SBB **shall** be sized for the immediate application, with consideration given to future growth (TIA-607-E, section D.2.2).

Refer to Table 5-2 for more specifications and requirements.

Table 5-2. Secondary Bonding Busbar Specifications

Item	Specification
Listing Requirement	**Shall** be listed by a Nationally Recognized Testing Laboratory (TIA-607-E).
Material	Bare, solid alloy 110 (99.9%) copper busbar or plate of one piece construction. May also be tinned-copper.
Minimum Dimensions (TIA-607-E)	**Height:** 50.8 mm (2 in.) **Thickness:** 6.35 mm (1/4 in.) **Length:** Variable to meet the application requirements and allow for future growth. 305 mm (12 in.) is recommended as the minimum length.
Mounting Brackets	Suitable for the application and should provide a minimum 50.8 mm (2 in.) separation from the supporting surface (TIA-607-E, section 7.3.1)
Insulators	Polyester fiberglass 2 kV minimum voltage rating
Conductor mounting holes	Dependent on number of conductors to be attached Holes should be 11 mm (7/16 in.) on 19 mm (3/4 in.) or 24.5 mm (1 in.) centers to permit the convenient use of two-hole lugs Slotted hole patterns may be used if sized to minimum dimensions listed in this table.
Method of conductor attachment: SBB-to-PBB, SBB-to-Grounding Electrode Conductor or bonding conductor.	Exothermic welding Two-hole exothermic lug Listed two-hole irreversible compression lug Irreversible high-compression connection

5.6.3.2 Secondary Bonding Busbar Location

Each area of telecommunications equipment concentration not directly served by a PBB **shall** contain at least one SBB (CSA ISO/IEC 30129:2015, section 8.3.2.1). The location and placement of a Secondary Bonding Busbar (SBB) are site-specific and may vary from one site to another. The general location requirements and guidelines are as follows:

- The SBB **shall** be installed in a position that provides the shortest, most direct routing for the bonding conductors to the Primary Bonding Busbar (PBB).
- The SBB **shall** be installed in a location that is easily accessible and most convenient for terminating bonding conductors.
- See Figures 5-17 through 5-20, starting on page 5-18, for SBB configuration examples.
- Where installed at a network operator position, the SBB **shall** be placed in an accessible area that prevents tripping hazards and damage to the bonding conductors. See Figure 5-21 for an example.
- Where used as a single-point bonding or grounding busbar for a separate room or area, the SBB **shall** be installed as follows (TIA-607-E, section 7.3.1):
  - The SBB should be placed within a single-point entry window for the equipment room or area.
  - Where practicable, the SBB should be located near the electrical distribution panel that supplies power to the equipment, and it **shall** be installed to maintain the clearances required by applicable electrical codes (see ISO/IEC 30129:2015, section 8.3.2.1).
  - The vertical placement of the SBB should be determined by the routing of bonding conductors, whether under a raised floor or in an overhead cable tray, as well as the routing of the SBB bonding conductor to the PBB.
- Where used as a common bonding busbar for primary, secondary, or RF surge protective devices, the SBB **shall** be installed within 610 mm (24 in.) of the communications cable entry point. See Figure 5-22 and Figure 5-23 for examples.

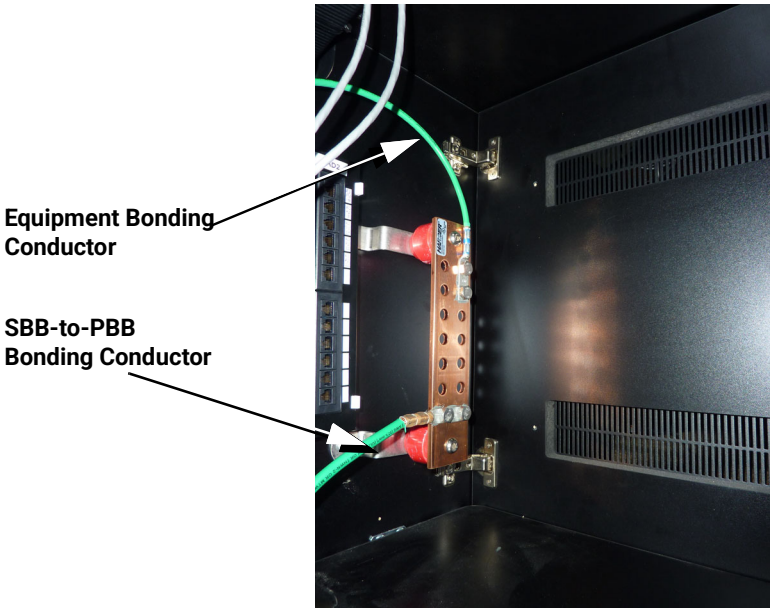


Figure 5-21. Example of a Secondary Bonding Busbar at a Network Operator (Dispatch) Position

NOTE: Where an SBB serves a separate equipment room or area, it effectively becomes the PBB for that area.

5.6.3.3 Secondary Bonding Busbar Support

The SBB supporting requirements are as follows:

- The SBB **shall** be secured to the structure using appropriate brackets for the application.
- The SBB **shall** be insulated from its support structure using listed insulators (TIA-607-E, section 7.3.1).
- A minimum clearance of 51 mm (2 in.) from the supporting surface is recommended to allow access to the rear of the busbar (TIA-607-E, section 7.3.1). This provides space for securing the hardware and adding additional bonding conductors, etc.
- An SBB can be mounted from the ceiling or wall using rigid trapeze mounting structures. See Figure 5-22 and Figure 5-23 for examples.

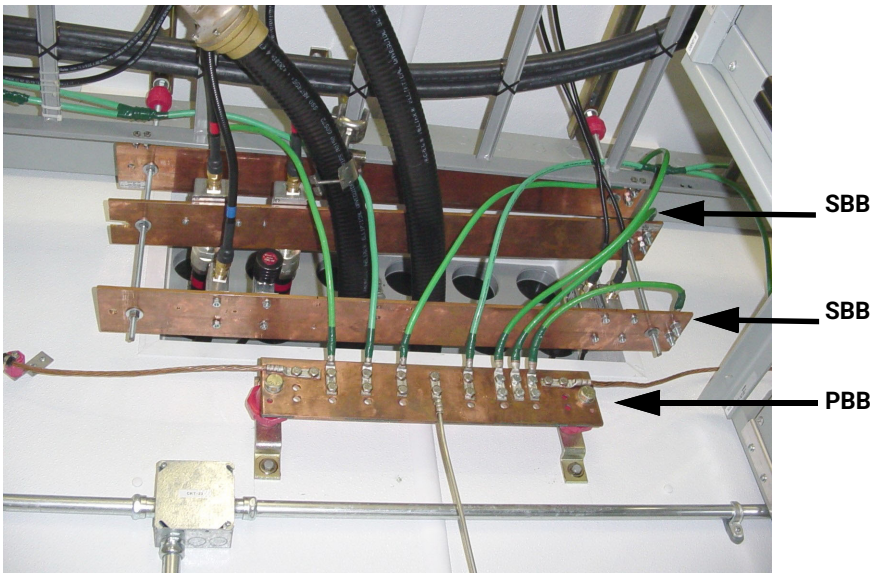


Figure 5-22. Ceiling Supported Secondary Bonding Busbars at a Ceiling Level Communications Cable Entry Panel



Figure 5-23. Wall Supported Secondary Bonding Busbar at a Floor Level Communications Cable Entry Panel

5.6.3.4 Secondary Bonding Busbar Bonding Conductor

An SBB bonding conductor connects the SBB to the internal bonding and grounding system. These bonds include the following: Primary Bonding Busbar (PBB), bonding backbone conductor, bonding bus conductor, or bonding grid. The SBB bonding conductor **shall** meet the following requirements:

- The SBB bonding conductor **shall** meet the requirements of “Bonding and Grounding (Earthing) Conductors” on page 5-41 and all applicable subsections.
- The SBB bonding conductor **shall** be free of splices. **Exception:** If a splice becomes necessary, splicing **shall** be permitted only by exothermic weld or listed irreversible compression-type connection (TIA-607-E).
- The SBB bonding conductor **shall** be 35 mm^2 csa (#2 AWG) or larger and sized according to Table 5-3.
- Where an SBB bonds directly to the PBB, the SBB-to-PBB conductor **shall** be 35 mm^2 csa (#2 AWG) or larger and **shall** be sized according to Table 5-3.
- Where an SBB bonds directly to a bonding backbone conductor, the SBB-to-bonding backbone conductor **shall** be sized the same as the bonding backbone conductor.
- Where an SBB bonds to a bonding grid, the SBB-to-bonding grid conductor **shall** be 35 mm^2 csa (#2 AWG) or larger and sized according to Table 5-3.

5.6.3.5 Secondary Bonding Busbar Conductor Connection Methods

Bonding conductor and grounding electrode conductor connection to the SBB **shall** be made according to “Bonding to the Primary Bonding Busbar, Secondary Bonding Busbar and Rack Bonding Busbar” on page 5-79.

- The SBB bonding conductor **shall** be bonded to the PBB using an exothermic weld, a listed irreversible compression two-hole lug, a two-hole exothermic lug, or an irreversible high compression-type connection (ATIS-0600334.2019(R2024), section 7.3; and BICSI N3-20). Single-hole lugs are not permitted.
- The SBB grounding electrode conductor **shall** be bonded to the SBB by exothermic weld, listed irreversible compression two-hole lug, two-hole exothermic lug, or irreversible high compression-type connection (ATIS-0600334.2019(R2024), section 7.3; BICSI N3-20; and TIA-607-E, section 7.3.4).
- The SBB grounding electrode conductor **shall** be bonded to the grounding electrode system using methods described in “Bonding to the External Grounding and Bonding System” on page 4-61.

5.6.3.6 Secondary Bonding Busbar Conductor and Grounding Electrode Conductor Identification

The SBB bonding conductor and grounding electrode conductor **shall** meet the following identification requirements:

- Where the conductors are insulated, the jacket **shall** be identified with green coloring as described in “Bonding and Grounding (Earthing) Conductor General Specifications” on page 5-41.
- The SBB bonding conductor **shall** be clearly labeled at each termination point (TIA-607-E, section 7.9).
- The SBB grounding electrode conductor **shall** be clearly labeled at the SBB.
- The labels **shall** be placed in clearly visible locations and **shall** be made of a nonmetallic material.
- Refer to Figure 5-24 and TIA-607-E, section 6.5.2, for labeling requirements.



Figure 5-24. Secondary Bonding Busbar Grounding Electrode Conductor Identification

5.6.3.7 Secondary Bonding Busbar Serving an Entry Point

Although not recommended and not a good design practice, a communications site may occasionally have a cable entry point outside the single-point entry window. This situation may occur if a secondary communications cable entry point is used, where the cable entry point is positioned away from the electrical service entry point, or where the communications or electronic equipment is located in a multi-story or commercial building.

There are two common types of Entry Point SBB configurations:

- Telco entry locations (e.g., telephone, cable, internet, etc.)
- RF cable entry locations (e.g., RF coaxes and waveguides)

IMPORTANT: Entry points at multiple locations should be avoided where practicable.

NOTE: If the SBB serves at an entry point, the SBB **shall** be sized the same as a PBB.

5.6.3.7.1 Grounding and Bonding Requirements for Both Configurations

Secondary cable entry points **shall** be equipped with an SBB (Entry Point SBB) for grounding and bonding the communications cables entering at this location, as well as any associated surge protective devices. The Entry Point SBB **shall** be bonded to the PBB as outlined in this chapter using a conductor of 35 mm^2 csa (#2 AWG) or larger.

5.6.3.7.2 Entry Point SBB Requiring a Grounding Electrode Conductor

RF Entry Point SBBs require a grounding electrode conductor that connects directly to the grounding electrode system via the shortest and most direct route available. Similarly, Telco Entry Point SBBs located more than 6.1 m (20 ft) from the PBB grounding electrode system have the same grounding electrode conductor requirement (see NFPA 70-2026, Article 750).

The SBB grounding electrode conductor **shall** comply with the same requirements as the PBB grounding electrode conductor described in “Primary Bonding Busbar” on page 5-10 and applicable subsections.

If an SBB requires a grounding electrode conductor, the conductor **shall** be installed and routed to the grounding electrode system as follows:

- The SBB grounding electrode conductor **shall** be routed directly to the grounding electrode system using the shortest, straightest practicable path (NFPA 70-2026, Article 750).
- The SBB grounding electrode conductor **shall** be free of splices (TIA-607-E, section C.10).
  Exception: If a splice becomes necessary, splicing **shall** only be allowed through an exothermic weld or a listed irreversible compression-type connection (NFPA 70-2026, Article 250.64(C)).
- The SBB grounding electrode conductor **shall** be bonded to the SBB by an exothermic weld, a listed irreversible compression two-hole lug, a two-hole exothermic lug, or an irreversible high compression-type connection (ATIS-0600334.2019(R2024), section 7.3; and BICSI N3-20). Single-hole lugs are not permitted.

- If the SBB grounding electrode conductor must pass through a perimeter wall to reach the external grounding electrode system, it **shall** adhere to the requirements outlined in “Primary Bonding Busbar Grounding Electrode Conductor Routing” on page 5-14.
- Where it is not practicable to bond the SBB to the external grounding electrode system, the SBB grounding electrode conductor **shall** be routed to the nearest accessible extension of the common grounding electrode system at the site (for example, effectively bonded structural metal or accessible rebar of the Ufer ground). See Figure 5-25 on page 5-27 for an example.
- See Figure 5-26 on page 5-28 for an example of a shelter secondary cable entry point SBB.

IMPORTANT: RF cable entry point SBBs require a grounding electrode conductor as described in this section. Telco cable entry point SBBs that are more than 6.1 linear meters (20 ft) away from the Primary Bonding Busbar (PBB) grounding electrode conductor also require a grounding electrode conductor as described in this section.

NOTE: All conductor sizes given in Figure 5-26 represent the minimum size.

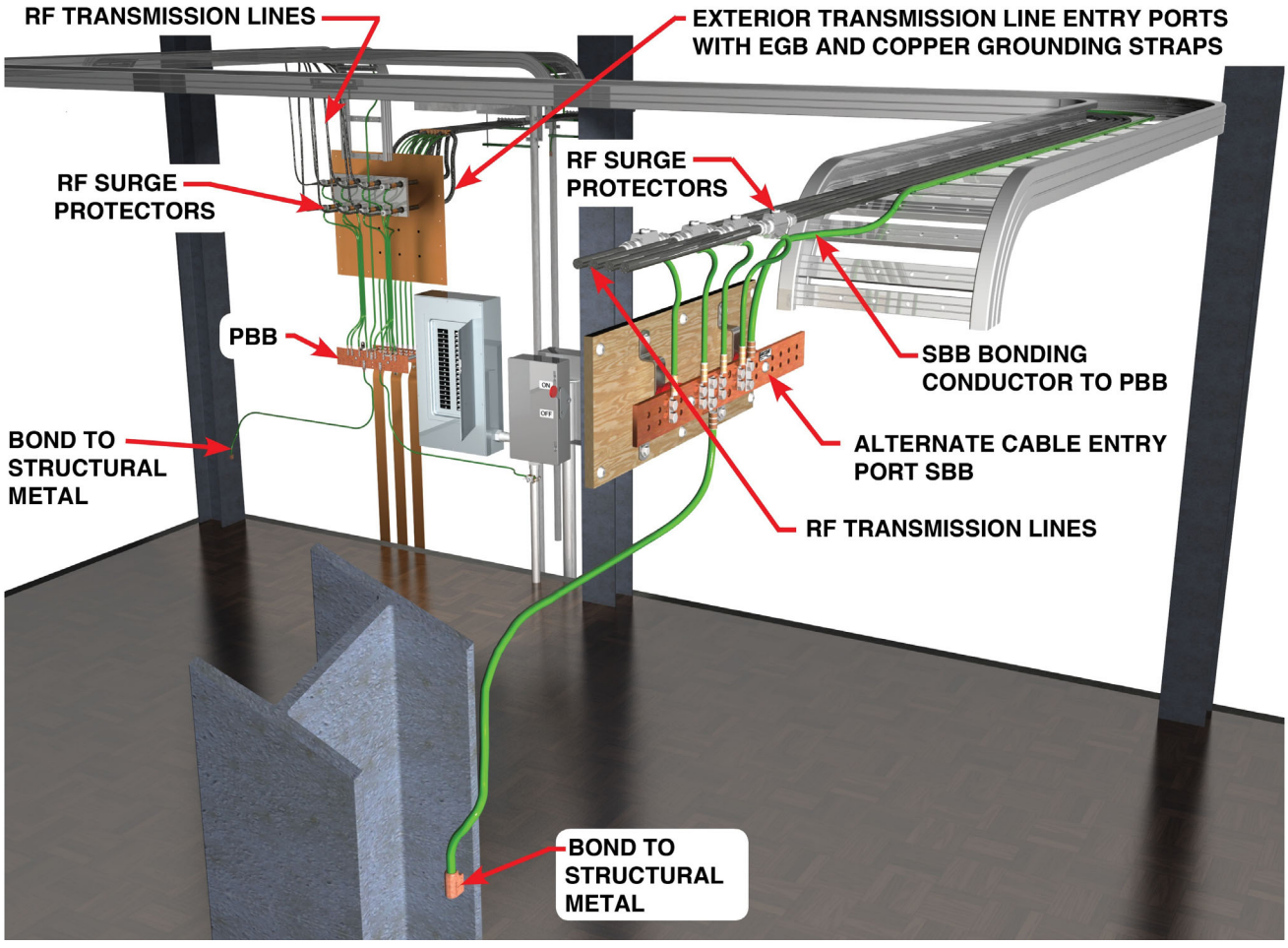


Figure 5-25. Entry Point SBB with Grounding Electrode Conductor at Alternate Entry

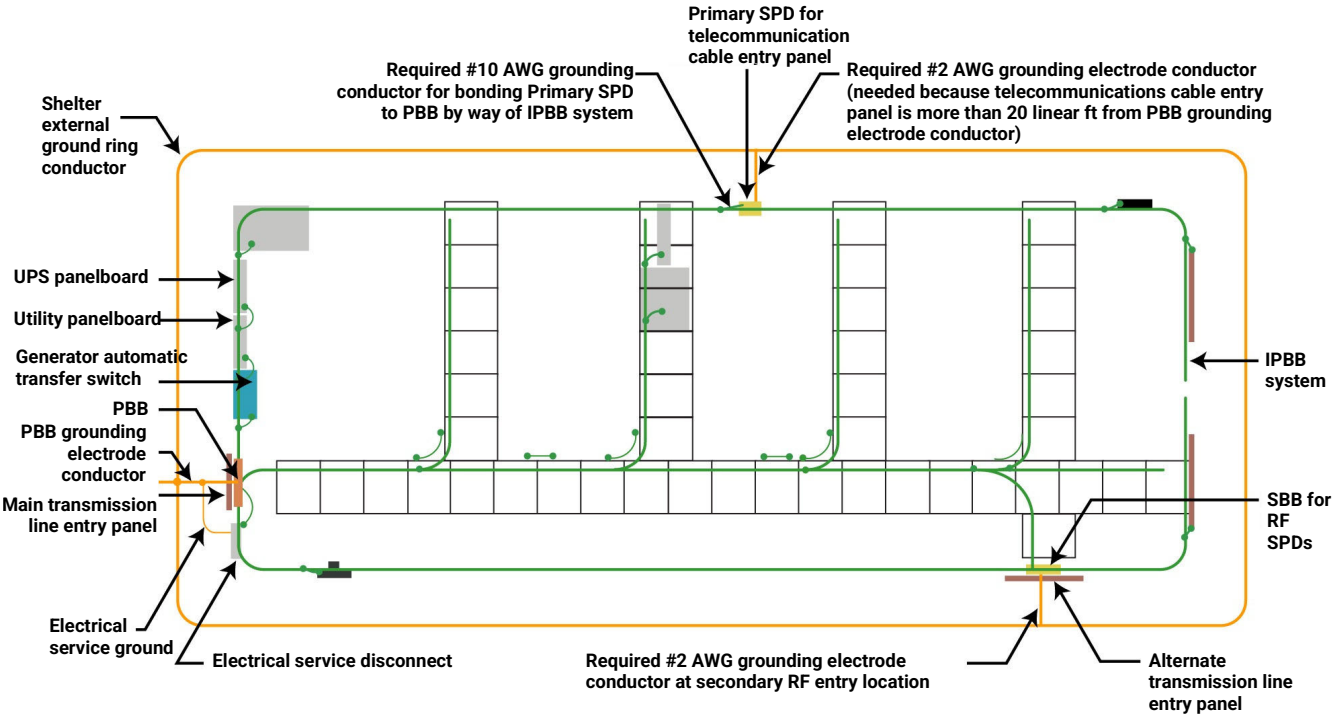


Figure 5-26. Secondary Communications Cable Entry Points at a Shelter

5.6.4 Rack Bonding Busbar

The purpose of a Rack Bonding Busbar (RBB) is to provide a convenient bonding termination point for individual pieces of equipment and/or secondary surge protective devices installed within a cabinet or rack. Other standards may refer to the RBB as a Rack Grounding Busbar (RGB) or a Single Point Ground Busbar (SPGB). See ISO/IEC 30129:2015, section 7.5.1.2; BICSI N3-20; and FAA-STD-019G, section 5.6.6 for more details.

The RBB can be mounted vertically or horizontally. The bonding conductor for the cabinet or rack supporting framework may also connect to the RBB. More than one RBB can be installed within a cabinet or rack, provided that both RBBs are bonded to the equipment bonding bus conductor with separate bonding conductors (see “Rack Bonding Busbar Bonding Conductor Specifications” on page 5-32). Refer to Figure 5-27 for an example.

IMPORTANT: Do not daisy-chain RBBs. Each RBB **shall** be bonded directly to an equipment bonding bus conductor, not to another RBB.

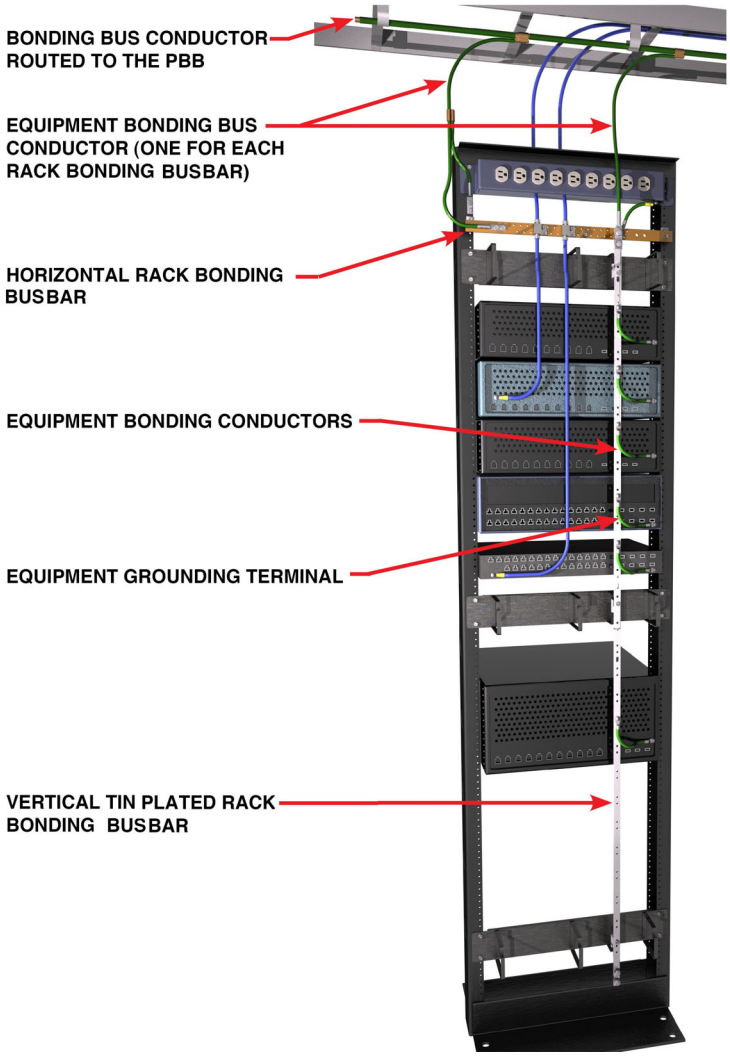


Figure 5-27. Equipment Rack with Multiple Rack Bonding Busbars

5.6.4.1 Rack Bonding Busbar Specifications

See Figure 5-28 for an RBB example. Specifications for a Rack Bonding Busbar (RBB) are as follows.

- The RBB **shall** be designed by the manufacturer for electrical bonding purposes.
- The RBB **shall** be constructed from solid copper, tin-plated copper, or copper alloy.
- The RBB **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL) (TIA-607-E, section 6.2.3).
- It is recommended that the busbar be electro-tin-plated to prevent dissimilar metal reactions.
- The RBB **shall** be at least 4.76 mm (3/16 in.) thick and 12.7 mm (0.5 in.) wide, and appropriately sized for the application.
- The busbar **shall** include an appropriate number of predrilled holes to accommodate the necessary equipment bonding conductors.
- The busbar's pre-drilled holes can be tapped to accommodate machine screw-type fasteners.
- The busbar **shall** include at least one set of pre-drilled holes or threaded posts at one end to fit a standard two-hole lug for the RBB bonding conductor.

NOTE: At the discretion of the Motorola Solutions R56 Committee, existing horizontal RBBs for secondary SPD products may utilize a single lug attachment point for the main bonding conductor. See Figure 5-124 on page 5-126 for an example.

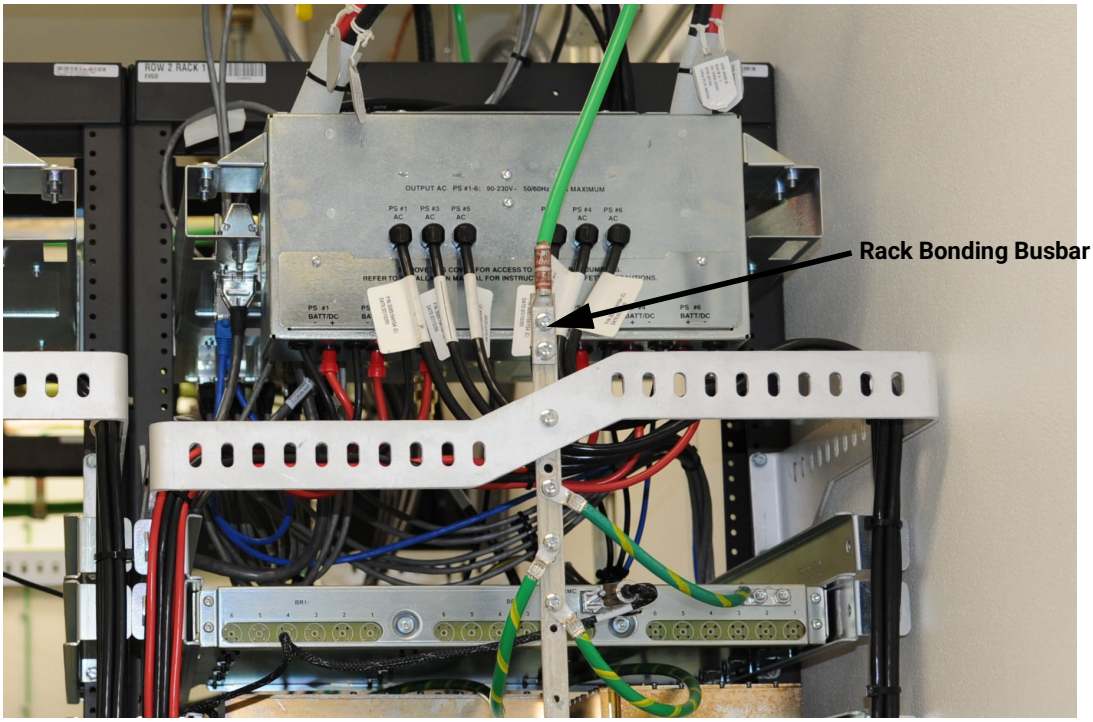


Figure 5-28. Example of Rack Bonding Busbar

5.6.4.2 Rack Bonding Busbar Location Requirements

The location and placement of a Rack Bonding Busbar (RBB) are as follows:

- The RBB **shall** be installed in an accessible location where it is easiest to connect communications equipment or secondary Surge Protective Devices (SPD) using the shortest practicable bonding conductors.
- The RBB can be mounted horizontally between the equipment's vertical support rails, at the top or bottom of the cabinet or rack, or attached to the vertical support rail using standoffs as described herein.
- The RBB can be supported vertically between horizontally positioned cable management rails. See Figure 5-29 for examples of the RBB placement.
- The vertical placement of a horizontally mounted RBB and/or the RBB bonding conductor connection point **shall** be determined by the routing of the RBB bonding conductor to the internal bonding and grounding system infrastructure (for example, bonding bus conductor, SBB, or PBB). Vertical placement should be based on the location of the bonding and grounding infrastructure (such as under a raised floor or in an overhead cable tray).
- The RBB **shall** be positioned to ensure the shortest, most direct route for the bonding conductor to the internal bonding and grounding system infrastructure (for example, bonding bus conductor, SBB or PBB).

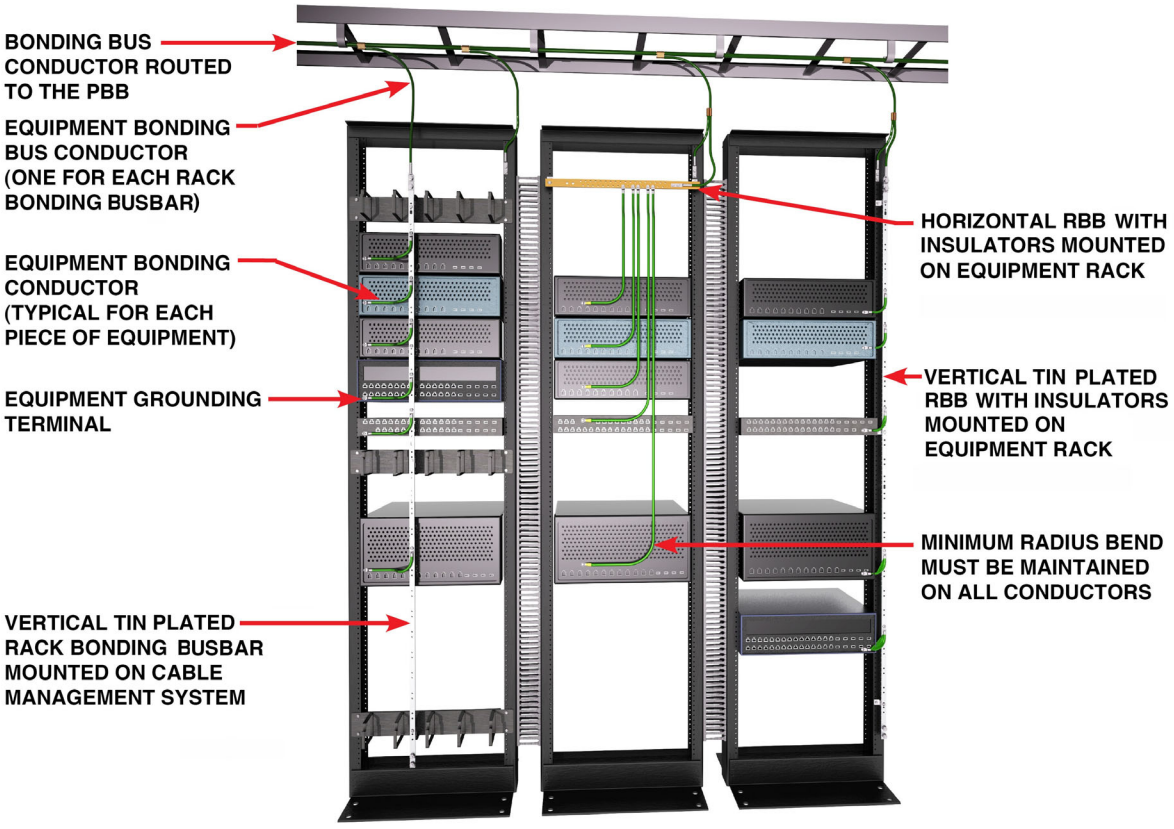


Figure 5-29. Rack Bonding Busbar Mounting Configurations

5.6.4.3 Rack Bonding Busbar Support Requirements

The Rack Bonding Busbar (RBB) supporting requirements are as follows:

- A bare copper or copper alloy RBB **shall** be securely supported with standoff hardware to ensure adequate separation between dissimilar metals and to enable conductor attachment. The use of insulators may be appropriate for this purpose.
- An RBB can be attached directly to the cabinet or rack framework if the RBB is tin-plated. See Figure 5-30.
- If the RBB is mounted directly to the cabinet or rack framework, it **shall** provide sufficient spacing for bonding conductors. See Figure 5-30 for an example.

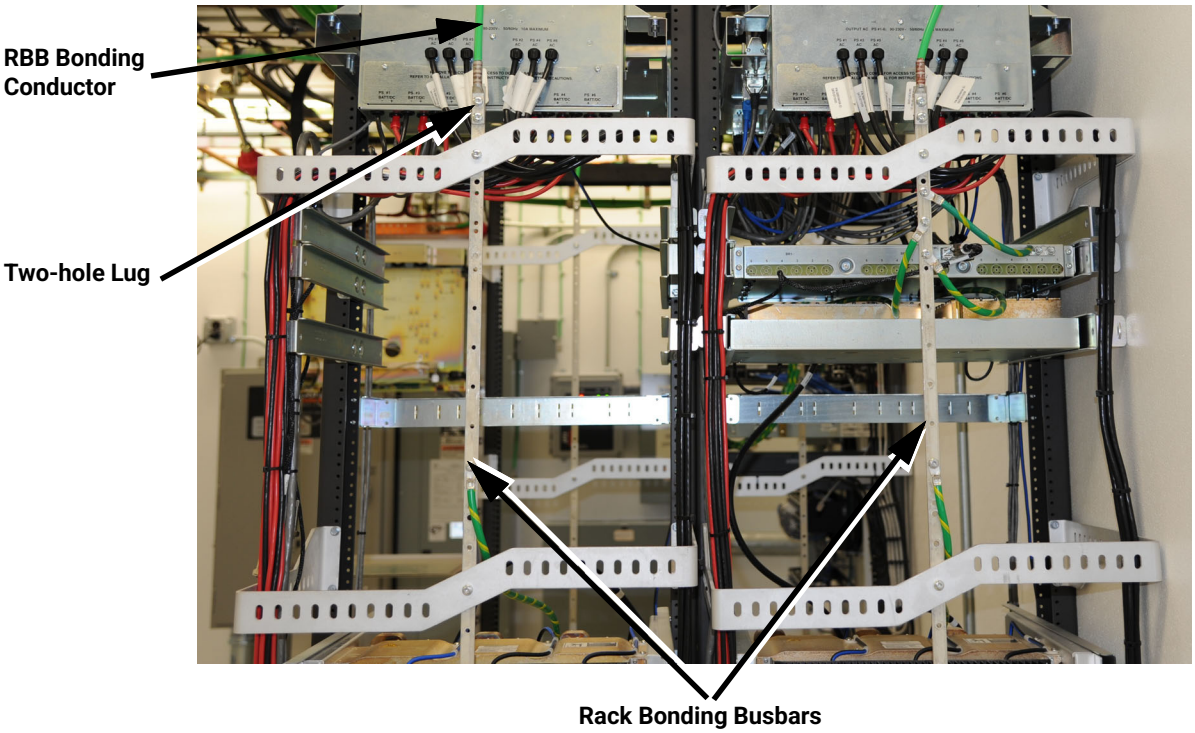


Figure 5-30. Example of Rack Bonding Busbar Mounted to Cable Management System

5.6.4.4 Rack Bonding Busbar Bonding Conductor Specifications

IMPORTANT: See "DC Powered Equipment Installed in a Rack or Cabinet" on page 5-100 for RBB bonding conductor sizing where the RBB supports DC powered equipment.

An RBB bonding conductor bonds the RBB to the internal bonding and grounding system infrastructure (for example, bonding bus conductor, SBB or PBB). In addition to the requirements described in "Bonding and Grounding (Earthing) Conductors" on page 5-41, the RBB bonding conductor **shall** meet the following specifications:

- The RBB bonding conductor **shall** be stranded copper unless otherwise specified in this chapter (TIA-607-E, section 6.3).
- The RBB bonding conductor **shall** be 35 mm^2 csa (#2 AWG) or larger and sized according to Table 5-3 on page 5-42.
- The RBB bonding conductor **shall** be green-jacketed as described in "Bonding and Grounding (Earthing) Conductors" on page 5-41.
- The RBB bonding conductor should be free of splices.

5.6.4.5 Rack Bonding Busbar Bonding Conductor Routing

In addition to the requirements outlined in "Bonding and Grounding (Earthing) Conductor Routing and Installation Requirements" on page 5-45, an RBB bonding conductor **shall** be routed toward the internal bonding and grounding system infrastructure (such as bonding bus conductors, SBB, or PBB), ensuring no sharp bends or narrow loops, and following the shortest and straightest routing path practicable.

5.6.4.6 Rack Bonding Busbar Bonding Conductor Connection Methods

The bonding conductor connection to the RBB **shall** be made using a two-hole lug according to “Bonding to the Primary Bonding Busbar, Secondary Bonding Busbar and Rack Bonding Busbar” on page 5-79 and “Connection to a Rack Bonding Busbar” on page 5-80. See Figure 5-30 for an example.

5.6.5 Network-Equipment Bonding Busbar

A Network-Equipment Bonding Busbar (NBB) is a termination point used for bonding network equipment within a cabinet or rack. Its purpose is to provide a convenient connection point for two or more similar network equipment units installed next to each other (either horizontally or vertically) in the same cabinet or rack. See Figure 5-31 and Figure 5-32 for examples.

Network equipment bonded to an NBB **shall** be limited to switches, routers, patch panels, or other low-powered or unpowered network devices installed within the same cabinet or rack. More than one NBB can be installed in the same cabinet or rack, provided each NBB is bonded to the Rack Bonding Busbar (RBB) or bonding bus conductor with a separate bonding conductor. See Figure 5-32 for an example of a rack installation with two NBBs bonded to an RBB



Figure 5-31. Example of Network-Equipment Bonding Busbar

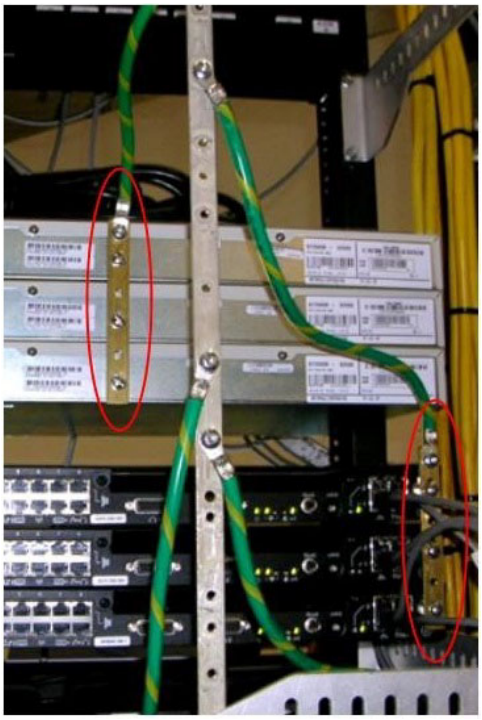


Figure 5-32. Example of Rack with Two NBBs Bonded to RBB

IMPORTANT: Radio transceivers and other high-power equipment **shall not** be bonded to an NBB.

5.6.5.1 Network-Equipment Bonding Busbar Specifications

Specifications for a Network-Equipment Bonding Busbar (NBB) are as follows:

- The NBB **shall** be designed by the manufacturer for electrical bonding.
- The NBB **shall** be made of solid copper, tinned-copper, or copper alloy.
- The NBB **shall** be at least 3.175 mm (1/8 in.) thick and 15.875 mm (5/8 in.) wide.
- The NBB length **shall** be appropriately sized for the application.
- The NBB **shall** have sufficient predrilled holes to accommodate the required chassis bonding connections for the equipment.
- The NBB should be listed by a Nationally Recognized Testing Laboratory (NRTL).
- The NBB may have scored and detachable sections for sizing the bonding busbar to length.

5.6.5.2 Network-Equipment Bonding Busbar Location Requirements

The location of an NBB is as follows:

- An NBB **shall** only be installed inside an equipment cabinet or rack.
- The NBB is typically mounted vertically between two or more pieces of equipment stacked one above the other, or horizontally between two or more pieces of equipment placed side-by-side. See Figure 5-33 for examples of typical NBB mounting locations.

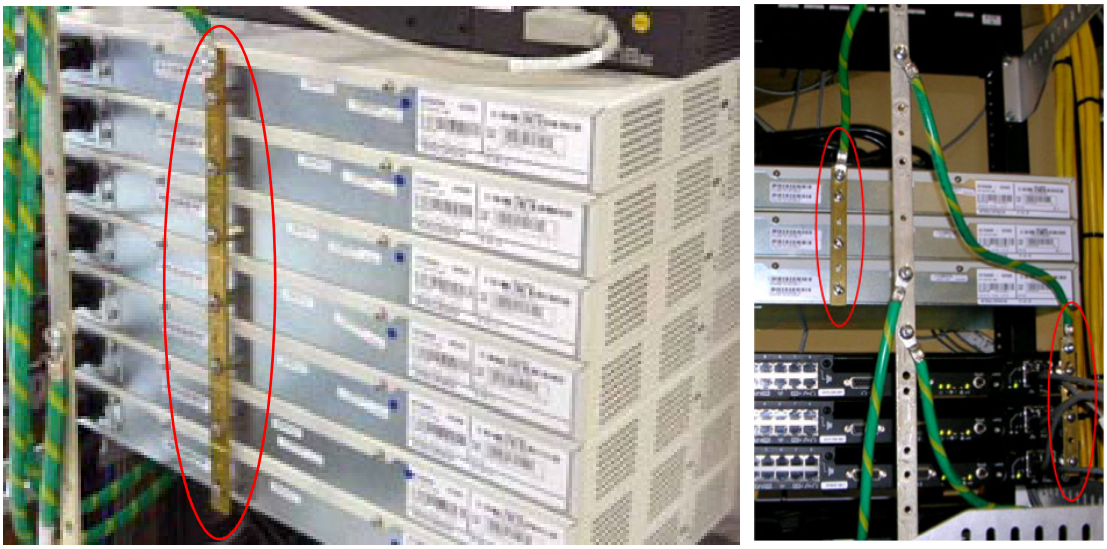


Figure 5-33. Typical Network-Equipment Bonding Busbar Mounting Locations

5.6.5.3 Network-Equipment Bonding Busbar Support and Bonding Requirements

The support requirements for the NBB are as follows:

- The NBB **shall** be mounted directly on the equipment chassis using approved hardware as described in this chapter.
- The NBB **shall** be attached to a manufacturer-provided grounding post or an equipment chassis threaded hole using appropriate hardware.
- The NBB **shall** be attached to each equipment chassis using appropriate stainless steel hardware. Stainless steel hardware is necessary to prevent issues caused by dissimilar metal reactions.
- If the equipment chassis grounding post is made of a material incompatible with copper (e.g., zinc-plated), a tin-plated bonding busbar **shall** be used.
- The equipment chassis **shall** be bonded to the NBB using stainless steel machine screw-type fasteners or nuts as follows:
  - The NBB **shall** be secured to the equipment chassis tapped hole using a machine screw-type fastener, as shown in Figure 5-34 and Figure 5-35.
  - The NBB **shall** be secured to the equipment chassis threaded grounding post using a nut, as shown in Figure 5-34 and Figure 5-35.
  - The fasteners **shall** be installed with lock washers and flat washers as shown in Figure 5-34.
  - When a fastener is subjected to thermal cycling, such as in equipment installed in a non-climate-controlled cabinet, the lock washer should be replaced with a flat washer and a Belleville washer, as shown in Figure 5-35 (BICSI N3-20, section 8.5.2.3).

IMPORTANT: Individual pieces of equipment **shall not** be attached to an NBB with a bonding conductor. An NBB **shall** only be used for bonding equipment that allows a direct connection to the NBB. See Figures 5-34 and 5-35.

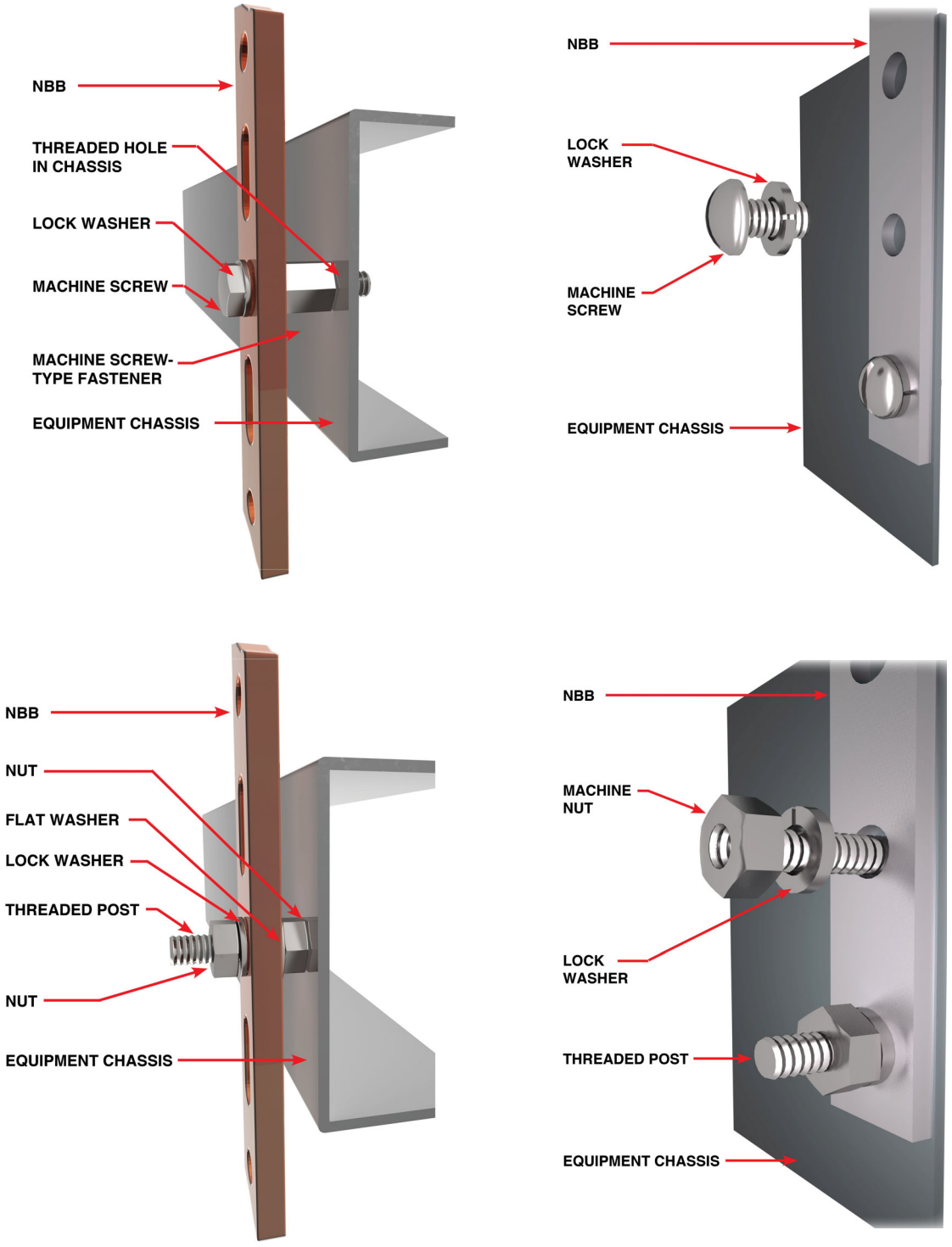


Figure 5-34. Examples of Bonding a Network-Equipment Bonding Busbar to an Equipment Chassis with Lock Washers

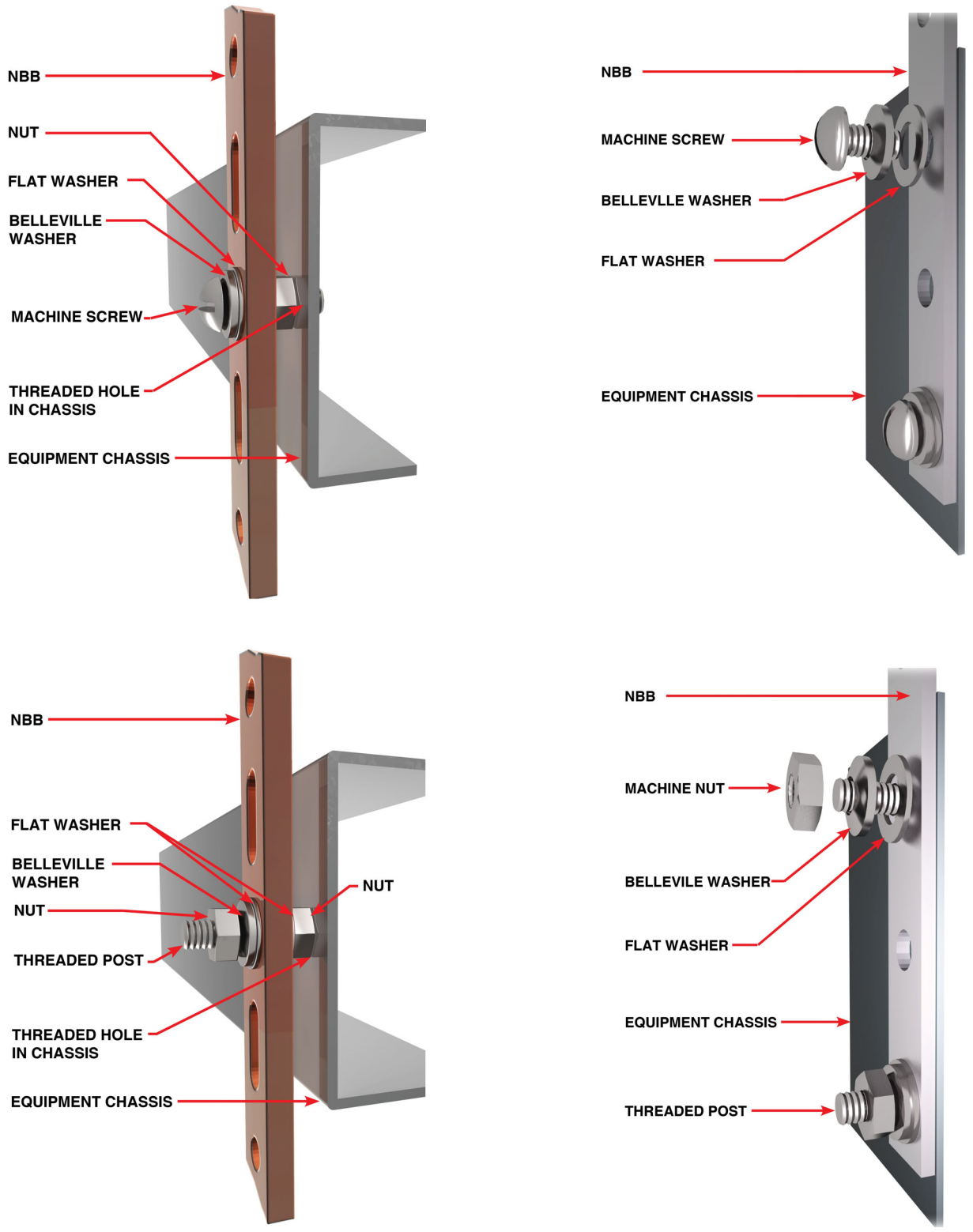


Figure 5-35. Examples of Bonding a Network-Equipment Bonding Busbar to an Equipment Chassis with Belleville Washers

5.6.5.4 Network-Equipment Bonding Busbar Bonding Conductor Specifications

The NBB bonding conductor bonds the NBB to an RBB or an equipment bonding bus conductor. In addition to the requirements described in “Bonding and Grounding (Earthing) Conductors” on page 5-41, the NBB bonding conductor **shall** meet the following specifications:

- The NBB bonding conductor **shall** be 16 mm^2 csa (#6 AWG) or larger.
- The NBB bonding conductor **shall** be sized according to Table 5-3.

5.6.5.5 Network-Equipment Bonding Busbar Bonding Conductor Routing Requirements

In addition to the requirements described in “Bonding and Grounding (Earthing) Conductor Routing and Installation Requirements” on page 5-45, NBB bonding conductors **shall** be routed toward the PBB as follows:

- The NBB bonding conductor **shall** be routed directly to the PBB bonding and grounding system, avoiding sharp bends or loops as described in this chapter. Refer to Figure 5-36 for the routing and attachment of the bonding conductor.
- Where practicable, the bonding conductor **shall** be attached to the end of the bonding busbar to ensure all network equipment chassis have a direct, continuous flow path toward the PBB.
- If equipment is placed at the top of the cabinet or rack and correct conductor routing to the RBB cannot be achieved, the NBB bonding conductor **shall** be bonded to the RBB bonding conductor to ensure appropriate routing toward the PBB. See Figure 5-36.
- If an NBB is mounted inside a cabinet or rack without an RBB, the NBB bonding conductor **shall** be connected to the cabinet or rack's equipment bonding bus conductor.

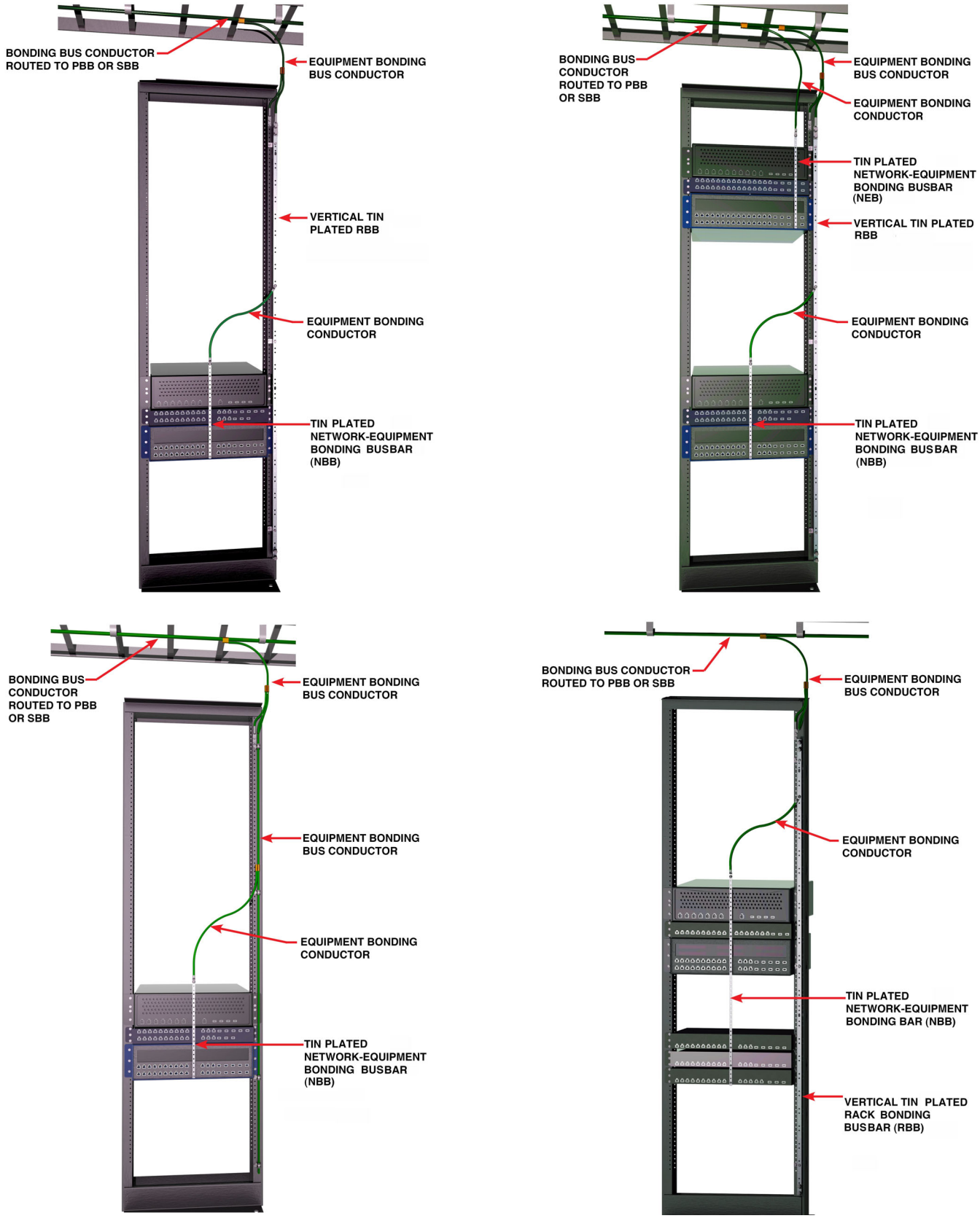


Figure 5-36. Acceptable Routing and Attachment of Network-Equipment Bonding Busbar Bonding Conductor

5.6.5.6 Network-Equipment Bonding Busbar Bonding Conductor Connection Methods

In addition to the requirements outlined in "Connection Methods for Internal Bonding and Grounding (Earthing) System" on page 5-69, a Network-Equipment Bonding Busbar (NBB) bonding conductor **shall** meet the following bonding requirements:

- The NBB bonding conductor **shall** be bonded to the NBB and the RBB using listed, irreversible compression lugs (single-hole or two-hole) and stainless steel securing hardware (BICSI N3-20).
- Where the NBB bonding conductor cannot be attached to the RBB due to conductor routing restrictions, the conductor **shall** be connected to a bonding bus conductor by following the requirements described in "Bonding to Bonding Bus Conductors" on page 5-82.

IMPORTANT: One NBB **shall not** be bonded to another NBB, thus establishing a daisy chain bonding connection. See Figure 5-37 for an example.

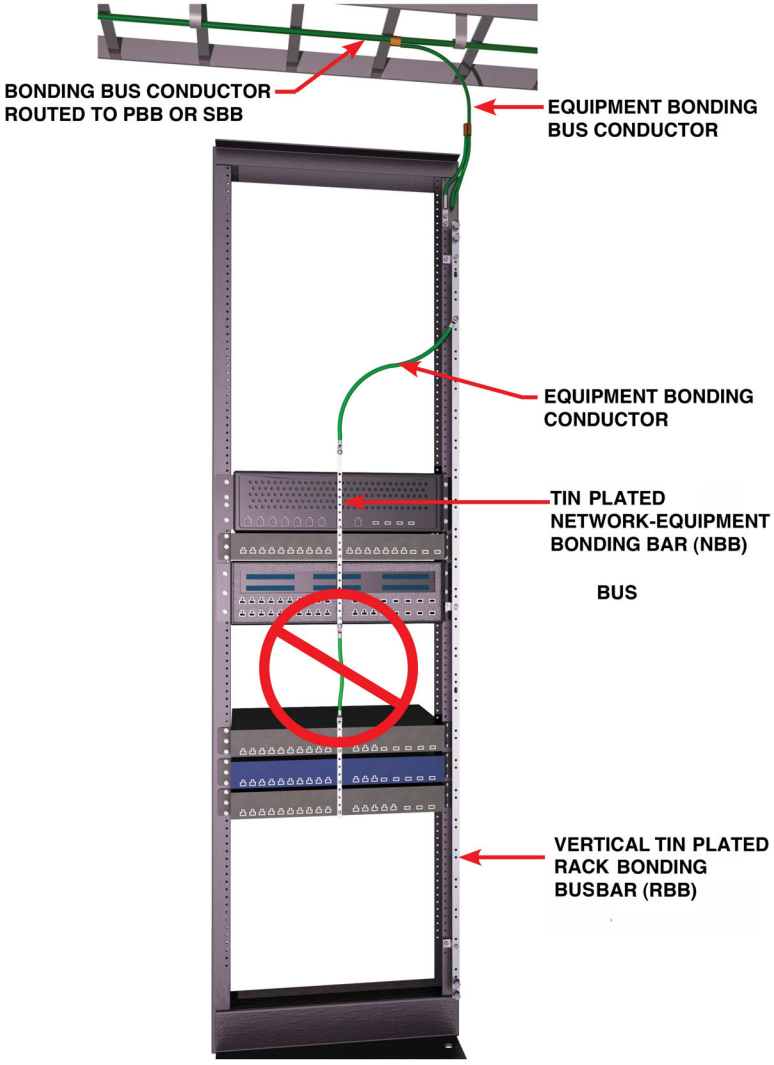


Figure 5-37. Non-acceptable Daisy Chain Bonding Connection

5.6.6 Bonding and Grounding (Earthing) Conductors

Equipment bonding and grounding help prevent differences in electrical potential between system components and metallic objects, thereby reducing the risk of personnel injury, system failure, and equipment damage.

Bonding and grounding conductors are the electrical conductors used to bond communications systems, equipment, and ancillary support apparatus to the site's Primary Bonding Busbar (PBB) and the grounding electrode system, creating an electrically conductive path.

The requirements in the following subsections apply to all interior bonding and grounding conductors unless otherwise specified or amended.

5.6.6.1 Bonding and Grounding (Earthing) Conductor General Specifications

Conductor general specification requirements are as follows:

- Interior bonding and grounding conductors **shall** be stranded copper unless otherwise specified in this chapter (ATIS-0600334-2019(R2024); BICSI N3-20, section 6; and Telcordia GR-3171-CORE.i02, section 10.8).
- The grounding electrode conductor for a PBB or SBB at an alternative cable entry point can be solid copper.
- Interior bonding and grounding conductors **shall** be jacketed unless otherwise specified in this chapter (BICSI N3-20, and ATIS-0600334-2019(R2024), section 7.1).
- The conductor insulating jacket **shall** be either green, green with a yellow stripe, or clearly identified with a distinctive green color, green tape, or green adhesive label at the termination points (BICSI N3-20, section 7.3.1; NFPA 70-2026, Article 250.119; Telcordia GR-3171-CORE.i02, section 10.8; and TIA-607-E, section 6.5.1).
- Bonding conductors **shall** be listed for the application (TIA-607-E, section 6.3.1). For example, conductors installed in a plenum space or riser space **shall** be rated for plenum or riser use, respectively.

IMPORTANT: Flat braided conductors **shall not** be used anywhere because they can generate RF noise

NOTE: Requirements for jacketing **do not** apply to conductors of a Bonding Grid. See “Supplementary Bonding Network or Bonding Grid” on page 5-63.

5.6.6.2 Bonding and Grounding (Earthing) Conductor Length and Gauge Requirements

Conductor length and gauge requirements are as follows:

- Bonding and grounding conductors **shall** be no longer than necessary to serve their intended purpose (BICSI N3-20, section 8.2).
- Bonding conductors **shall not** decrease in size as the bonding path approaches the Primary Bonding Busbar (PBB) (TIA-607-E, section 6.3.1).
- Conductor gauge requirements are detailed in the relevant sections of this chapter. Typically, the following are required:
  - Bus conductors (that is, conductors used to bond multiple items) **shall** be 35 mm² csa (#2 AWG) or larger.
  - Bus conductors longer than 10 meters (33 ft) **shall** be increased in size according to Table 5-3.
  - Conductors bonding individual items **shall** be at least 16 mm² csa (#6 AWG). Some exceptions to this requirement are listed in the following sections:
    - “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137
    - “Primary Surge Protective Devices” on page 5-124
    - “Secondary Surge Protective Devices” on page 5-125

- Bonding and grounding conductors within the bonding system infrastructure (such as grounding electrode conductor, PBB-to-SBB conductor, bonding backbone conductors, and bonding bus conductors) **shall** meet the size requirements specified in Table 5-3, unless otherwise noted (TIA-607-E).

IMPORTANT: Bonding conductors **shall not** decrease in size as the bonding path approaches the Primary Bonding Busbar (TIA-607-E, section 6.3.1).

NOTE: Improved bonding performance at high frequencies can be achieved by utilizing structural metal instead of, or alongside, a bonding/grounding conductor, as specified in Table 5-3.

Table 5-3. Bonding and Grounding Infrastructure Conductor Size Requirements

Conductor Linear Length	Conductor Size		International Available Conductor Size
less than 4 m (13 ft)	13.30 mm^2 csa	6 AWG	16 mm^2
4 to 6 m (14 to 20 ft)	21.15 mm^2 csa	4 AWG	25 mm^2
6 to 8 m (21 to 26 ft)	26.67 mm^2 csa	3 AWG	-
8 to 10 m (27 to 33 ft)	33.62 mm^2 csa	2 AWG	35 mm^2
10 to 13 m (34 to 41 ft)	42.41 mm^2 csa	1 AWG	-
13 to 16 m (42 to 52 ft)	53.49 mm^2 csa	1/0 AWG	50 mm^2
16 to 20 m (53 to 66 ft)	67.43 mm^2 csa	2/0 AWG	70 mm^2
20 to 26 m (67 to 84 ft)	85.01 mm^2 csa	3/0 AWG	95 mm^2
26 to 32 m (85 to 105 ft)	107.26 mm^2 csa	4/0 AWG	120 mm^2
32 to 38 m (106 to 125 ft)	126.70 mm^2 csa	250 kcmil	-
38 to 46 m (126 to 150 ft)	152.012 mm^2 csa	300 kcmil	150 mm^2
46 to 53 m (151 to 175 ft)	177.39 mm^2 csa	350 kcmil	185 mm^2
53 to 76 m (176 to 250 ft)	253.35 mm^2 csa	500 kcmil	240 mm^2
76 to 91 m (251 to 300 ft)	304.025 mm^2 csa	600 kcmil	300 mm^2
greater than 91 m (301 ft)	380.13 mm^2 csa	750 kcmil	400 mm^2

5.6.6.3 Bonding and Grounding (Earthing) Conductor Bending Requirements

Bonding and grounding conductor bending requirements are as follows. Figure 5-38 shows bending examples.

- Bonding and grounding conductors of all sizes **shall** maintain a minimum bending radius of 203 mm (8 in.) as practicable, unless otherwise specified (BICSI-N3-20, section 8.6.2; Telcordia GR-3171-CORE.i02, section 10.8; and TIA-607-E, section 7.5.2).
- The angle of any bend **shall not** be less than 90 degrees (BICSI N3-20, section 8.6.2; Telcordia GR-3171-CORE.i02, section 10.8; and TIA-607-E, section 7.5.2).

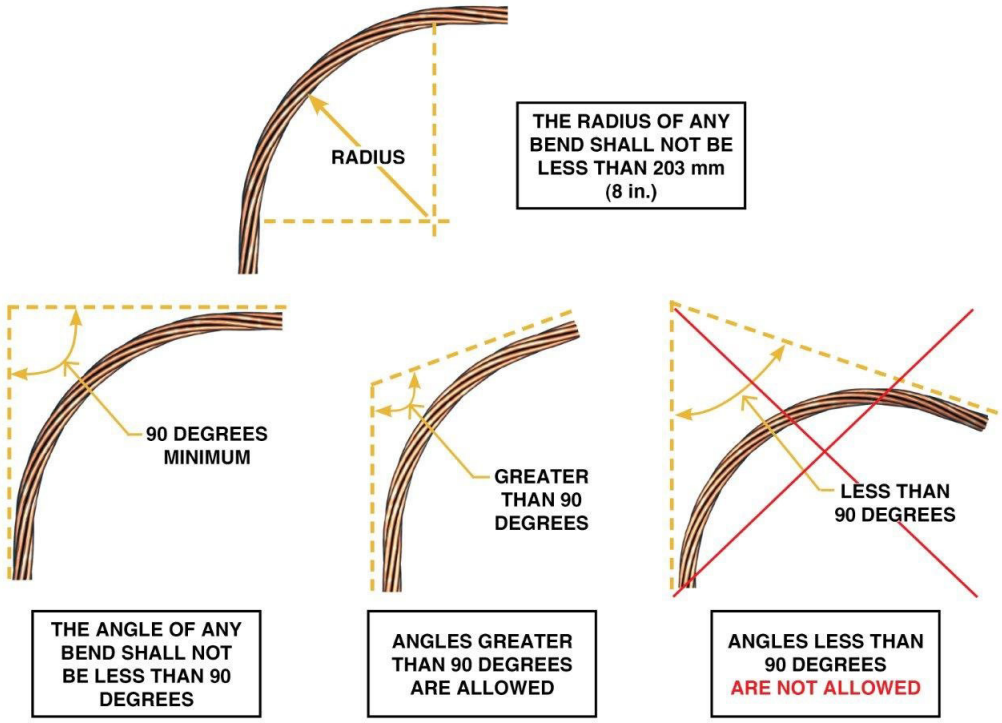


Figure 5-38. Minimum Conductor Bending Radius

5.6.6.4 Bonding and Grounding (Earthing) Conductor Separation

Conductor separation requirements are as follows:

- All bonding and grounding conductors **shall** be separated by at least 51 mm (2 in.) from conductors of other cable types, such as power, RF, and telecommunications (BICSI N3-20, section 8.6.3, and TIA-607-E, section 7.5.8.2).
- Bonding and grounding conductors may come closer to other cable groups if they cross at a 90-degree angle, and the crossing angle is maintained.
  - **Exception:** Conductors can be grouped together to enter or exit a cabinet or enclosure, provided the conductors are adequately separated on either side of the opening (BICSI N3-20, section 8.6.3, and TIA-607-E, section 7.5.8.2). See Figure 5-39.
- To minimize potential inductive effects where routing a bonding conductor through ferrous material, the conductor **shall** be kept at least 51 mm (2 in.) away from the ferrous material (TIA-607-E, section 7.5.8.2). See Figure 5-39 for an example.
- If a bonding conductor cannot maintain at least 51 mm (2 in.) separation from ferrous material, it **shall** be effectively bonded to the ferrous material as described in “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69 and applicable subsections (BICSI N3-20, section 8.6.3).

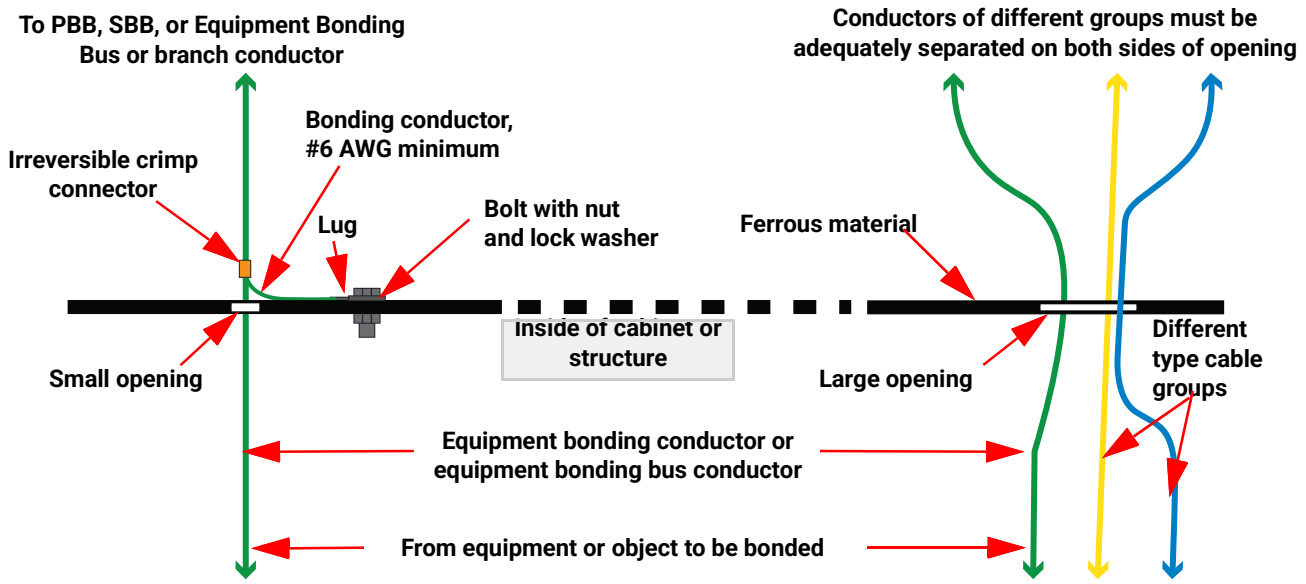


Figure 5-39. Conductor Routing Through Holes or Openings in Metallic Surfaces

NOTE: See "Primary Surge Protective Devices" on page 5-124 for primary SPD bonding conductor separation requirements.

5.6.6.5 Bonding and Grounding (Earthing) Conductor Protection

Conductor protection requirements are as follows:

- Conductors exposed to physical damage **shall** be sleeved in conduit securely attached to the surface where they are routed (BICSI N3-20, section 8.2).
- Bonding conductors should not be placed in ferrous metallic conduits (TIA-607-E, section 7.5.1).
- Where ferrous metallic conduit is necessary for adequate protection, the conductor **shall** be effectively bonded to each end of the conduit using appropriate hardware as described in "Connection Methods for Internal Bonding and Grounding (Earthing) System" on page 5-69 and applicable subsections (TIA-607-E, section 7.5.1).
- The conduit bonding conductor at both ends **shall** be at least 16 mm^2 csa (#6 AWG) (TIA-607-E, section 7.5.1); additionally, it is recommended to be the same size as the conductor in the conduit.
- Conductors installed inside metallic conduits should be jacketed.

5.6.6.6 Bonding and Grounding (Earthing) Conductor Support

Conductor support requirements are as follows:

- Conductors **shall** be secured or attached to surfaces as required to prevent damage or disconnection (BICSI N3-20, section 8.2).
- Conductors **shall** be secured in a manner that permits associated equipment to be easily serviced (BICSI N3-20, section 8.2).
- Conductors **shall** be secured at no greater than 914 mm (3 ft) intervals unless otherwise specified in this chapter (BICSI N3-20, section 8.2, and TIA-607-E).
- Conductor securing clamps **shall** be non-ferrous and specifically designed for the purpose.

- Jacketed bonding conductors installed on a cable tray **shall** be supported at intervals no greater than 914 mm (3 ft) (see TIA-607-E, section 7.5.8.1 for more details). The conductor can be installed either inside or outside the cable tray, using appropriate supporting hardware. Examples of suitable hardware include cable brackets and other brackets designed for this purpose (BICSI N3-20, section 8.6.1). See Figure 5-40 for an example.
- If a bare conductor is installed on a cable tray (or other metallic surface), it **shall** be supported with insulated standoffs to help prevent dissimilar metal reactions and incidental contact with the tray.
- Bare conductors **shall** be securely supported on appropriate standoff insulators at intervals no greater than 610 mm (24 in.), unless covered with electrical non-metallic tubing (ENT) (TIA-607-E).

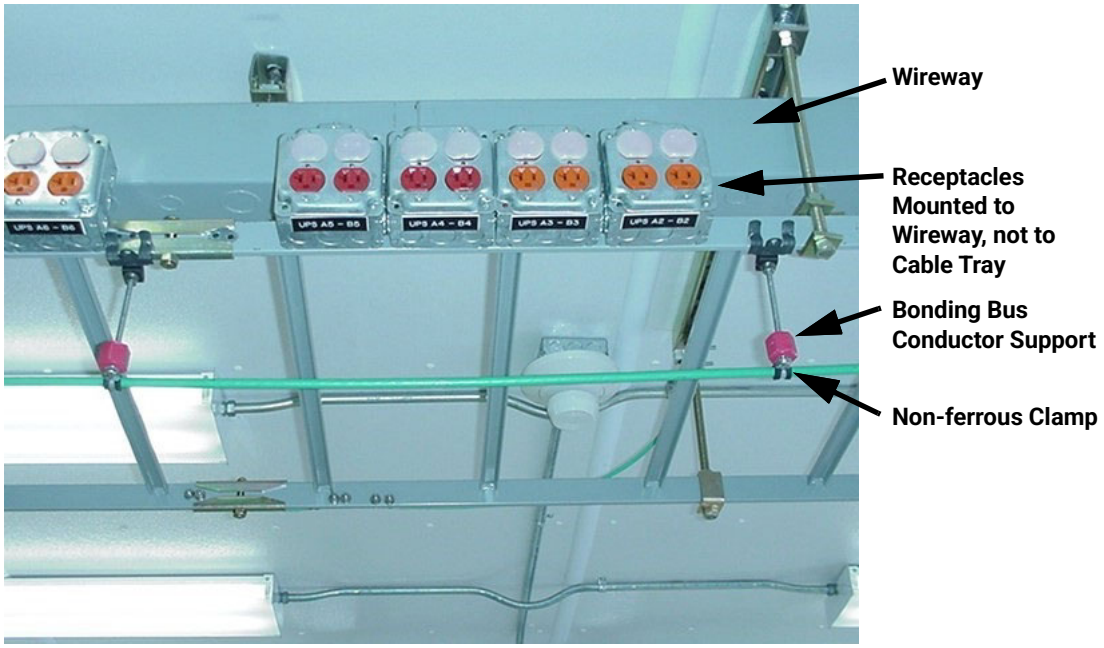


Figure 5-40. Supporting Bonding Bus Conductor on Outside of Cable Tray

5.6.6.7 Bonding and Grounding (Earthing) Conductor Routing and Installation Requirements

Bonding and grounding conductor routing and installation requirements are as follows:

- Conductors **shall** be installed in a professional, skillful, and workmanlike manner (see NFPA 70-2026, Article 110.12; BICSI N3-20, section 8.2; and TIA-607-E).
- Conductors **shall** be installed and routed to ensure that personnel safety is not compromised (BICSI N3-20, section 8.2).
- Conductors **shall** be installed and routed to ensure all equipment is serviceable (BICSI N3-20, section 8.2).
- Conductors **shall** be routed along the shortest and straightest practicable path, ensuring the conductors are no longer than required to achieve their purpose (BICSI N3-20, section 8.2).
- Conductors **shall** route toward the termination point (for example, the Primary Bonding Busbar (PBB) or grounding electrode system) as follows:
  - Where a grounding electrode conductor is attached to the PBB or a Secondary Bonding Busbar, it **shall** be placed on the busbar to ensure a direct flow path to the grounding electrode system.
  - Bonding conductors **shall** be placed on bonding busbars to ensure direct flow paths toward the PBB and earth.
  - Connections to the bonding backbone and equipment bonding bus conductors **shall** be made with the tap conductors routed toward the PBB (BICSI N3-20, section 8.6).
  - See Figure 5-41 for an example of connecting conductors to bonding busbars and tap conductors.

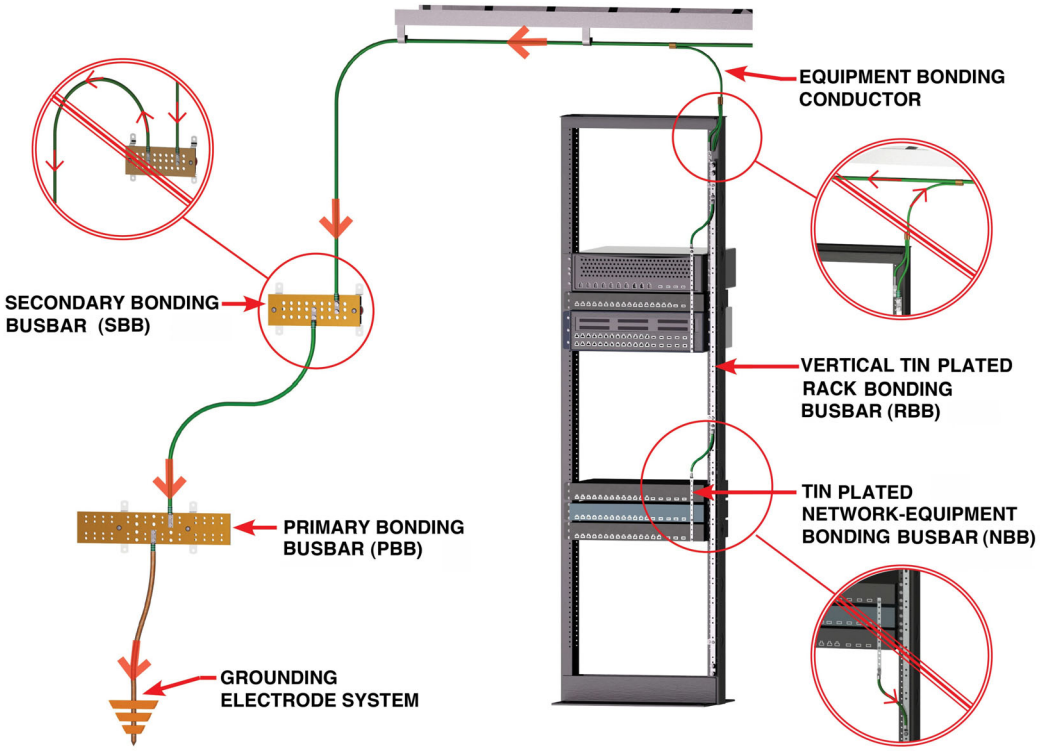


Figure 5-41. Example of Connecting Conductors to Bonding Busbars and Tap Conductors

- Bare conductors **shall not** contact metallic surfaces unless they are meant to be bonded to those surfaces.
  - Requirements for isolation **shall not** apply to flat copper straps of a Bonding Grid. See “Supplementary Bonding Network or Bonding Grid” on page 5-63.
- At points where conductors pass through holes in metallic surfaces, the surfaces **shall** be adequately protected with grommets or other materials to reduce damage to the conductor or the insulating jacket (BICSI N3-20, section 8.6.1).
- A conductor routed through an air-handling space **shall** have an approved jacket (plenum rated), or it may be bare (see BICSI N3-20, section 8.2, and NFPA 70-2026, Article 300.25). Refer to “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30.
- Bare conductors routed through an air-handling space **shall** be jacketed upon exiting that space (see BICSI N3-20, section 8.2 for additional information). The conductor may be spliced at this point using an approved irreversible splicing method described in “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69.
- A conductor routed between floors of a building **shall** have an approved jacket (plenum or riser rated), or it may be bare. See “Communications Cabling Requirements for Risers” on page 9-32.

IMPORTANT: Conductors installed in risers or air handling spaces **shall** have an approved jacket or be bare. See “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30 and “Communications Cabling Requirements for Risers” on page 9-32.

5.6.6.7.1 Conductor Routing and Installation Above Suspended Ceilings

The requirements for routing and installing bonding and grounding conductors above a suspended ceiling are as follows:

- Conductors **shall** be supported as described in “Bonding and Grounding (Earthing) Conductor Support” on page 5-44.

- Conductors installed above a suspended ceiling **shall** be supported to avoid excessive sagging.
- Conductors installed above a suspended ceiling **shall** be supported by a cable tray system or with listed hardware designed for the purpose.
- Conductors installed above a suspended ceiling **shall not** be supported by the ceiling grid (see NFPA 70-2026, Article 300.13). Refer to “Support and Securing” on page 9-27 for an exception.
- Conductors **shall** follow the same requirements outlined in “Support and Securing” on page 9-27.
- Conductors installed above a suspended ceiling **shall not** contact light fixtures or other sources of electromagnetic interference (EMI) generating sources.

IMPORTANT: Conductors installed in air handling spaces **shall** comply with requirements in “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30

5.6.6.7.2 Conductor Routing and Installation Under Raised Floors

Bonding conductors are typically secured beneath raised floors using two methods: attached to the floor pedestals or placed directly on the subfloor. The bonding conductor securing requirements are as follows:

- **If the bonding conductor is suspended from raised floor pedestals,** the conductor **shall** be secured at intervals of at least 914 mm (3 ft) using appropriate hardware (see Figure 5-42).
- **If the bonding conductor is placed directly on the subfloor,** it **shall** be secured at intervals not exceeding 3.66 m (12 ft) and as needed to prevent accidental displacement (see Figure 5-42).

IMPORTANT: Conductors installed in air handling spaces **shall** comply with the requirements in “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30.

NOTE: Bond the grid to the flooring system at least every fourth pedestal to ensure equal potential bonding between the flooring system and the grid (see Figure 5-64). Refer to “Supplementary Bonding Network or Bonding Grid” on page 5-63 and “Raised Computer Floor Bonding” on page 5-120 for more information.

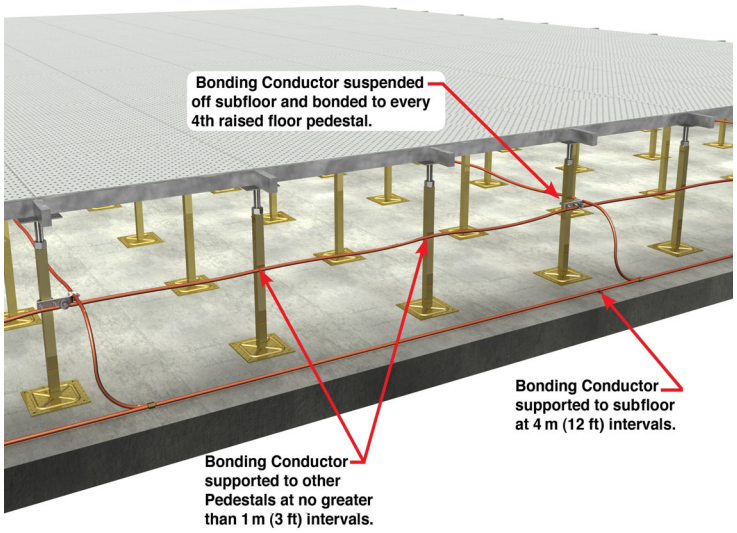


Figure 5-42. Securing Bonding Conductors Under Raised Flooring System

5.6.6.8 Equipment Bonding Conductor

An equipment bonding conductor bonds the equipment chassis or frames and metallic support structures to the internal bonding and grounding system. Each piece of equipment **shall** have a dedicated bonding conductor bonded to the Rack Bonding Busbar (RBB), bonding bus conductor, Bonding Grid, Secondary Bonding Busbar (SBB), or Primary Bonding Busbar (PBB) using suitable methods described in this chapter. Additionally, a bonding conductor from each piece of ancillary support apparatus **shall** be bonded to the PBB, an SBB, the Internal Perimeter Bonding Bus (IPBB), or Halo Ground Ring using appropriate methods described in this chapter.

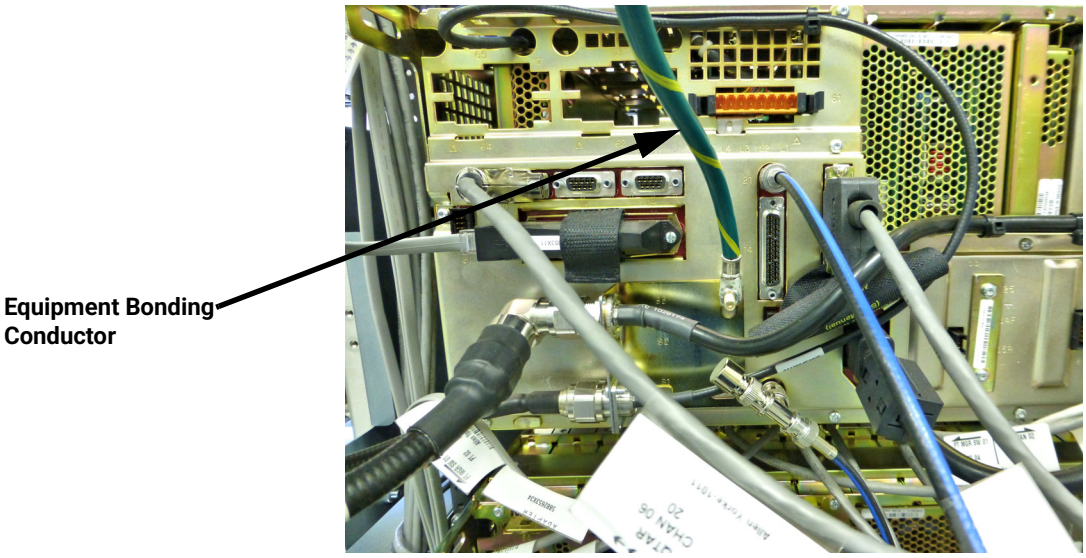


Figure 5-43. Example of Equipment Bonding Conductor

5.6.6.8.1 Equipment Bonding Conductor Location

One end of the conductor **shall** be bonded to the equipment or support apparatus using methods described in this chapter. The other end **shall** be bonded to the bonding bus conductor, bonding grid, RBB, SBB, PBB, or IPBB/Halo Ground Ring (ancillary support apparatus only) using suitable methods outlined in this chapter.

5.6.6.8.2 Equipment Bonding Conductor Specifications

Equipment bonding conductors **shall** comply with “Bonding and Grounding (Earthing) Conductors” on page 5-41 and relevant subsections. Additionally, bonding conductors **shall** meet the following requirements:

- Equipment bonding conductors **shall** be 16 mm^2 csa (#6 AWG) or larger, unless otherwise specified.
- If an equipment bonding conductor length must exceed 4 m (13 ft) before it terminates to a bonding bus conductor (including IPBB or Halo Ground Ring for ancillary support apparatus), bonding grid, RBB, SBB or PBB, the conductor **shall** be increased in size according to Table 5-4.

Table 5-4. Minimum Sizing of Bonding Conductors and Jumpers

Conductor Length	Conductor Size	International Conductor Size	Notes
-	3.3 mm^2 csa (12 AWG)	4 mm^2 csa	This size conductor **shall** be used only for bonding detachable cabinet doors and other detachable parts. See "Bonding Jumper Specifications" on page 5-50.
-	5.26 mm^2 csa (10 AWG)	6 mm^2 csa	This size conductor **shall** be used only in special applications as permitted in this chapter. See "Surge Protective Devices" on page 5-122 and "Bonding and Grounding for Dispatch Centers and Network Operator Positions" on page 5-137.
Less than 4 linear meters (13 ft)	13.30 mm^2 csa (6 AWG)	16 mm^2 csa	
4 to 6 linear meters (14 to 20 ft)	21.15 mm^2 csa (4 AWG)	25 mm^2 csa	
6 to 8 linear meters (21 to 26 ft)	26.67 mm^2 csa (3 AWG)	-	
8 to 10 linear meters (27 to 33 ft)	33.62 mm^2 csa (2 AWG)	35 mm^2 csa	
NOTE: See Table 5-3 for sizing of bonding conductors that exceed the distances listed in Table 5-4.			

5.6.6.9 Bonding Jumpers

A bonding jumper is a short conductor, usually 46 cm (18 in.) or less, used to create an electrically conductive path between components (see Figure 5-44). Examples include sections of cable trays that must be bonded together, or sections of structural steel, roof trusses, piping systems, conduits, or other metallic surfaces that need to be connected to maintain electrical conductivity. A bonding jumper **shall not** be used to replace equipment bonding or grounding (earthing) conductors

IMPORTANT: Flat braided conductors **shall not** be used anywhere, as they can generate RF noise, unless they are insulated and designed for the purpose as shown in Figure 5-47. Refer to Figure 5-45 for an example of a flat-braided jumper connecting the shelter door to the door frame. See Figure 5-114 for an example of correct door bonding.

NOTE: Bonding jumpers described in this subsection only apply to bonding jumpers as part of the bonding network, not to those used as part of the building electrical system.



Figure 5-44. Examples of Premanufactured Bonding Jumpers

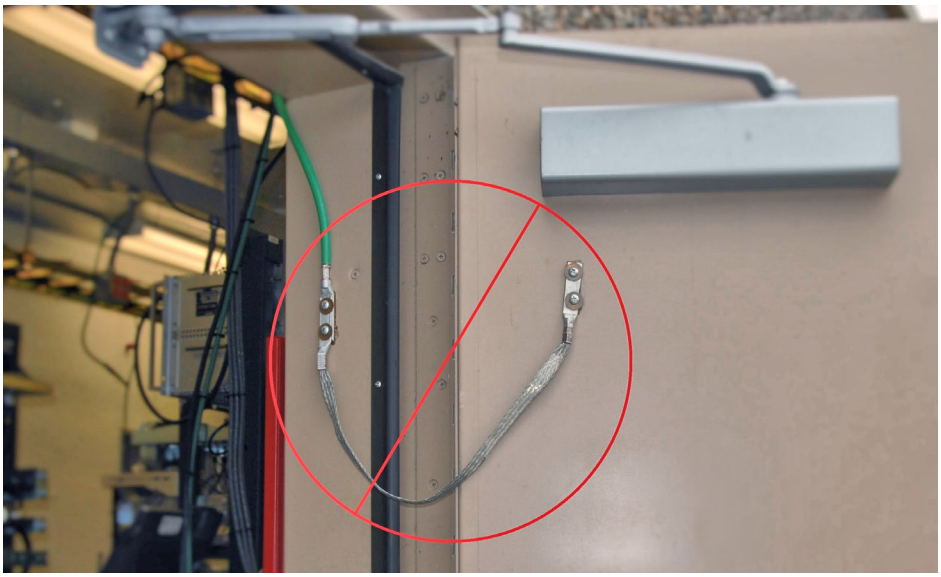


Figure 5-45. Incorrect Use of Flat Braided Bonding Conductor

5.6.6.9.1 Bonding Jumper Location Requirement

Bonding jumpers **shall** be installed to connect components of the same or similar structure. The placement will depend on the specific application. See Figure 5-46 for examples of cable tray section bonding jumpers.



Figure 5-46. Examples of Bonding Cable Tray Sections Using Jumpers

5.6.6.9.2 Bonding Jumper Specifications

Bonding jumpers **shall** meet the requirements of "Bonding and Grounding (Earthing) Conductors" on page 5-41 and relevant subsections. Additionally, bonding jumpers **shall** meet the following criteria:

- Bonding jumpers **shall** be 16 mm^2 csa (#6 AWG) or larger, unless otherwise specified.
- Bonding jumpers for equipment cabinet detachable doors (or other detachable metallic parts) **shall** be 3.3 mm^2 csa (#12 AWG) or larger (TIA-607-E, section 7.7). See Figure 5-47 for an example.
- Bonding jumpers **shall** be as short as practicable.
- Bonding jumpers **shall** be routed as straight as practicable, minimizing any bends.
- If the bonding jumper exceeds 4 m (13 ft) in length, the conductor **shall** be increased in size in accordance with Table 5-4.

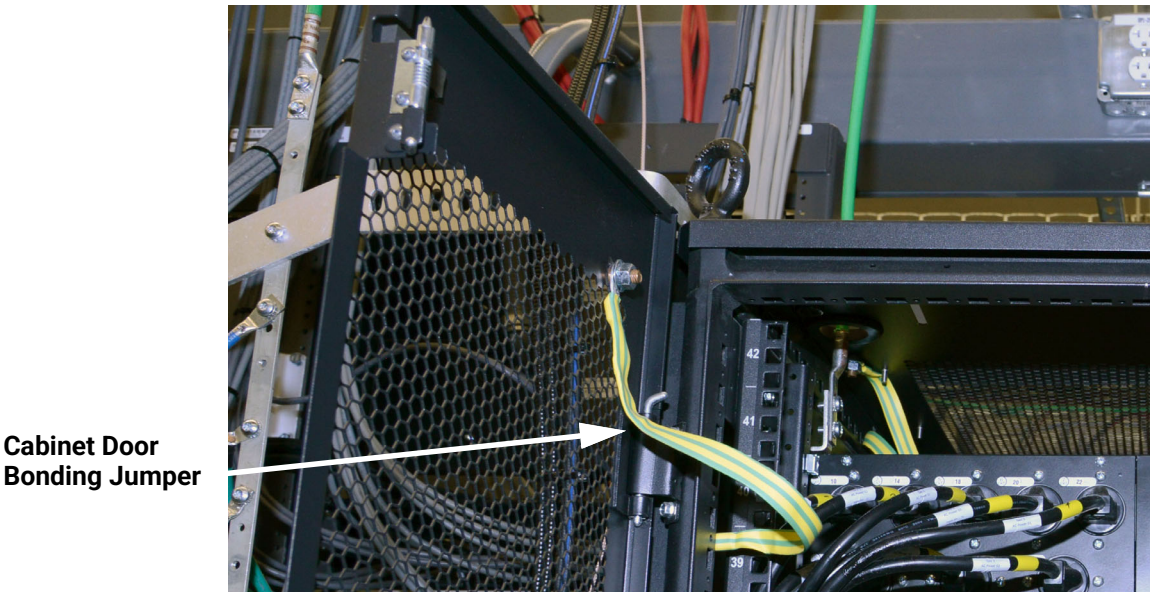


Figure 5-47. Example of Cabinet Door Bonding Jumper

5.7 Bonding and Grounding Infrastructure Subsystems

The following subsections describe the different bonding system infrastructure subsystems:

- "Equipment Bonding Bus Conductor" on page 5-51
- "Bonding Backbone and Bonding Backbone Conductor" on page 5-55
- "Backbone Bonding Conductor" on page 5-58
- "Internal Perimeter Bonding Bus Conductor or Halo Ground Ring" on page 5-58
- "Halo with Corner Down Conductors" on page 5-63
- "Supplementary Bonding Network or Bonding Grid" on page 5-63

5.7.1 Equipment Bonding Bus Conductor

Equipment bonding bus conductors are conductors used as a convenient bonding point for multiple pieces of equipment. A single bus conductor provides a more effective bond than running multiple individual conductors, thereby reducing the possibility of a voltage difference between components. Equipment bonding bus conductors typically originate at the Primary Bonding Busbar (PBB) or a Secondary Bonding Busbar (SBB) and extend throughout the equipment area, usually within the cable tray system.

The far end of the equipment bonding bus conductor, opposite the PBB or SBB, may remain unterminated or be connected to a cabinet, rack, individual system component, or RBB.

IMPORTANT: Do not terminate the far end (opposite the PBB/SBB) of the equipment bonding bus conductor to the cable tray system.

Equipment bonding bus conductors connect a Rack Bonding Busbar (RBB) to the PBB or a SBB (see Figure 5-48). They are also used to interconnect an SBB to the PBB; however, the SBB must be installed in the same equipment room or area. Otherwise, the requirements of a bonding backbone conductor **shall** be met (see "Bonding Backbone and Bonding Backbone Conductor" on page 5-55).

NOTE: By definition, equipment bonding bus conductors that extend beyond the PBB/SBB area into other rooms and/or areas of the building become bonding backbone conductors. See “Bonding Backbone and Bonding Backbone Conductor” on page 5-55 for more information.

Equipment bonding bus conductors may have branches that serve as additional equipment bonding bus conductors for extra rows of equipment (see Figure 5-49). These branches **shall** be the same size as the main equipment bonding bus conductor. All connections to the main bus conductor **shall** flow toward the PBB or SBB (see Figure 5-50). The branches **shall** be bonded to the main equipment bonding bus conductor using appropriate methods described in this chapter.

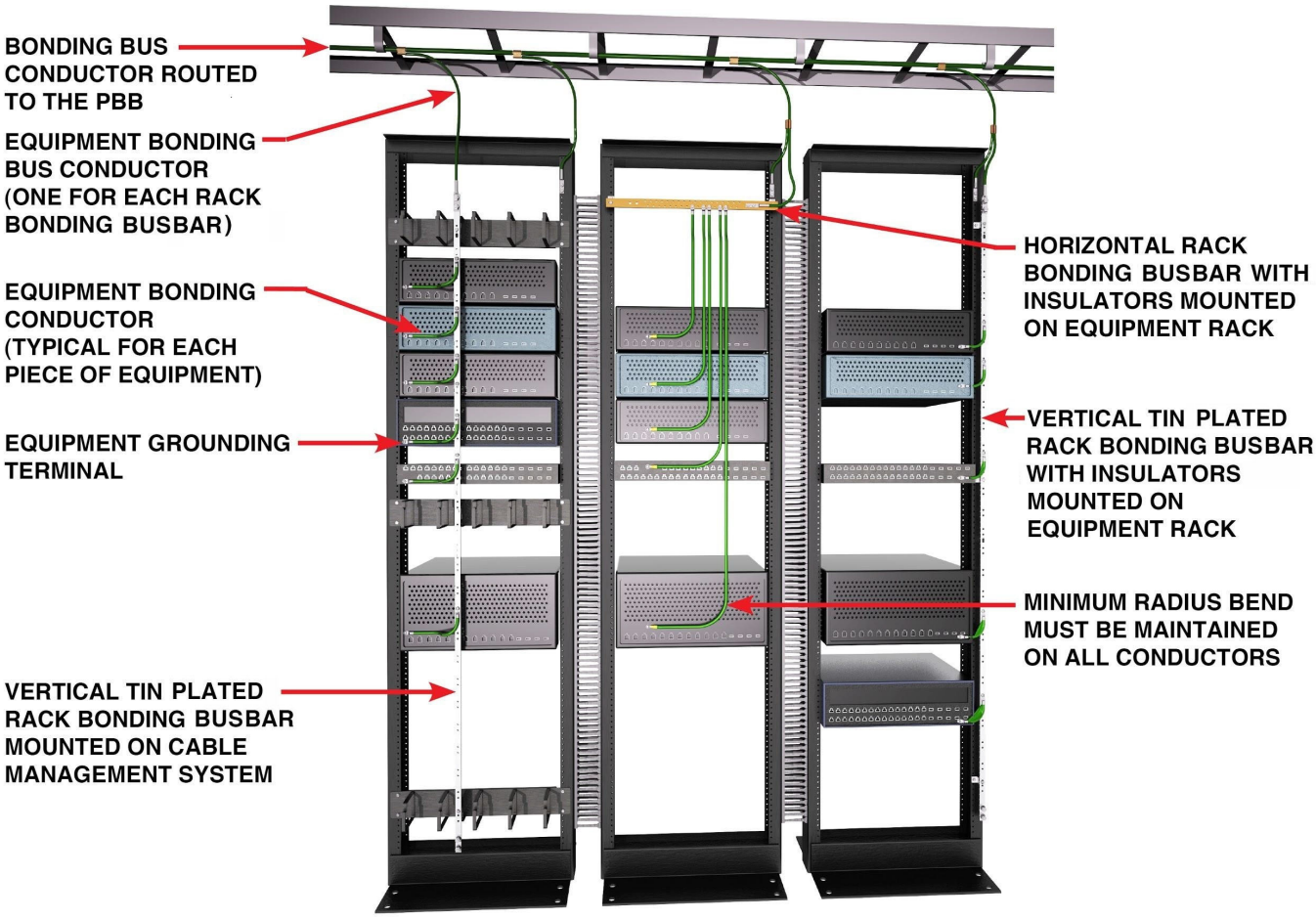


Figure 5-48. Equipment Bonding Bus Conductors Used to Bond Racks of Equipment

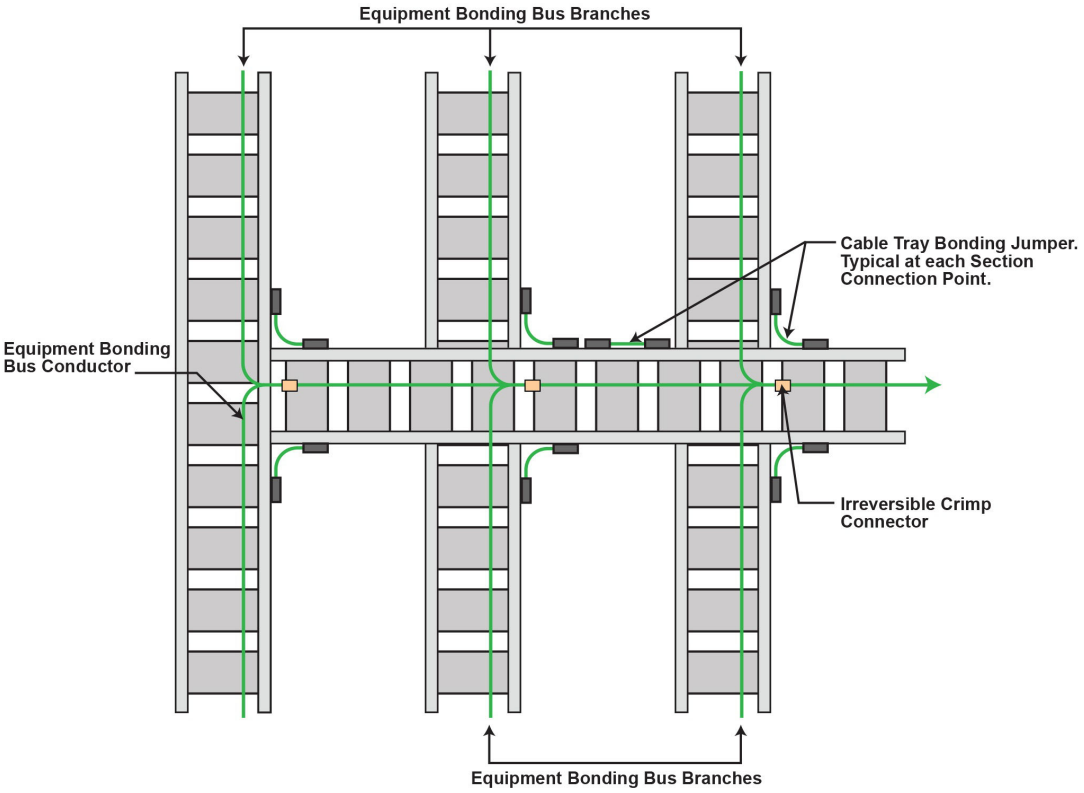


Figure 5-49. Example of Equipment Bonding Bus

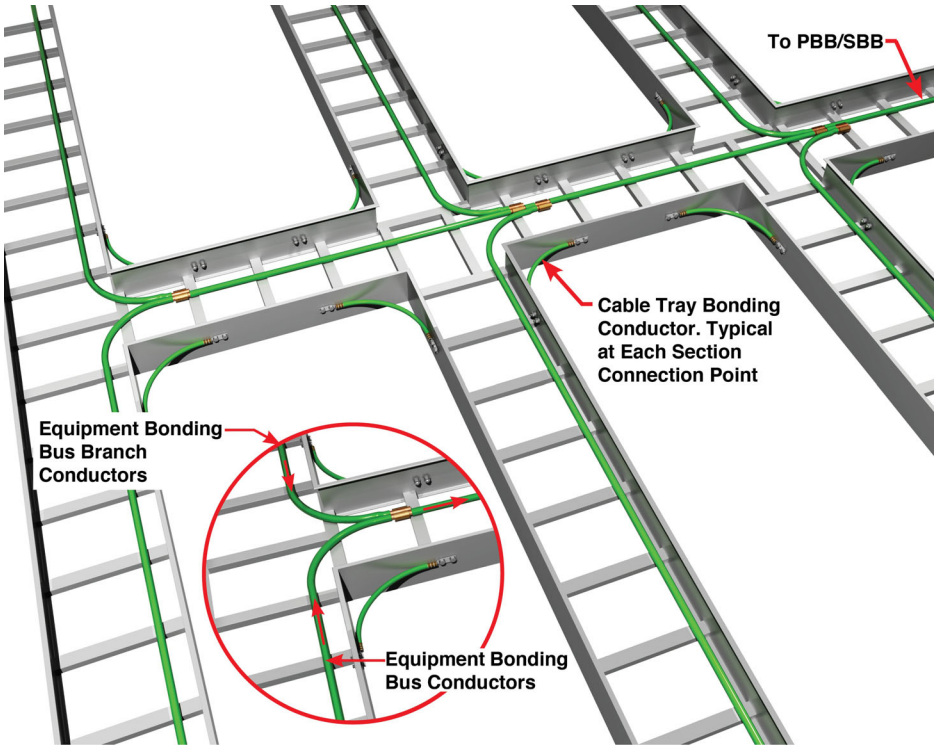


Figure 5-50. Equipment Bonding Bus Branch Conductor Routing to Primary Bonding Busbar or Secondary Bonding Busbar

5.7.1.1 Equipment Bonding Bus Conductor Location

One or more equipment bonding bus conductors are generally installed within the cable tray system above or below the equipment rows, depending on the equipment layout and cable tray configuration. Each equipment row **shall** have an equipment bonding bus conductor installed in each cable tray cross-section. This is necessary to ensure effective equipment bonding.

A common configuration is to have one equipment bonding bus conductor running the length of the equipment area, with bonding bus branch conductors serving additional equipment rows (see Figure 5-51).

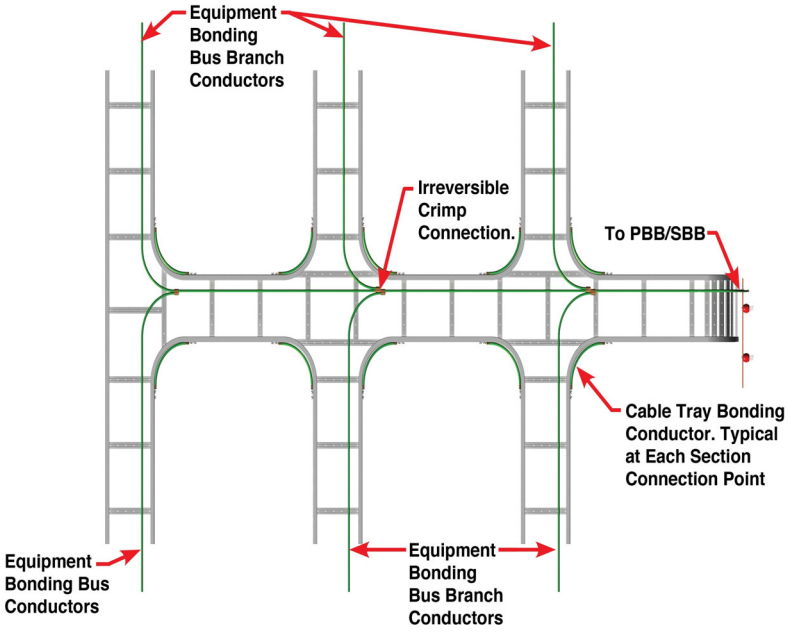


Figure 5-51. Example of Equipment Bonding Bus with Branch Conductors - Top View of Cable Trays

5.7.1.2 Equipment Bonding Bus Conductor Specifications

Equipment bonding bus conductors, including equipment bonding bus branch conductors, **shall** meet the following requirements:

- Equipment bonding bus conductors and bonding bus branch conductors **shall** be the same size.
- Equipment bonding bus conductors **shall** be 35 mm^2 csa (#2 AWG) or larger and **shall** be sized according to Table 5-3.
- Equipment bonding bus conductors **shall** be sized based on their lengths, which are determined by the farthest distance from the Primary Bonding Busbar (PBB) or, if applicable, from the Secondary Bonding Busbar (SBB) where it is part of a bonding backbone system.
- Where the bonding bus conductor terminates at an SBB that is part of a bonding backbone (such as in a commercial building), the bonding bus conductor **shall** be minimally sized based on the length, considering the farthest distance from the SBB.
- Equipment bonding bus conductors **shall** comply with the applicable requirements, specifications, and installation requirements of “Bonding and Grounding (Earthing) Conductors” on page 5-41 and related subsections.
- All bonding bus conductors should be installed without splices. If splices are necessary, their number must be minimized, and they **shall** be accessible and located only within telecommunication spaces. Joined segments **shall** be connected using exothermic welding or approved irreversible compression-type connectors. All bonding joints **shall** be adequately supported and protected from damage. See TIA-607-E, section 7.5.4.

For specific applications, a copper busbar of equal or larger size may be used instead of round conductors.

5.7.2 Bonding Backbone and Bonding Backbone Conductor

The bonding backbone conductor connects Secondary Bonding Busbars (SBBs) to the Primary Bonding Busbar (PBB) across multiple equipment areas in small, large, and multi-story buildings, forming the bonding backbone system. Its primary function is to reduce or equalize potential differences among all interconnected communication and electronic systems within the building. See Figure 5-52 and Figure 5-53 for examples.

Where two or more bonding backbones are used within a large or multi-story building, the communication bonding backbone conductors **shall** be bonded together with backbone bonding conductors (see “Backbone Bonding Conductor” on page 5-58). See Figure 5-52 for an example.

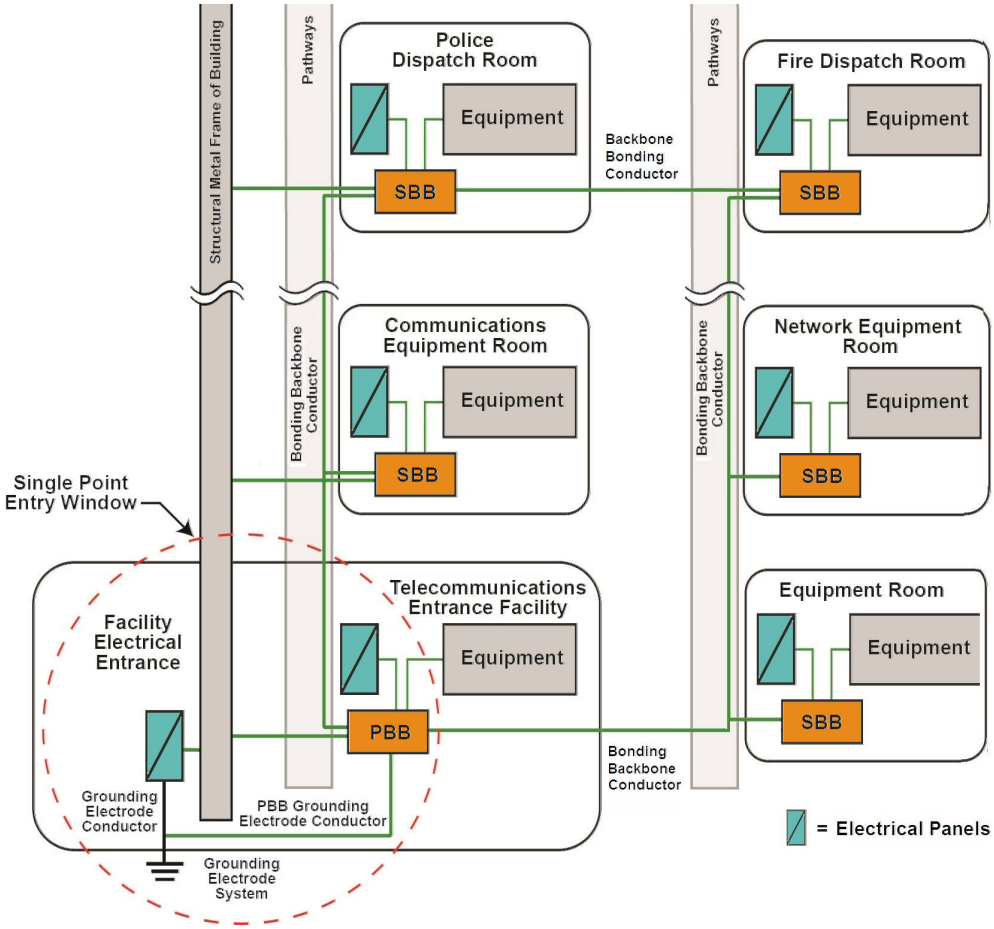


Figure 5-52. Example of Bonding Backbone in Multi-Story Building

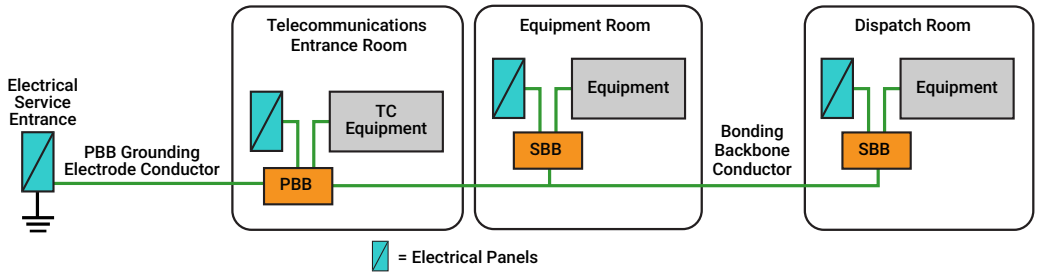


Figure 5-53. Example of Bonding Backbone in Single-Story Building

Where structural metal is bonded to the building's grounding electrode system, it may replace a bonding backbone conductor. Before using structural metal as a bonding backbone conductor, building plans, as-builts, and specifications **shall** be reviewed to ensure the metal is electrically continuous or can be made so. Additionally, electrical continuity tests should be conducted on the structural metal to verify continuity along the paths used as bonding conductors. See TIA-607-E, section 6.3.6.1 for additional information.

IMPORTANT: Concrete reinforcing steel, water piping systems, cable shields, metallic pathways, and conduits **shall not** be used as a bonding backbone conductor (TIA-607-E, sections 6.3.6.1 and 7.5.4).

NOTE: Improved bonding performance at high frequencies can be achieved by using structural metal, either instead of or in combination with a bonding backbone conductor (TIA-607-E, section 6.3.2).

NOTE: Modern building construction techniques will bond structural metal to the main AC power entrance or another grounding source. When working in existing buildings, ensure that the structural metal is bonded to an adequate ground source, such as an electrical power grounding electrode system. See TIA-607-E for additional information.

The PBB **shall** be bonded to the electrical service equipment (power) ground using a conductor of the same size or larger, as the bonding backbone conductor (TIA-607-E, section 6.3.3).

A bonding backbone conductor can serve as the grounding and bonding source for an SBB in a large equipment area, such as a dispatch floor. This SBB becomes the main SBB for that area, providing a common bonding point, as described in “Secondary Bonding Busbar” on page 5-17. Additionally, this main SBB may also serve as a common bonding point for dispatch operator position SBBs (or Position Bonding Terminals).

An operator position SBB bonding conductor (operator position SBB to area primary or main SBB) **shall** be sized at a minimum based on the length between the operator position SBB and the main SBB for the area, according to Table 5-3. This conductor does not need to be the same size as the bonding backbone conductor. See Figure 5-54.

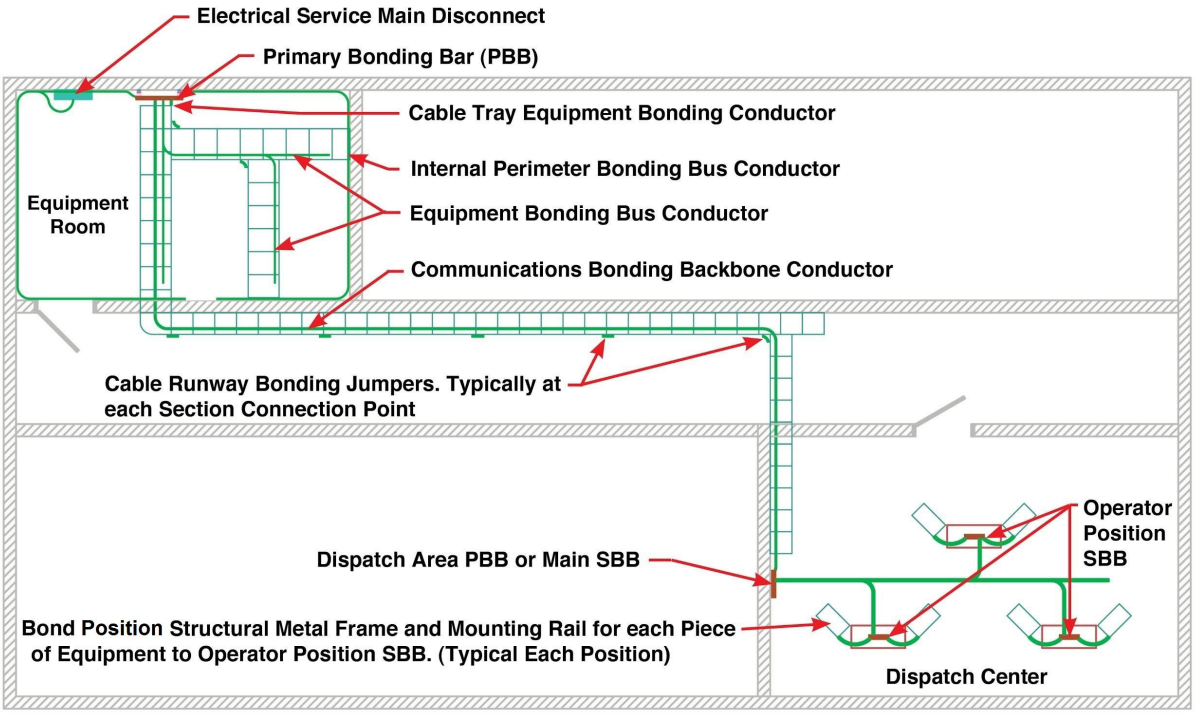


Figure 5-54. Example of Area Primary or Main Secondary Bonding Busbar

An operator position SBB (or Position Bonding Terminal) **shall not** serve another operator position SBB. Any additional SBB must be directly connected to the primary or main SBB in the area, or to the bonding backbone conductor. Also see “Interposition Bonding” on page 5-143.

- The bonding backbone conductor **shall** be a continuous conductor extending all the way to the farthest SBB (see Figure 5-52 and Figure 5-53).
- Intermediate SBBs **shall** be bonded to the bonding backbone conductor using the same size conductor as the bonding backbone. Bonding of the SBB conductor to the bonding backbone conductor **shall** be made according to “Bonding to Bonding Bus Conductors” on page 5-82.

5.7.2.1 Bonding Backbone Conductor Location

The bonding backbone conductor originates at the Primary Bonding Busbar (PBB), extends throughout the building along the telecommunications backbone pathways, and connects to Secondary Bonding Busbars (SBBs) in equipment rooms. The pathways **shall** be arranged to keep the required cable separation from other cable groups and to route cables efficiently, minimizing the length of the bonding backbone conductor.

Depending on the building construction, size, communication system requirements, and telecommunication cable pathways, one or more bonding backbone conductors may be installed (see Figure 5-52). Each bonding backbone conductor **shall** be installed to ensure protection against physical damage.

Typically, where equipment rooms or areas are located on different floors of a large multi-story building or a sizable single-story building (such as a dispatch center), separate bonding backbone conductors are routed on opposite sides of the building. To equalize potential, these bonding backbone conductors are bonded together using a backbone bonding conductor. See “Backbone Bonding Conductor” on page 5-58.

5.7.2.2 Bonding Backbone Conductor Specifications

Bonding backbone conductors **shall** meet the following requirements:

- Bonding backbone conductors **shall** be 35 mm² csa (#2 AWG) or larger and **shall** be sized according to Table 5-3.

IMPORTANT: Where a DC power system (see “DC Power Systems” on page 5-94) is bonded to the Primary Bonding Busbar (PBB) via a bonding backbone conductor, the conductor **shall** be sized according to “Sizing of SBB-to-PBB Conductor Where Part of a DC System” on page 5-103.

- Bonding backbone conductors **shall** meet the applicable requirements, specifications, and installation requirements of “Bonding and Grounding (Earthing) Conductors” on page 5-41 and associated subsections.
- Bonding backbone conductors **shall** be as free of splices as practicable (TIA-607-E, section 7.5.4).
  - If splices become necessary, they **shall** be made using exothermic welds or listed irreversible compression-type connectors.
  - Splices **shall** be accessible.
- The bonding backbone conductor **shall** be bonded to the Primary Bonding Busbar (PBB) (TIA-607-E, section 7.5.4).
- The bonding backbone conductor **shall** be continuous from the PBB to the farthest Secondary Bonding Busbar (SBB) (TIA-607-E, section 7.5.4). See Figure 5-52 and Figure 5-53.
  - The bonding backbone conductor **shall not** be daisy-chained from SBB to SBB (TIA-607-E, section 7.5.4).

5.7.3 Backbone Bonding Conductor

Where two or more bonding backbones are used within a multi-story building, the bonding backbones **shall** be interconnected (using the same size conductor or larger) with a backbone bonding conductor (formerly called a grounding equalizer conductor) at the top floor and at least every third floor down to the lowest level (see Figure 5-52).

Where two or more bonding backbones are used within a large single-story building, they **shall** be bonded together with a backbone bonding conductor at the location farthest from the Primary Bonding Busbar (PBB), as practicable. Additionally, the bonding backbone conductors **shall** be bonded together at minimum intervals of 30.5 m to 45.7 m (100 ft to 150 ft), as practicable.

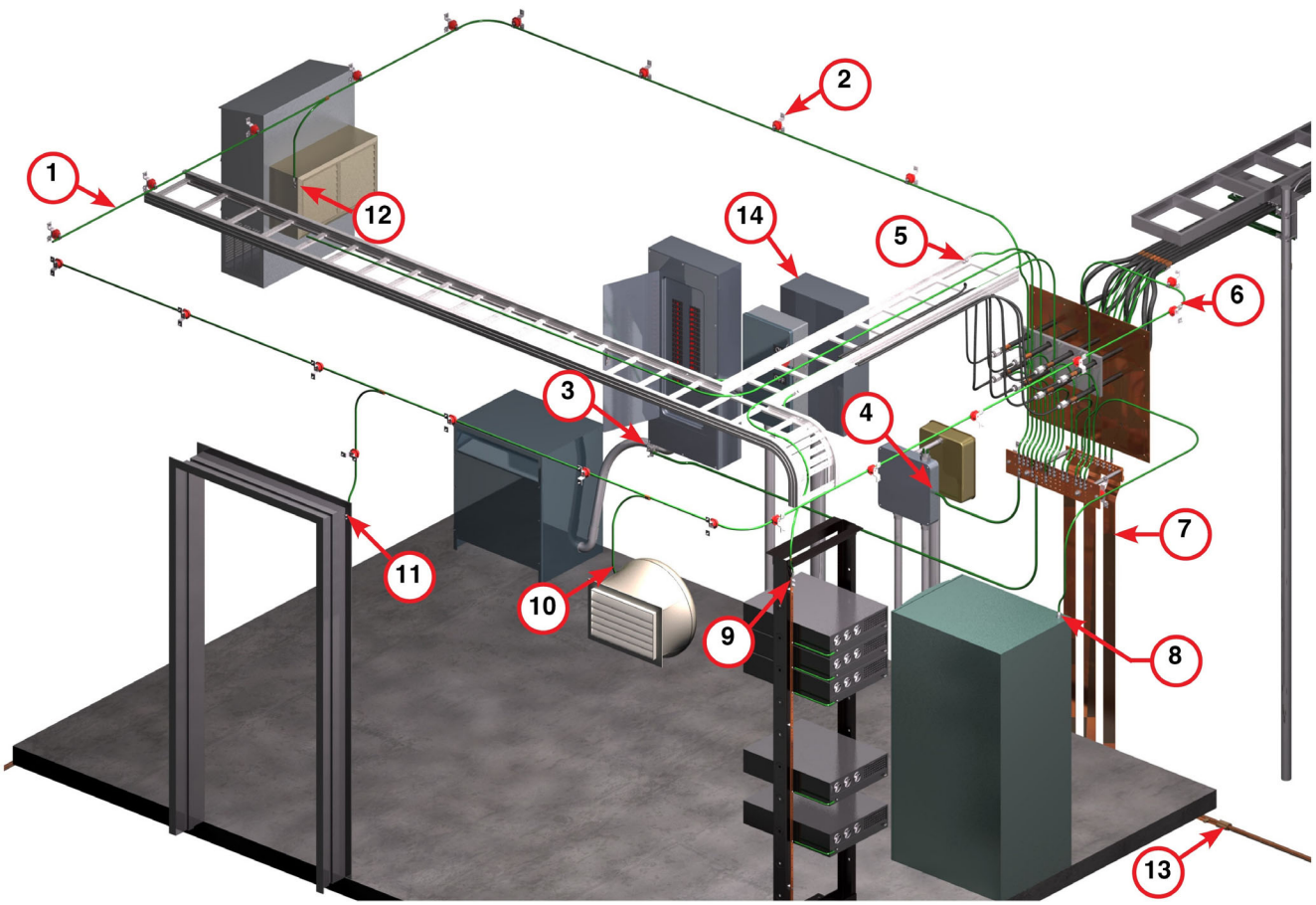
Where structural metal is bonded to the building's grounding electrode system, it can be used instead of a backbone bonding conductor. Before using structural metal as a substitute, review building plans, as-builts, and specifications to confirm that the structural metal is electrically continuous or can be made so. See TIA-607-E, section 6.3.6.1, for more information.

5.7.4 Internal Perimeter Bonding Bus Conductor or Halo Ground Ring

All ancillary metallic items larger than 10 cm^2 (4 $in.^2$) in a communications equipment area **shall** be bonded to the building's single-point ground as described in “Ancillary Support Apparatus” on page 5-112. The Internal Perimeter Bonding Bus (IPBB), also known as the Halo Ground Ring, serves as a bonding bus for ancillary support equipment, electrical conduits, ventilation louvers, metal door frames, and other metallic items (such as non-electronic items) located throughout the shelter, building, or room.

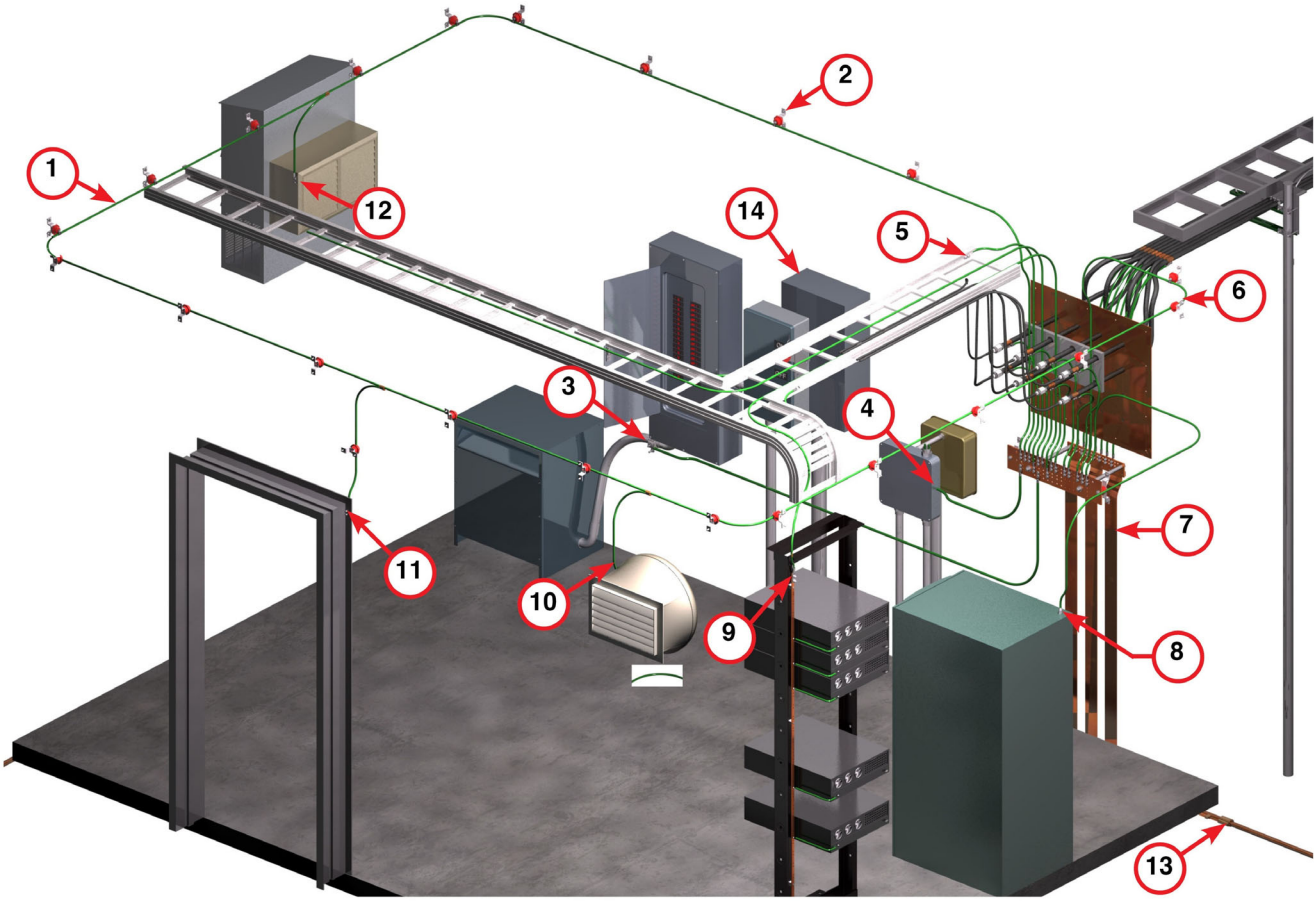
Differences:

- An IPBB includes an open loop as shown in Figure 5-55.
- A Halo Ground Ring contains a closed loop as shown in Figure 5-56.



1	#2 AWG INTERNAL PERIMETER BONDING BUS CONNECTED TO THE PBB AT ONE END	8	UPS EQUIPMENT GROUND CONDUCTOR TO THE PBB
2	STANDOFF CLAMP WITH INSULATOR	9	EQUIPMENT BONDING BUS TO PBB
3	BOND AC ELECTRICAL SERVICE TO THE PBB	10	BOND EXHAUST FANS AND AIR VENTS TO THE INTERNAL PERIMETER BONDING BUS
4	BOND TELCO GROUND TO THE PBB	11	BOND DOOR FRAME TO THE INTERNAL PERIMETER BONDING BUS
5	BOND CABLE TRAY TO THE PBB	12	BOND HVAC TO THE IPBB
6	BOND INTERNAL PERIMETER BONDING BUS TO PBB	13	SHELTER GROUND RING
7	ENTRANCE PANEL GROUND STRAPS EXOTHERMICALLY WELDED TO THE SHELTER GROUND RING	14	AC ELECTRICAL METER BOX

Figure 5-55. Example of Internal Perimeter Bonding Bus



1	#2 AWG HALO GROUND RING CONNECTED TO THE PBB AT BOTH ENDS	8	UPS EQUIPMENT GROUND CONDUCTOR TO THE PBB
2	STANDOFF CLAMP WITH INSULATOR	9	EQUIPMENT BONDING BUS TO THE PBB
3	BOND AC ELECTRICAL SERVICE TO THE PBB	10	BOND EXHAUST FANS AND AIR VENTS TO THE HALO GROUND RING
4	BOND TELCO GROUND TO THE PBB	11	BOND DOOR FRAME TO THE HALO GROUND RING
5	BOND CABLE TRAY TO THE PBB	12	BOND HVAC TO THE HALO GROUND RING
6	BOND HALO GROUND RING TO THE PBB	13	SHELTER GROUND RING
7	ENTRANCE PANEL GROUND STRAPS EXOTHERMICALLY WELDED TO THE SHELTER GROUND RING	14	AC ELECTRICAL METER BOX

Figure 5-56. Example of Halo Ground Ring

An IPBB or Halo Ground Ring **shall** be installed in all equipment shelters, buildings, or rooms designated for communications equipment, or in a generator power distribution room. An IPBB or Halo Ground Ring is not required in areas within a larger building where ancillary support apparatus (non-electronic equipment) is not present or where it is more practical to bond this support equipment directly to the Primary Bonding Busbar (PBB) or a Secondary Bonding Busbar (SBB) using individual equipment bonding conductors. An IPBB or Halo Ground Ring may be installed in locations where it is necessary to bond multiple support apparatus, regardless of the area's specific use. Motorola Solutions recommends installing an IPBB/Halo Ground Ring wherever a tower is associated with the site. See IEEE 1692-2023, section 8.6 and TIA-607-E, section D.2.9.

IMPORTANT: The Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring **shall not** be used for bonding communications or electronics equipment, such as cabinets, racks, or individual equipment chassis. The IPBB/Halo Ground Ring **shall** only be used for bonding ancillary metallic items.

5.7.4.1 Internal Perimeter Bonding Bus or Halo Ground Ring Specifications

In addition to the requirements described in “Bonding and Grounding (Earthing) Conductors” on page 5-41 and associated subsections, the Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring conductors **shall** meet the following specifications:

- The conductors **shall** be 35 mm^2 csa (#2 AWG) or larger and **shall** be sized according to Table 5-3.
  Halo Ground Ring Exception: Because a closed-loop configuration provides two parallel paths to the PBB or an SBB, the maximum conductor lengths in Table 5-3 may be doubled. For example, a 35mm^2 (#2 AWG) conductor can support a total ring perimeter of 20 m (66 ft).
- The conductors should be routed to minimize bends. The conductor bending radius **shall not** be less than 203 mm (8 in.). A bending radius of 305 mm (12 in.) is recommended (ATIS-0600334.2019(R2024), section 7.1).
- The conductors may be bare or jacketed.
- The IPBB or Halo Ground Ring can be made from stranded or solid copper conductors, copper bars, or solid copper straps with equal or larger surface areas. Stranded conductors are recommended for ease of installation.
- The conductors should be installed without splices. If splices are necessary, they **shall** be established using exothermic weld or listed irreversible compression crimping connections as described in “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69.

NOTE: The conductors may be either green-jacketed or bare. Green-jacketed is preferred to help prevent incidental contact with nearby metallic objects such as conduits.

5.7.4.2 Internal Perimeter Bonding Bus or Halo Ground Ring Installation

The Internal Perimeter Bonding Bus (IPBB) is typically installed to surround the equipment area with two separate conductors on opposite sides of the room, forming an open loop. In contrast, a Halo Ground Ring creates a closed loop with a single conductor (see IEEE 1692-2023 for more details).

- **IPBB:** The two conductors should meet at a point within the equipment area, approximately opposite the Primary Bonding Busbar (PBB) or Secondary Bonding Busbar (SBB). At the location where the two conductors meet, they **shall** be separated by a minimum distance of 104 mm (4 in.). See Figure 5-57 for an example. The maximum separation distance is site-specific; however, a 305 mm (12 in.) limit is recommended to minimize the length of ancillary equipment bonding jumpers.

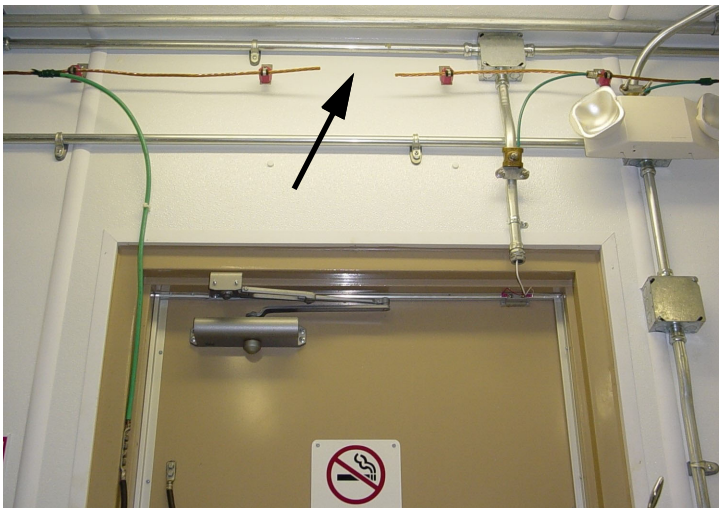


Figure 5-57. Example of Internal Perimeter Bonding Bus Conductors Separation - Opposite Primary Bonding Busbar

- **IPBB and Halo Ground Ring:** The conductors originate at the Primary Bonding Busbar (PBB), or from a Secondary Bonding Busbar (SBB) in a separate equipment area. These conductors are distributed throughout the equipment area, on interior perimeter walls just below the ceiling. The conductors **shall** be bonded to the PBB or SBB as described in “Bonding to the Primary Bonding Busbar, Secondary Bonding Busbar and Rack Bonding Busbar” on page 5-79. See “Ancillary Support Apparatus” on page 5-112 for more IPBB example figures.

IMPORTANT: If an Entry Point Secondary Bonding Busbar is present, the IPBB or Halo Ground Ring **shall not** daisy-chain through the SBB. The IPBB or Halo Ground Ring **shall** remain continuous and be bonded to the entry point SBB using a bidirectional method (see Figure 5-58).

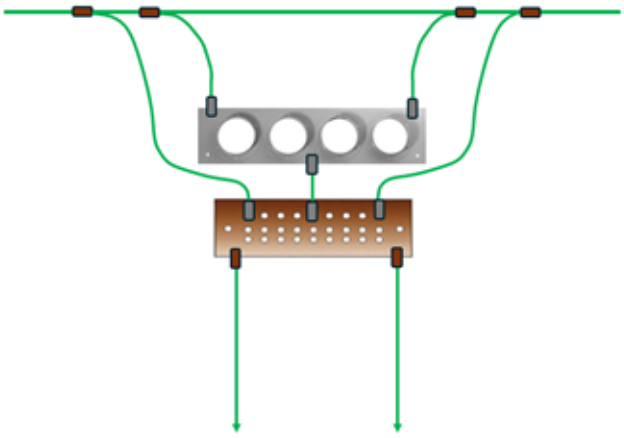


Figure 5-58. Example of Entry Point SBB Bonding to IPBB or Halo Ground Ring

5.7.4.3 Internal Perimeter Bonding Bus or Halo Ground Ring Location

The Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring conductors **shall** be located horizontally along the wall, close to the same height as the building entrance panel, typically between 2.1 m to 2.4 m (7 ft to 8 ft) above the finished floor or within 305 mm (1 ft) below the ceiling (ATIS-0600334.2019(R2024), section 7.1, and IEEE 1692-2023, section 8.5). See Figure 5-57 for an example.

5.7.4.4 Internal Perimeter Bonding Bus or Halo Ground Ring Support

In addition to the requirements described in “Bonding and Grounding (Earthing) Conductor Support” on page 5-44, the Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring conductors **shall** be supported as follows:

- The conductors **shall** be supported approximately 51 mm (2 in.) from the wall surface on insulated standoffs as shown in Figure 5-59.
- The standoffs **shall** be installed at approximately 610 mm (2 ft) intervals, or as necessary, to keep the conductor securely in place without noticeable sags or bends (ATIS-0600334.2019(R2024), section 7.1).
- The conductors **shall not** be completely enclosed in a ferrous metal, such as metal sleeves passing through walls or floors, or metal clamps (ATIS-0600334.2019(R2024), section 7.1), unless the conductor is bonded to the device.

Where transmission lines enter the equipment area at a lower point along the wall or through the floor or ceiling, and the PBB is located lower on the wall or on the floor or ceiling, the IPBB or Halo Ground Ring conductors **shall** be routed as specified in this section. **Exception:** at a point where these conductors can be easily connected to the PPB or SBB, they **shall** be routed across the ceiling or downward along the wall and connected to the PBB or SBB; a vertical cable ladder of appropriate design may be used for protection support.

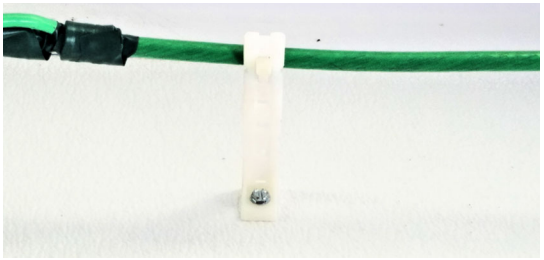


Figure 5-59. Example of Internal Perimeter Bonding Bus Mounting to Wall with Insulated Standoffs

5.7.5 Halo with Corner Down Conductors

The halo with corner down conductors is similar to the Internal Perimeter Bonding Bus or Halo Ground Ring, except that the conductor forms a continuous, unbroken loop and has direct connections to the grounding electrode system at each corner. Motorola Solutions does not recommend this grounding method because the direct connections to earth at each corner undermine the single-point grounding concept (see “Single-Point Grounding (Earthing) and the Single-Point Entry Window” on page 5-7). If a customer requires a halo with down conductors, the appropriate industry standard **shall** be followed.

5.7.6 Supplementary Bonding Network or Bonding Grid

The supplementary bonding network, also known as a bonding grid (mesh bonding network or mesh-BN), is a bonding system that can be used in conjunction with the bonding infrastructure described in this chapter. A bonding grid is typically installed in computer or IT rooms and/or dispatch centers to provide a higher level of equal potential bonding. Bonding grids are used for bonding electronic equipment and supporting devices. Bonding grids are bonded to the bonding and grounding infrastructure—such as the Primary Bonding Busbar (PBB), Secondary Bonding Busbar (SBB), or bonding backbone conductor—within the building or facility; thus, becoming part of the bonding and grounding infrastructure. Refer to Figure 5-60 for an example of a bonding grid.

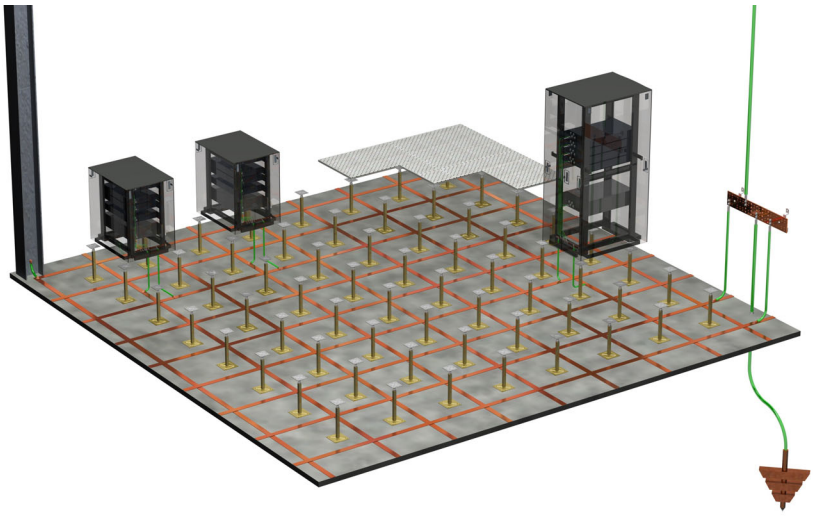


Figure 5-60. Example of Bonding Grid

IMPORTANT: See “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137 for further bonding requirements at these locations.

NOTE: Bonding grids are usually installed beneath a raised computer floor system. Unless otherwise specified, the installation will assume placement under the raised floor.

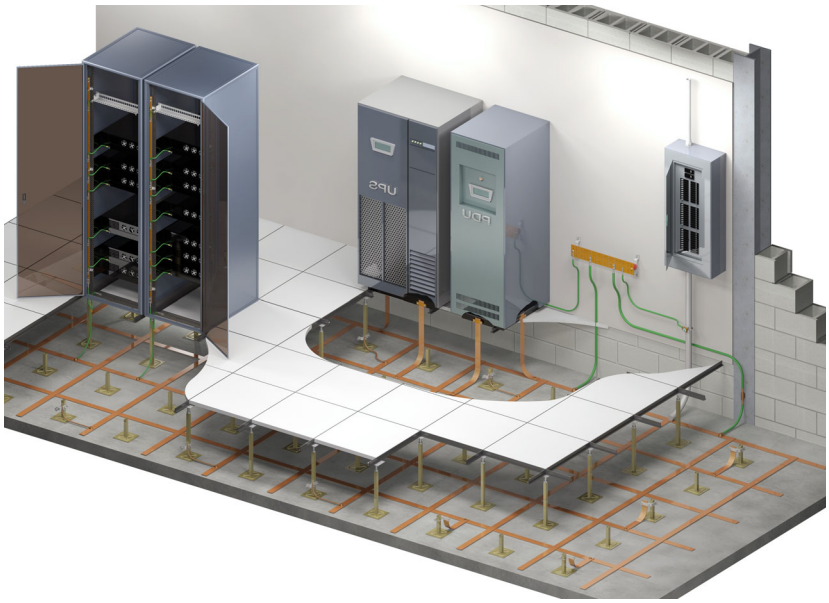


Figure 5-61. Example of Computer or IT Room Copper Strap Bonding Grid

5.7.6.1 Bonding Grid Material Requirements

The bonding grid may be constructed from flat copper strap or round conductors.

If the bonding grid is constructed from **flat copper strap**, the following **shall** apply:

- The bonding grid should be prefabricated (see Figure 5-61 and Figure 5-62).

- The copper strap **shall** be a minimum of 0.4 mm (.0159 in.; 26 gauge) by 50 mm (2 in.) wide (TIA-607-E, section 7.8.1).
- All crossings and joined sections **shall** be welded (TIA-607-E, section 7.8.1).
- The copper strap may be tinned.

If the bonding grid is constructed from **round conductors**, the following **shall** apply:

- The minimum size conductor **shall** be a 16 mm^2 csa (# 6 AWG) (ATIS-0600321.2020, section 7.7.1, and TIA-607-E, section 7.8.1).
- The conductor may be bare or jacketed.
  - If the conductor is bare, it **shall** be appropriately secured to prevent unintentional and/or incidental contact with metallic objects.
  - See "Bonding Grid Installation Requirements" below.

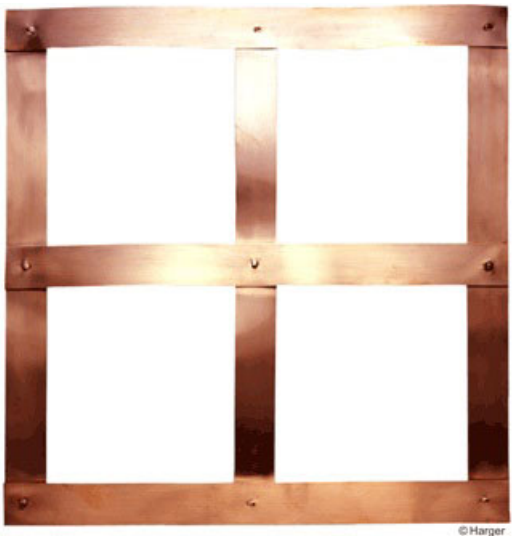


Figure 5-62. Example of Prefabricated Copper Strap Bonding Grid

5.7.6.2 Bonding Grid Installation Requirements

The bonding grid installation requirements are as follows:

- The bonding grid conductors (or straps) **shall** be arranged in a grid pattern with a spacing of 0.6 m (2 ft) to 3 m (10 ft). See TIA-607-E, section 7.1.3.
  - For improved high-frequency performance or lower impedance, a grid spacing of 0.6 m (2 ft) is recommended (TIA-607-E, section 7.1.3).
- The bonding grid conductors **shall** be bonded together at every intersection point using appropriate methods (TIA-607-E, section 7.8.1):
  - Exothermic welding
  - Listed irreversible compression connectors
  - Listed clamps (see Figure 5-63 for examples)
  - Listed combination clamp designed to bond floor pedestals and bonding grid conductors (see Figure 5-64)
  - Bonding grids constructed from straps **shall** be bonded together as described in "Bonding Grid Material Requirements" on page 5-64.
- The bonding grid conductors **shall** be secured as described in "Conductor Routing and Installation Under Raised Floors" on page 5-47.

- Where the conductors are placed directly on the subfloor, they **shall** be secured at intervals not exceeding 3.66 m (12 ft) and as needed to prevent accidental displacement.
- Where the conductors are suspended from raised floor pedestals, they **shall** be secured at least every 914 mm (3 ft) using appropriate hardware.
- See Figure 5-64 and Figure 5-65 for examples of conductor securing.

NOTE: Bond the grid to the flooring system at every fourth pedestal to ensure equal potential bonding between the grid and the flooring system (see Figure 5-65). Refer to “Raised Computer Floor Bonding” on page 5-120 for more information.



Figure 5-63. Examples of Bonding Grid Listed Clamps

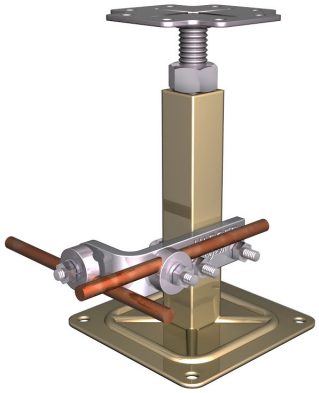


Figure 5-64. Example of Combination Floor Pedestal and Grid Bonding Clamp

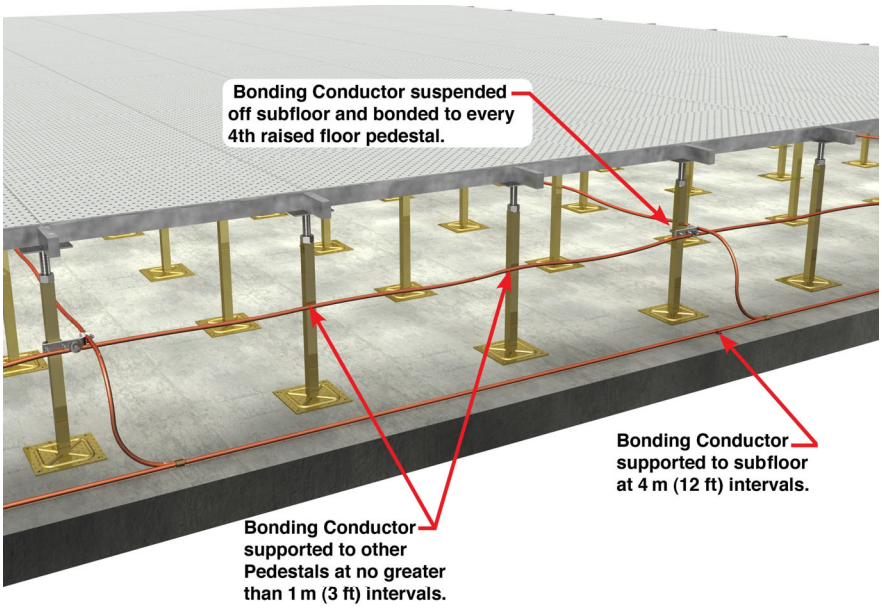


Figure 5-65. Example of Securing Grid Bonding Conductors Under Raised Flooring System

5.7.6.3 Items to be Bonded to the Bonding Grid

Bonding grids are used for bonding electronic equipment and support devices. The bonding grid (mesh-BN) **shall** have the following bonding connections, as applicable (see ATIS-0600321.2020, section 7.7.2, and TIA-607-E, section 7.8.1, for more information):

- Secondary Bonding Busbar(s) (SBB) as described in “Bonding Grid Connection to Earth” on page 5-68.
- Ancillary support apparatus as described in “Ancillary Support Apparatus” on page 5-112.
  - AC panel(s) serving AC receptacles in the room
  - HVAC equipment
  - Metallic air ducts
  - Metallic conduits
  - Metallic plumbing
- Structural metal columns within the computer, IT room, or dispatch area (see Figure 5-66).
- Electronic equipment as described in “Equipment” on page 5-103.
- Cabinets and racks as described in “Cabinets and Racks” on page 5-107. See TIA-607-E, section 7.1.4.
- Network operator (dispatch) positions Secondary Bonding Busbars (SBB). See “Equipotential Grounding (Earthing) of the Network Operator Position” on page 5-138 for more information.
- Cable tray systems as described in “Cable Trays” on page 5-109.
- Power Distribution Unit (PDU) in a computer, IT room, or dispatch area should follow the manufacturer's recommendations and NFPA 70-2026, Article 250.122.
- Raised computer floors as described in “Raised Computer Floor Bonding” on page 5-120 and applicable subsections.

Bonding to the bonding grid **shall** be done using exothermic welding or listed irreversible compression-type connectors (see “Bonding to Bonding Bus Conductors” on page 5-82 for more information).

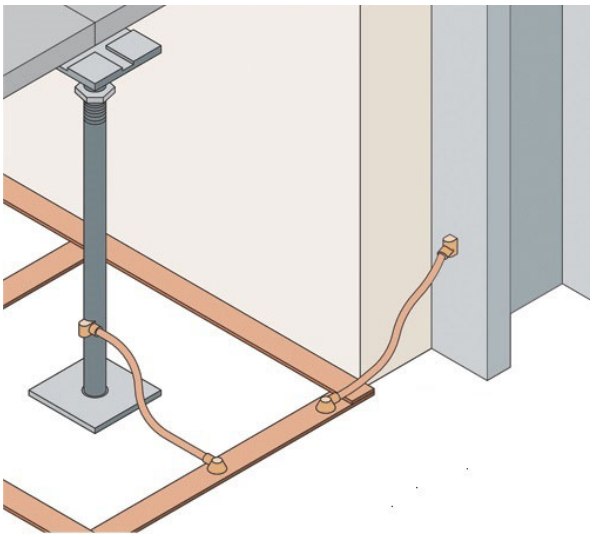


Figure 5-66. Example of Structural Metal and Floor Pedestal Bonding

5.7.6.4 Bonding Grid Connection to Earth

The bonding grid **shall** be bonded to the building's internal bonding and grounding system as follows:

- Each computer/IT room and/or dispatch area **shall** have at least one Secondary Bonding Busbar (SBB) for easy bonding of the grid and other items (TIA-607-E, section 7.1.3).
- If the facility has a bonding backbone with more than one vertical riser or horizontal backbone conductor, the computer/IT room and/or dispatch area **shall** contain at least two SBBs as practicable.
  - The SBBs **shall** be installed as far apart as practicable and positioned close to each respective bonding backbone conductor.
  - Each SBB **shall** be bonded to the closest location on the bonding backbone.
- The SBBs **shall** be strategically positioned in the computer/IT room or the dispatch area to enable easy connection of the bonding grid while maintaining a flow toward earth.
- The SBBs **shall** be bonded to the Primary Bonding Busbar (PBB) or bonding backbone conductor(s) using a conductor that is at least 35 mm² csa (#2 AWG).
  - The conductor(s) **shall** also be sized according to "Bonding and Grounding (Earthing) Conductor Length and Gauge Requirements" on page 5-41.
  - See "Secondary Bonding Busbar" on page 5-17 for more information.
- The bonding grid **shall** connect to the SBB(s) with a conductor that is at least 35 mm² csa (#2 AWG).
  - If more than one SBB is installed (such as in a bonding backbone with multiple vertical risers or horizontal backbone conductors), the bonding grid **shall** be bonded to each SBB.
  - The conductors **shall** also be sized based on "Bonding and Grounding (Earthing) Conductor Length and Gauge Requirements" on page 5-41.
  - If only one SBB is installed, it is recommended to bond the grid to the SBB using two bonding conductors. The conductors should be kept at least 0.6 m (2 ft) apart from each other, from the SBB to the bonding grid.

5.8 Connection Methods for Internal Bonding and Grounding (Earthing) System

All components of the internal bonding and grounding system and all equipment and ancillary support apparatus including, but not limited to, the items listed in Table 5-9, **shall** be effectively bonded together using the following requirements and connection methods:

- "General Bonding Requirements" on page 5-69
- "Lugs and Connection Devices" on page 5-72
- "Securing Hardware" on page 5-76
- "Mechanical Bonding Requirements" on page 5-76
- "Bonding Objects in Blind Locations" on page 5-77
- "Antioxidant Compound" on page 5-77
- "Exothermic Welding" on page 5-78
- "Bonding to Equipment and Ancillary Support Apparatus" on page 5-78
- "Bonding to the Primary Bonding Busbar, Secondary Bonding Busbar and Rack Bonding Busbar" on page 5-79
- "Bonding to Bonding Bus Conductors" on page 5-82
- "Bonding to Bonding Backbone Conductors and Backbone Bonding Conductors" on page 5-84

NOTE: In this standard, a 2-ton (1.81 tonne) connection is considered irreversible compression; a 12-ton (10.89-metric-tons) connection is considered irreversible high-compression.

NOTE: A tonne is also called a metric ton.

5.8.1 General Bonding Requirements

The following requirements apply where attaching conductors to equipment, ancillary support apparatus, bonding/grounding busbars and when attaching one conductor to another:

- Only connection devices that require the complete removal of the conductor jacket or insulation and create a connection to the entire conductor surface area **shall** be suitable for use.
- Listed two-hole, long-barrel, irreversible compression lugs are preferred over single-hole lugs and **shall** be required where two-hole lugs are specified within this chapter.
- No more than one clamp, fitting, or lug may be attached by the same bolt or bolts. An exception to this is where a jumper from a terminal strip or other internal connection point of the same equipment must be bonded to the equipment bonding/grounding conductor. See BICSI N3-20, section 8.5.2.3.
- No more than one conductor **shall** be connected by a single clamp, fitting, or lug unless the clamp, fitting, or lug is listed for multiple conductors.
- Solid conductors **shall** be attached to lugs and other conductors by an irreversible compression crimping process or exothermic weld. Only listed irreversible compression-type lugs and connection devices **shall** be used.
- Connections between dissimilar metals **shall not** be made unless the conductors are separated by a suitable material that is part of the attachment device. Only attachment devices listed and approved for use with the specific dissimilar metals are permitted for this purpose.
- An appropriate type of listed conductive antioxidant **shall** be applied to all dissimilar metal connections. See "Antioxidant Compound" on page 5-77 for more information.

- Where threaded or tapped holes are provided for attachment purposes, a star or split lock washer **shall** be installed under the screw or bolt head. See Figure 5-67 for the correct location of the star or split washer in these instances.
- Self-tapping or sheet metal screws **shall not** be used for attaching grounding conductors, except as permitted in “Bonding Objects in Blind Locations” on page 5-77. See NFPA 70-2026, Article 250.8, for additional information.
- Paint, enamel, lacquer, or other nonconductive coatings **shall** be removed from threads and surface areas where connections are made (NFPA 70-2026, Article 250.12). Using a star washer does not exempt the requirement to remove nonconductive coatings from attachment surfaces. Star or split-type washers **shall not** be installed between conductive surfaces. Correct placement of the lock washer is shown in Figure 5-67 (see BICSI N3-20, Figure 8-14).
- All two-hole lugs **shall** have bolts in both holes with lock washers placed on the nut side of the bonding surface.

IMPORTANT: Do not install any washer between the ground lug and the bonding surface.

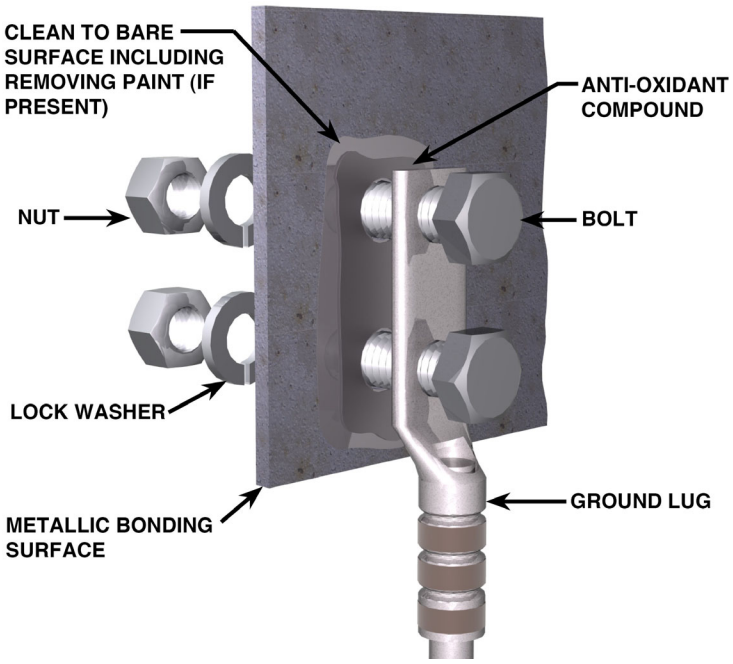


Figure 5-67. Proper Location of Washer When Connecting Ground Lug

The following methods of connection are **unacceptable** and **shall not** be used:

- Insulation piercing connectors **shall not** be used.
- Self-tapping or sheet metal screws **shall not** be used to establish continuous and permanent electrical bonds (see NFPA 70-2026, Article 250.8, and FAA-STD-019G, section 4.2.3.4.21), except as permitted in “Bonding Objects in Blind Locations” on page 5-77.
- Captive nuts (also known as Tinnerman clips or nuts) **shall not** be used (see FAA-STD-019G, section 5.6.5.5.2).
- Aluminum connection devices **shall not** be used.
- Star or split washers **shall not** be placed between conductive surfaces. These washers are only permitted under the head of the bolt and/or nut as shown in Figure 5-67.

- The series or daisy chain method of connecting a conductor from one piece of equipment to another and then to the bonding bus conductor **shall not** be permitted (see BICSI N3-20, section 8.2 and FAA-STD-019G). The series, or daisy chain, method refers to any connection in which conductors link from one chassis, equipment frame, or rack connection point to a second, and then to a third, forming a series arrangement. Removing the second connection point breaks the ground path from the first chassis, equipment frame, or rack. See Figure 5-68.
- Where attaching two conductors or attaching a conductor to a lug, connections **shall not** depend solely on solder (NFPA 70-2026, Articles 250.8 and 250.70), although crimped connections may be soldered.
- Crimp connections **shall not** be used on solid conductors unless they are listed and approved for the specific application.
- The use of mechanical set-screw lugs for grounding or bonding is prohibited, except where such hardware is an integral, factory-installed component of the equipment.
- Conductors **shall not** extend through or beyond the clamp, fitting, or lug unless the device is specifically designed and listed to allow this conductor extension.
- See Table 5-5 for a summary of the approved methods of bonding to the bonding and grounding infrastructure components.

NOTE: See Table 5-9 for more detailed information.

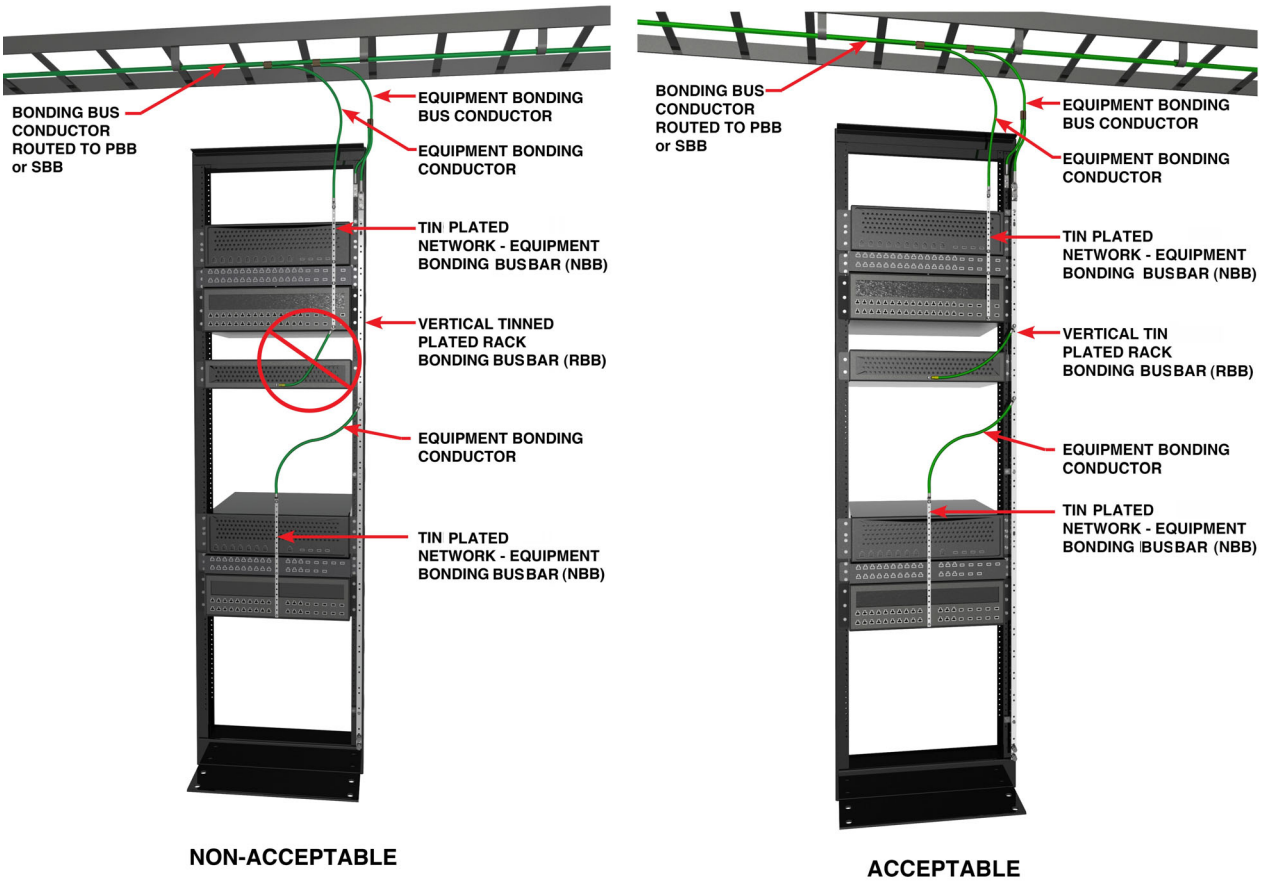


Figure 5-68. Daisy Chain Grounding Not Allowed

Table 5-5. Approved Methods for Bonding Connections to the Bonding and Grounding Infrastructure

Item	Single-Hole Lug	Two-Hole Lug	Irreversible Compression	Exothermic
PBB	-	✔	✔	✔
SBB	-	✔	✔	✔
RBB				
RBB Bonding Conductor	-	✔	-	-
Equipment	✔	✔	-	-
NBB	-			
NBB Bonding Conductor	✔	✔	-	-
Equipment	Direct connection only			
Bonding Bus Conductors	-	-	✔	✔
Bonding Grid	-	-	✔	✔

5.8.2 Lugs and Connection Devices

Interior bonding connections are typically made using listed single-hole lugs, listed two-hole lugs, listed coupling devices (such as thick- or thin-wall C-crimp, C-tap, or H-tap), or other approved component clamps.

The requirements for lugs and connection devices (such as coupling devices and clamps) are as follows:

- Lugs and connection devices **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL), such as CSA or UL (ATIS-0600333.2013(S2023)). See CSA C22.2 NO. 41:22 and UL 467-2022 for more information.
- Lugs and connection devices **shall** be listed for their intended purpose, the type of conductor, and the size and number of conductors used. See Figure 5-70 for an example of a listed lug marking.
- Lugs **shall** be of irreversible compression or exothermically welded types (ATIS-0600333.2013(S2023) and BICSI N3-20). See Figure 5-69 for examples of exothermically welded lugs.

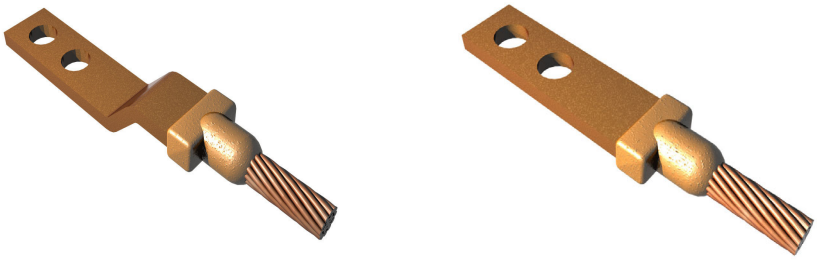


Figure 5-69. Lugs Exothermically Welded to Conductor

- Lugs used **shall** be the two-hole style, where practicable (ATIS-0600333.2013(S2023)).

NOTE: Two-hole long barrel lugs are preferred over single-hole lugs and **shall** be used where practicable. Two-hole lugs prevent movement of the lug (BICSI N3-20).

- Lugs and connection devices used on solid conductors **shall** be listed for use on solid conductors. See product documentation for listing details.
- Lugs used **shall** be designed to accommodate a minimum of 0.64 cm (0.25 in.) securing hardware, where practicable.

- Lugs and coupling/connection devices **shall** be made from copper, copper alloy, tinned-copper, tinned-copper alloy, or stainless steel.
- Clamping devices connected to steel or aluminum alloy pipes/conduits **shall** be tin-plated or stainless steel.
- Clamping devices **shall** be equipped with stainless steel securing hardware for attaching the conductor to the clamp.
- Connection devices used in lightning protection systems **shall** be listed for the purpose.
- Lugs **shall** be attached to conductors using either an exothermic weld process or an irreversible compression-type connection. See Figure 5-70 for an example of an irreversible compression connection and Figure 5-69 for examples of exothermic weld connections.
- Irreversible compression lugs and coupling devices **shall** be capable of being crimped to a minimum of 1.81437 tonnes (2-tons) of force.
- Irreversible compression lugs and coupling devices **shall** be crimped to the conductor with a minimum force of 1.81437 tonnes (2-tons).

IMPORTANT: Where aluminum lightning protection system conductors are used, appropriate listed connection devices **shall** be used.

IMPORTANT: Setscrew-style lugs are not permitted in the Internal Bonding and Grounding system. Lugs **shall** be either the exothermic weld type or an irreversible compression type (BICSI N3-20 and ATIS-0600333.2013(S2023)).

Table 5-6 provides general guidance on the correct hardware and bonding device. See product documentation for listing details and intended purpose.

Table 5-6. Recommended Bonding Matrix for Above-Grade Objects

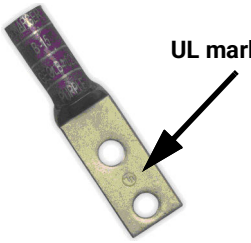
Item to be Bonded	Hardware		Connector				
	Stainless Steel	Silicon Bronze	Tin-Plated Copper/ Bronze Clamp	Tin-Plated Bronze Pipe Clamp	Tin-Plated Fence Fabric Clamp	Tin-Plated Conduit Clamp	Stainless Steel Clamp
Black Pipe (Fire Suppression Systems)	✓		✓	✓			
Galvanized Steel Conduit	✓					✓	
Aluminum Conduit	✓					✓	
Galvanized Steel	✓		✓				
Guy Wires	✓						✓
Copper Water Pipe	✓	✓		✓			
Galvanized Water Pipe	✓			✓			
Galvanized Fence/Gate Post (where exothermic welding is not possible)	✓			✓			
Galvanized Fence Fabric	✓				✓		
Generator Exhaust Pipes	✓		✓				
Rebar	✓		✓	✓			
Strut Channel (Painted)	✓	✓	✓				
Strut Channel (Galvanized)	✓		✓				

Figure 5-70 on page 5-75 illustrates the typical irreversible compression crimping process for a lug. Refer to the lug and/or compression tool manufacturer for specific instructions. See BICSI N3-20, section 8.5.2.1 for more information.

Table 5-7 lists the color code for typical irreversible compression lugs. Refer to the specific compression lug documentation for details.

Table 5-7. Typical Irreversible Compression Lug Color Code

Conductor Size	Lug Color Code
# 6 AWG	Blue
# 6 AWG Solid	Red
# 4 AWG	Gray
# 2 AWG	Brown
# 2 AWG Solid	White
# 1 AWG	Green
# 1/0 AWG	Pink
# 2/0 AWG	Black
# 3/0 AWG	Orange
# 4/0 AWG	Purple
250 kcmil	Yellow
500 kcmil	Brown
750 kcmil	Black



STEP 1:
Choose a lug appropriate for the application and conductor size.



STEP 2:
Strip the conductor jacket to appropriate length for the lug.



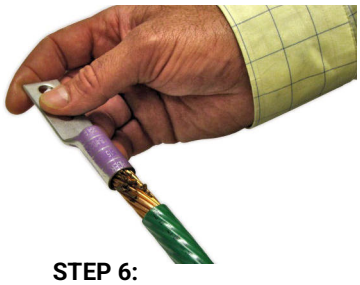
STEP 3:
Verify conductor fits into the lug. There should be no exposed conductor between the lug and the conductor jacket. The conductor should reach the inspection hole.



STEP 4:
Apply appropriate antioxidant compound inside the lug.



STEP 5:
Apply appropriate antioxidant compound to the conductor.



STEP 6:
Insert conductor into lug.

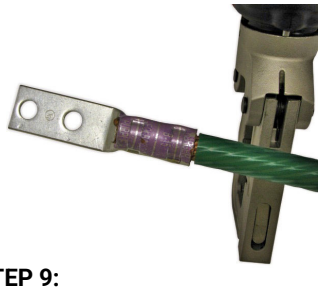


STEP 7:
Position the lug so it makes contact with the conductor jacket.





STEP 8:
Crimp long barrel lugs in at least two locations:
Place the first crimp adjacent to the inspection window.
Place the second crimp adjacent to the conductor jacket.



STEP 9:
Remove excess antioxidant compound from the lug and conductor jacket. Connection is complete.

Figure 5-70. Irreversible Compression Connector and Typical Crimping Tool

5.8.3 Securing Hardware

Securing hardware refers to the fasteners (such as bolts, nuts, screws, and washers) used to attach a bonding or grounding conductor to a clamping device or a lug/clamping device to a busbar or metallic object. The minimum requirements for securing hardware are as follows:

- All securing hardware **shall** be made from 300 series stainless steel or silicon bronze (BICSI N3-20 and FAA-STD-019G, section 4.2.3.4.2), unless otherwise specified or allowed. 300 series stainless steel is commonly known as 18-8.
- For saltwater environments where corrosion is a concern, Type 316 stainless steel or silicon bronze is recommended.
- For specific applications, such as when making a connection to a tinned busbar (e.g., tinned RBB), the use of tinned hardware is permissible.
- The bolts or screws **shall** be sized appropriately to match the lug or clamp size. The recommended minimum bolt diameter is 6.35 mm (0.25 in.).
- Securing hardware **shall** be torqued sufficiently to ensure a reliable bond without over-compressing the lock washer (FAA-STD-019G, section 4.2.3.4.2).

IMPORTANT: Stainless steel in contact with dissimilar metals, such as galvanized steel, can lead to severe corrosion, which may result in an ineffective electrical bond and a potential source of RF interference. To help prevent corrosion, ensure all securing hardware components are compatible with one another before installation.

NOTE: 300-series stainless steel, commonly known as 18-8, has very little magnetic attraction, whereas 400-series stainless steel does.

5.8.4 Mechanical Bonding Requirements

Bonding to communication system devices, ancillary equipment, or busbars usually requires mechanical bonding connections. See Figure 5-67 for examples of bonding. The mechanical bonding requirements are as follows:

- Lugs and clamps **shall** meet the requirements of “Lugs and Connection Devices” on page 5-72.
- Paint, enamel, lacquer, and other nonconductive coatings **shall** be removed from threads and surface areas where connections are made to ensure good electrical continuity (BICSI N3-20, section 8.5.2.3 and NFPA 70-2026, Article 250.12).

NOTE: Using a star washer does not eliminate the need to remove non-conductive coatings from attachment surfaces. Star washers should be used only as lock washers. See Figure 5-67 for the correct star/lock washer location.

- Bonding surfaces (such as galvanized steel) **shall** be cleaned to remove dirt, corrosion, and oxidized material from the connection surface area (ATIS-0600334.2019(R2024), section 9).
- All mechanical joints **shall** be protected with a listed conductive anti-oxidation compound (ATIS-0600334.2019(R2024), section 9 and BICSI N3-20). See “Antioxidant Compound” on page 5-77.
- After cleaning the mating surfaces, the bond members should be assembled or attached as soon as possible. The assembly should be finished within 30 minutes. If more than two (2) hours pass between cleaning and assembly, a temporary protective antioxidant compound coating must be applied (MIL-HDBK-419A).
- After bonding to a painted or galvanized steel structure, the area **shall** be thoroughly cleaned and coated with an approved corrosion inhibitor, such as an enamel or zinc-enriched paint.
- Two-hole long barrel lugs are preferred over single-hole lugs and **shall** be used where practicable. Two-hole lugs prevent the lug from moving. See BICSI N3-20.

- Where two-hole lugs are used, securing hardware **shall** be used in both holes.
- Lugs and clamps **shall** be attached to the surface using a nut, bolt, and lock washer where both sides of the bonding surface are accessible (see Figure 5-67).
- Bolts **shall** be tightened sufficiently to maintain the contact pressures required for adequate bonding, but **shall not** be over-tightened to the point that deformation of bond members occurs (FAA-STD-019G, section 4.2.3.4.2).
- Where connecting ground lugs or fasteners to ancillary equipment, such as air conditioners and vent hoods, a lock washer **shall** be placed on the nut side. See Figure 5-67 for an example.

5.8.5 Bonding Objects in Blind Locations

Blind locations are bonding locations where the rear of the object being bonded is inaccessible for nut installation. Typical examples include door frames, metal siding, and vent covers.

Follow all requirements in “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69 and all applicable subsections. Use two-hole lugs where feasible. Install a lock washer between the lug and the bolt or screw head.

The following methods can be used where the metallic object to be bonded is thick enough to engage at least two threads from the fastener:

- Drill and tap the appropriate size hole(s) in the object for the fastener being used. Attach the ground lug with stainless steel hardware.
- Drill the appropriate size hole(s) in the object for the fastener being used. Attach the ground lug using stainless steel thread-forming machine screw(s).

NOTE: A typical thread-forming machine screw used in this application has approximately 32 threads per inch.

The following methods can be used where the metallic object is too thin to engage at least two threads from the fastener:

- Attach the ground lug using an existing screw already in place for securing the metallic object. If possible, use a two-hole lug. When using a two-hole lug, secure the second hole with one of the following options.
  - Attach the ground lug using the appropriate stainless steel screw(s) that penetrate wood or metal framing.
  - Drill an appropriately sized hole and install an internally threaded rivet. Attach the ground lug using stainless steel hardware.
  - Punch a small hole in the metal with an awl. Attach the ground lug using stainless steel thread-forming machine screw(s). Punching a hole with an awl can increase the surface area for thread contact.
- In some applications, stainless steel sheet metal screws may be the only viable option for bonding certain items, such as metallic siding. Sheet metal screws **shall** be used only when no other alternatives are available. A recommended best practice is to first punch a small hole in the metal with an awl.

5.8.6 Antioxidant Compound

Antioxidant compound helps prevent oxidation of mechanical bonds to help maintain good electrical connections. All mechanical bonding joints **shall** be protected with a listed conductive antioxidant compound (ATIS-0600333.2013(S2023), section 9.2.2, and ATIS-0600334.2019(R2024), section 9). The requirements for antioxidant compounds are as follows:

- The antioxidant compound **shall** be a conductive type and designed for use on electrical connections.
- The antioxidant compound **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL).
- The antioxidant compound **shall** be listed for the type(s) of metal it is applied on.
- The antioxidant compound **shall** be used according to the manufacturer's instructions.

- Use the type of antioxidant shown in Table 5-8 for each combination of connection device and bonding surface.

Table 5-8. Antioxidant Compounds for Bonding Surface Types

<table>
<tr><th rowspan="2">Connection Device Metal</th><th colspan="5">Bonding Surfaces</th></tr>
<tr><th>Copper or copper alloys (such as bronze and brass)</th><th>Tin-plated</th><th>Steel</th><th>Galvanized steel</th><th>Aluminum</th></tr>
<tr><td>Copper or copper alloys (bronze, brass)</td><td rowspan="3">Use copper antioxidant (typically copper-colored)</td><td>Use copper antioxidant (typically copper-colored)</td><td colspan="3">N/A. Copper or copper alloys are not approved as connection devices to steel, galvanized steel, or aluminum bonding surfaces.
Tin-plated or stainless steel connection devices are required.</td></tr>
<tr><td>Tin-plated</td><td colspan="4">Use zinc antioxidant (typically gray-colored)</td></tr>
<tr><td>Stainless steel</td><td>Use copper or zinc antioxidant</td><td colspan="3">Use zinc antioxidant typically gray-colored)</td></tr>
<tr><td colspan="6">NOTE: Follow manufacturer’s instructions when applying antioxidant compound.</td></tr>
</table>

5.8.7 Exothermic Welding

See “Exothermic Welding” on page 4-71 for details.

5.8.8 Bonding to Equipment and Ancillary Support Apparatus

In addition to the applicable requirements from “General Bonding Requirements” on page 5-69, the following requirements **shall** apply where attaching equipment bonding/grounding conductors to equipment and metallic ancillary support apparatus:

- Each electronic equipment chassis **shall** have a separate and independent bonding conductor. See “Equipment” on page 5-103 for examples.

NOTE: Using a star washer does not eliminate the need to remove non-conductive coatings from attachment surfaces, as it provides insufficient contact surface area.

- Connections to steel and galvanized steel pipes, conduits, or other round members **shall** be made using a UL 467-listed bolted clamp with stainless steel securing hardware or other suitable listed means. In high-humidity areas, the clamps **shall** be made of stainless steel or tin-plated, UL 467-listed material to prevent galvanic corrosion. See Table 5-6 and BICSI N3-20 for more information.
- Connections to vibrating or movable items **shall** be made by using an exothermic weld or an irreversible compression-type two-hole lug.
- Connections to structural metal (building steel) **shall** be made by using an exothermic weld, listed irreversible high compression-type connection, or a listed tin-plated flange-type bonding connector equipped with two securing bolts (BICSI N3-20, section 8.10). Figure 5-71 shows examples of acceptable bonding connections to structural metal (building steel).

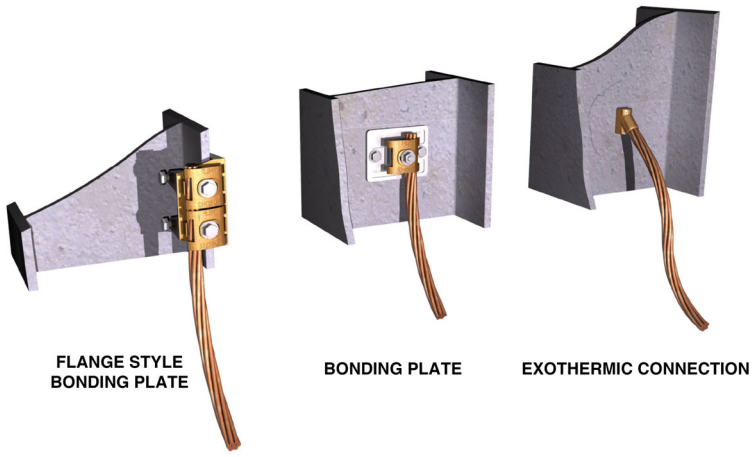


Figure 5-71. Examples of Acceptable Structural Building Steel Bonding Connections

5.8.9 Bonding to the Primary Bonding Busbar, Secondary Bonding Busbar and Rack Bonding Busbar

All applicable general bonding requirements and the requirements listed in this section **shall** be followed when attaching bonding or grounding conductors, grounding electrode conductors, bonding bus conductors, and equipment bonding conductors to the Primary Bonding Busbar (PBB), Secondary Bonding Busbars (SBB), or Rack Bonding Busbars (RBB).

Conductors **shall** meet the physical and installation requirements of "Bonding and Grounding (Earthing) Conductors" on page 5-41 and all subsections. Figure 5-72 illustrates the correct attachment of lugs to a busbar.

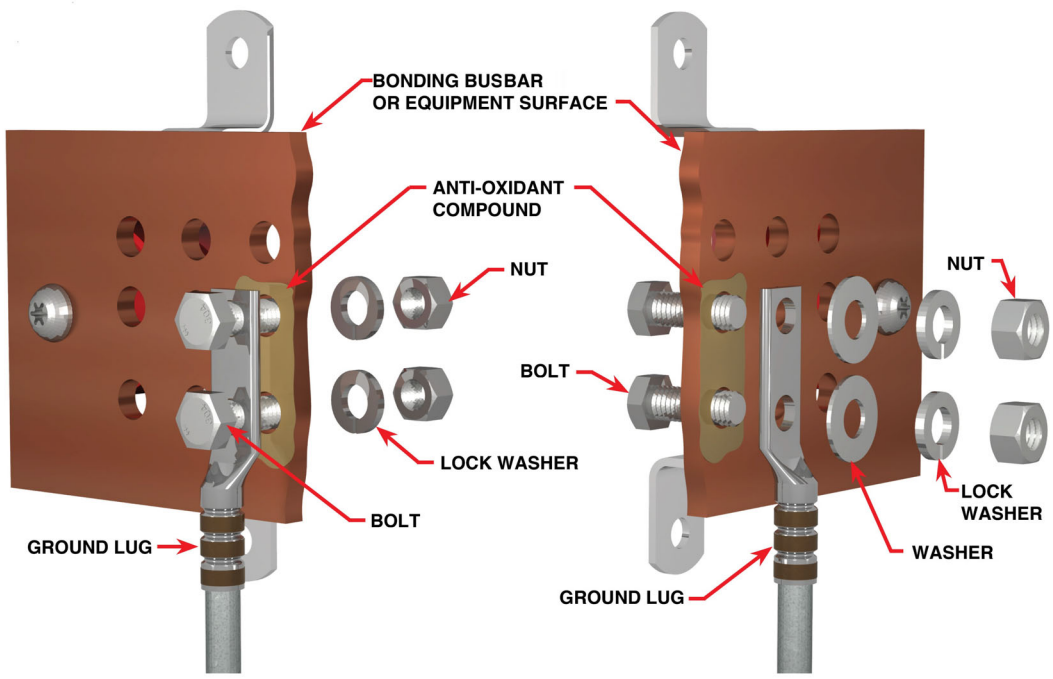


Figure 5-72. Fastening Hardware Configurations for Two-Hole Lug Attachment to a Busbar

5.8.9.1 Connection to the Primary Bonding Busbar

Connections to the Primary Bonding Busbar (PBB) **shall** use exothermic welding, an irreversible high-compression connection, listed irreversible compression two-hole lugs, or listed exothermic two-hole lugs (BICSI N3-20, section 8.5 and TIA-607-E, section 7.2.3). Such connections include, but are not limited to, the following:

- PBB grounding electrode conductor
- Bonding backbone conductor
- Bonding bus conductor
- Individual equipment (electronic or ancillary) bonding conductor

See Table 5-9 for more information.

IMPORTANT: Single-hole lugs **shall not** be used.

5.8.9.2 Connection to a Secondary Bonding Busbar

Connections to a Secondary Bonding Busbar (SBB) **shall** use exothermic welding, irreversible high-compression connection, listed irreversible compression two-hole lugs, or listed exothermic two-hole lugs (BICSI N3-20, section 8.5 and TIA-607-E, section 7.3.4). Such connections include, but are not limited to, the following:

- SBB grounding electrode conductor (for SBB serving an entry location)
- Bonding backbone conductor
- Bonding bus conductor
- Individual equipment (electronic or ancillary) bonding conductor

See Table 5-9 for more information.

IMPORTANT: Single-hole lugs **shall not** be used.

5.8.9.3 Connection to a Rack Bonding Busbar

Connections to a Rack Bonding Busbar (RBB) from the RBB bonding conductor **shall** use listed irreversible compression two-hole lugs or listed exothermic two-hole lugs (TIA-607-E, section 7.4.3). See “Rack Bonding Busbar Specifications” on page 5-29 and Table 5-9.

Connections to the RBB from individual pieces of equipment can use the two-hole lugs discussed in the previous sections, as well as single-hole irreversible compression lugs or listed single-hole exothermic lugs. Refer to Figure 5-73 for an example of an irreversible compression two-hole lug supplying the RBB and single-hole lugs on the equipment bonding conductors.

NOTE: At the discretion of the R56 committee, some existing small rack bonding busbars designed for direct attachment of Telco-style surge protective devices may be considered acceptable if they only accept a single-hole lug.

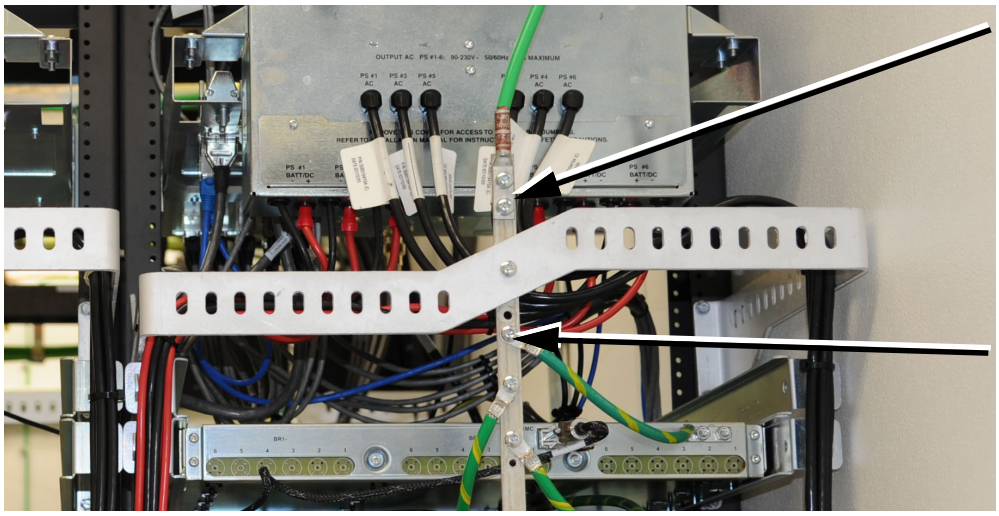


Figure 5-73. Example of Connection to Rack Bonding Busbar

5.8.9.4 PANI Method

Some customers, such as cellular operators, may require conductors to be bonded to the Primary Bonding Busbar (PBB) in a specific sequence, determined by the conductor's origin or the type of equipment bonded to the PBB. One method of doing this, known as PANI, designates specific areas of the PBB for bonding surge energy Producers, Absorbers, Non-isolated equipment, and Isolated equipment. An example of this setup is shown in Figure 5-74. This method is not necessary for compliance with the installation standard and is provided for reference only. Consult ATIS-0600313.2019(R2024) and ATIS-0600333.2013(S2023) for more details on this bonding method.

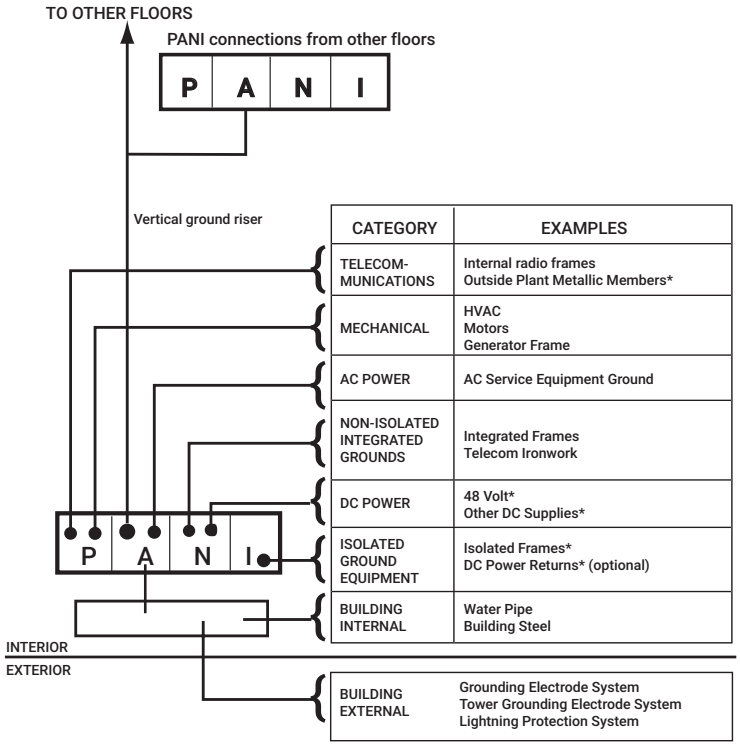


Figure 5-74. PANI Grounding System Sequence

P	A	N	I
Surge Producers	Surge Absorbers	Non IGZ	Isolated Ground Zones (IGZ)
• RF SPD • AC Equipment • Telco SPD • Cable Shields • ESD	• Building Steel • AC N-G Bond • Water Line • Metallic Piping • Concrete Encased Electrode • Ground Rings	• +48VDC Ground • -24VDC Ground • Cable Tray System • Equipment Frame • Battery Racks • Ancillary Equipment	• Logic Ground • IG Zones

Figure 5-75. PANI Busbar Configuration

5.8.10 Bonding to Bonding Bus Conductors

All applicable general bonding requirements **shall** apply where attaching bonding bus branch conductors and equipment bonding conductors to a bonding bus conductor. The following requirements also apply:

- All bonding bus conductors should be installed without splices. Where splices are necessary, they should be minimized, accessible, and only located in telecommunication spaces. Joined segments **shall** be connected using exothermic welding or listed irreversible compression-type connectors. All bonding joints **shall** be adequately supported and protected from damage. See TIA-607-E for more information.
- Bonding bus branch conductors **shall** be routed toward the Primary Bonding Busbar (PBB) or Secondary Bonding Busbar (SBB) at the connection point to the central/main bonding bus conductor. See Figure 5-76.
- Bonding bus branch conductors **shall** be connected to the central bonding bus conductor using exothermic welding or listed irreversible compression-type connectors. Connection points **shall** be taped with suitable green tape or otherwise isolated from contact with the cable tray or other metallic surfaces.
- Equipment bonding conductors **shall** be routed toward the PBB or SBB at their connection point to the bonding bus conductor. They **shall** be connected to the bonding bus conductor using exothermic welding or listed irreversible compression-type connections. Connection points **shall** be taped with a suitable green tape or otherwise isolated from contact with the cable tray or other metallic surfaces. See Figure 5-77 and Figure 5-78.
- Equipment bonding conductors **shall** be connected so that removing a connection does not break the bonding path to any other piece of equipment or ancillary support device.
- Multiple connections **shall not** be made to a single attachment point on the bonding bus conductor unless this connection is made using exothermic welding or a listed irreversible compression-type connector designed for multiple conductors. In all cases, the connection means **shall** be listed for the size and number of conductors to be connected.

IMPORTANT: Split bolt connection devices are not permitted and **shall not** be used.

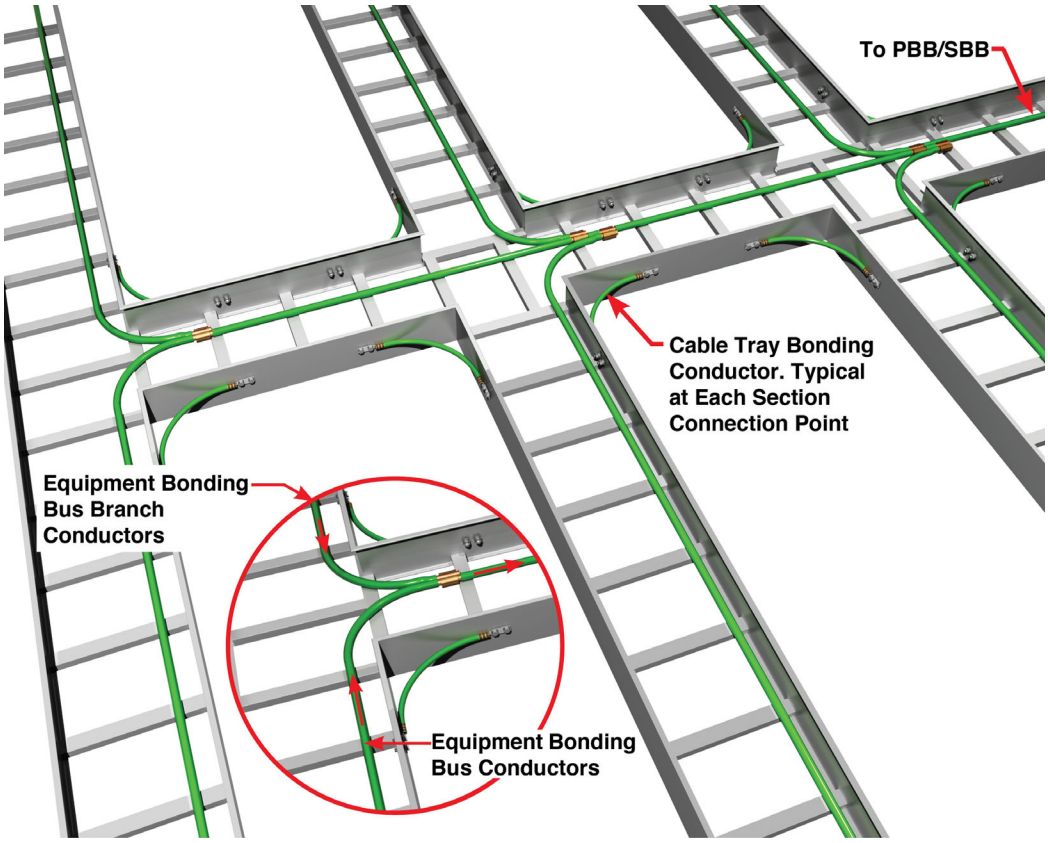


Figure 5-76. Examples of Bonding to a Bonding Bus Conductor

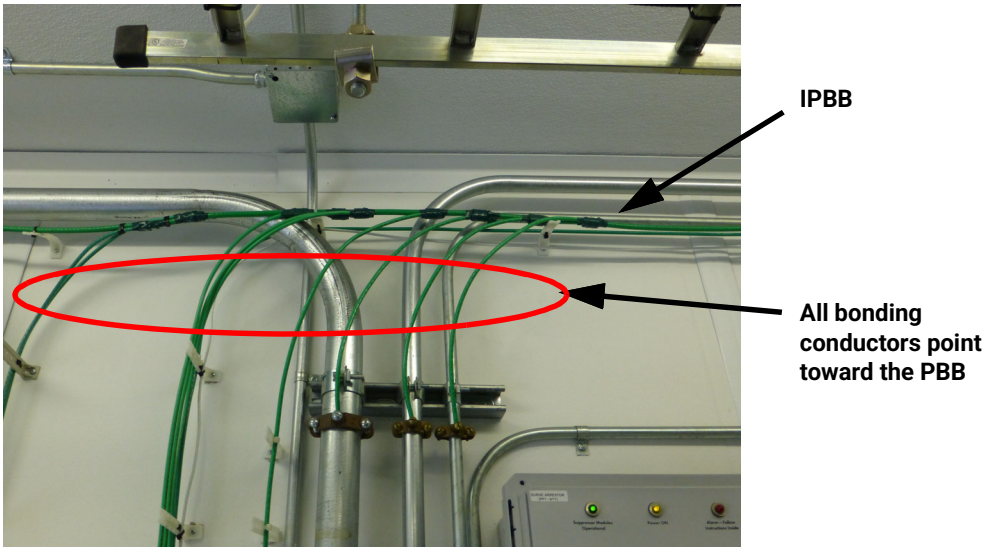


Figure 5-77. Bonding to the Internal Perimeter Bonding Bus (IPBB) Conductor

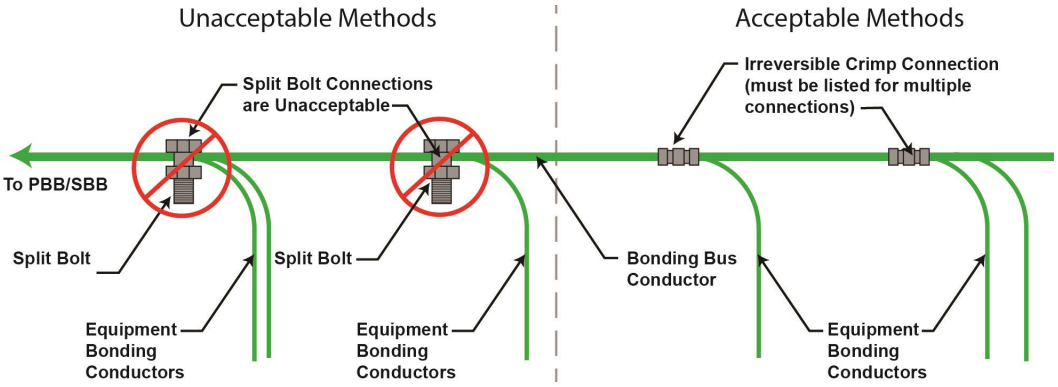


Figure 5-78. Acceptable and Unacceptable Methods for Bonding to a Bonding Bus Conductor

5.8.11 Bonding to Bonding Backbone Conductors and Backbone Bonding Conductors

All applicable general bonding requirements and the requirements described in this section **shall** apply when attaching Secondary Bonding Busbar (SBB) bonding conductors to a bonding backbone system.

NOTE: Equipment and ancillary apparatus are typically not bonded directly to a bonding backbone. Instead, this equipment should be bonded to a Secondary Bonding Busbar (SBB), which in turn bonds to the bonding backbone.

- All bonding backbone conductors should be installed without splices. When splices are necessary, their number should be minimized, and they **shall** be accessible and only located in telecommunication spaces. Joined segments **shall** be connected using exothermic welding or listed irreversible compression-type connectors. All bonding joints **shall** be adequately supported and protected from damage. See TIA-607-E for more information.
- The bonding conductor between the SBB and the bonding backbone conductor **shall** match the specifications of the bonding backbone conductor.
- The bonding conductor between the SBB and the bonding backbone **shall** be continuous and routed in the shortest practical straight-line path toward the Primary Bonding Busbar (PBB).
- The SBB bonding conductor **shall** be connected to the bonding backbone using exothermic welding or a listed irreversible compression-type connection (TIA-607-E, section 7.5.4).

IMPORTANT: Split bolt connection devices are not permitted and **shall not** be used.

5.9 Bonding Equipment to Internal Bonding and Grounding (Earthing) System

All equipment and ancillary support apparatus **shall** be bonded as described in this section and its subsections.

Table 5-9 shows bonding methods to use for connecting to the internal bonding system from the items listed in Column 1 to the PBB using the connection devices described in this section.

- Column 1 represents the point of origin (opposite the PBB/earth) for the conductor represented in Column 2. The numbers in Column 1 correspond to the acceptable means of connecting the conductor represented in Column 2 to the point of origin listed in Column 1.

- The remaining columns represent the destination of the conductor described in Column 2. The numbers in those columns represent the acceptable means (if any) of connecting that conductor to the destination point listed in Column 2.

Bonding devices are identified numerically in Table 5-9 as follows:

1. Single-hole lug
2. Two-hole lug
3. Irreversible high compression device
4. Exothermic welding
5. Clamping device
6. Manufacturer-approved methods
7. Directly secured to busbar

NOTE: Table 5-9 represents a typical installation. See the specific sections in this chapter for more details.

NOTE: Metallic pathways and associated hardware under 1 m (3 ft) in length (for example, wall and floor sleeves, J-hooks, and so on) are not required to be bonded (BICSI N3-20, section 8.2 and TIA-607-E, section 7.1).

The following example is for using Table 5-9 to bond an SBB to a PBB:

1. Locate “SBB” in Column 1.
   - Column 1 indicates that the acceptable means of bonding the grounding conductor to the SBB are device 2 (two-hole lug), device 3 (irreversible high compression device) or device 4 (exothermic welding).
   - Column 2 indicates the minimum size bonding conductor required.
2. Cross-reference the “PBB” column, which shows that the acceptable means to connect the other end of the conductor to the PBB are devices 2, 3 and 4.

Table 5-9. Connection Methods for Bonding to the Internal Bonding System from an Item Toward Earth

From Item	Minimum Conductor Size Unless Otherwise Specified*	Toward Earth					
		Rack Bonding Busbar (RBB)	Bonding Bus Conductor	Bonding Grid	IPBB or Halo Ground Ring	Secondary Bonding Busbar (SBB)	Primary Bonding Busbar (PBB)
SBB (2, 3, 4)	35 mm^2 csa (#2 AWG)	N/A	3, 4	3, 4	–	2, 3, 4	2, 3, 4
RBB (2, 6)	35 mm^2 csa (#2 AWG)	N/A	3, 4	3, 4	–	2, 3, 4	2, 3, 4
NBB (1, 2, 3)	16 mm^2 csa (#6 AWG)	1, 2, 3	3, 4	3, 4	–	–	–
Bonding bus conductor	35 mm^2 csa (#2 AWG)	N/A	N/A	N/A	–	2, 3, 4	2, 3, 4
*Size the conductor according to its length as described in this chapter.							

Table 5-9. Connection Methods for Bonding to the Internal Bonding System from an Item Toward Earth

From Item	Minimum Conductor Size Unless Otherwise Specified*	Toward Earth					
		Rack Bonding Busbar (RBB)	Bonding Bus Conductor	Bonding Grid	IPBB or Halo Ground Ring	Secondary Bonding Busbar (SBB)	Primary Bonding Busbar (PBB)
Bonding bus branch conductor	Use the same size as the main bonding bus conductor.	N/A	3, 4	N/A	–	–	–
Bonding grid (round conductor) (3, 4)	35 mm^2 csa (#2 AWG)	N/A	3, 4	–	–	2, 3, 4	2, 3, 4
Bonding grid (copper strap) (4, 6)	35 mm^2 csa (#2 AWG)	N/A	3, 4	–	–	2, 3, 4	2, 3, 4
IPBB or Halo Ground Ring	35 mm^2 csa (#2 AWG)	–	–	–	–	2, 3, 4	2, 3, 4
Cable tray (2, 6)	16 mm^2 csa (#6 AWG)	–	3, 4	3, 4	–	2, 3, 4	2, 3, 4
Equipment cabinet (1, 2, 6)	16 mm^2 csa (#6 AWG)	1, 2	3, 4	3, 4	–	2, 3, 4	2, 3, 4
Equipment rack (1, 2, 6)	16 mm^2 csa (#6 AWG)	1, 2	3, 4	3, 4	–	2, 3, 4	2, 3, 4
Network operator electronic equipment and metallic furniture framework (1, 2, 6)	6 mm^2 csa (#10 AWG) for lengths up to 3 m (10 ft) 16 mm^2 csa (#6 AWG) for lengths up to 3.9 m (13 ft)	–	3, 4 Connection to the SBB is preferred and is required where practicable.		–	2, 3, 4	–
Network operator position AC receptacle boxes and/or PDU (5, 6)	6 mm^2 csa (#10 AWG) for lengths up to 1 m (3 ft) 16 mm^2 csa (#6 AWG) for lengths up to 3.9 m (13 ft)	–	3, 4 Connection to the SBB is preferred and is required where practicable.		–	2, 3, 4	–
*Size the conductor according to its length as described in this chapter.							

Table 5-9. Connection Methods for Bonding to the Internal Bonding System from an Item Toward Earth

From Item	Minimum Conductor Size Unless Otherwise Specified*	Toward Earth					
		Rack Bonding Busbar (RBB)	Bonding Bus Conductor	Bonding Grid	IPBB or Halo Ground Ring	Secondary Bonding Busbar (SBB)	Primary Bonding Busbar (PBB)
Network operator position Surge Protective Devices (6)	6 mm^2 csa (#10 AWG) for lengths up to 1 m (3 ft) 16 mm^2 csa (#6 AWG) for lengths up to 3.9 m (13 ft)	–	3, 4 (Connection to the SBB is preferred and is required where practicable)		–	2, 3, 4, 7	–
Transmission line surge protective device (1, 2, 6, 7)	16 mm^2 csa (#6 AWG)	–	–	–	–	2, 3, 4, 7	2, 3, 4, 7
Telco/Data primary surge suppressor (1, 2, 6, 7)	6 mm^2 csa (#10 AWG) for single line device 16 mm^2 csa (#6 AWG) for multiple line device	-	-	-	3, 4	2, 3, 4, 7	2, 3, 4, 7
Telco/Data secondary surge suppressor (1, 2, 6, 7)	6 mm^2 csa (#10 AWG) for single line device 16 mm^2 csa (#6 AWG) for multiple line device	1, 2, 7	3, 4	-	-	2, 3, 4, 7	2, 3, 4, 7
DC power plant return busbar or terminal (2, 6)	Sized according to “DC Power Systems” on page 5-94	-	-	-	-	2, 3, 4	2, 3, 4
Generator support frame (2, 4, 6)	16 mm^2 csa (#6 AWG)	-	-	-	3, 4	2, 3, 4	2, 3, 4
Separately derived system (1, 2, 6)	Sized according to “Separately Derived AC Systems” on page 5-89	-	3, 4	-	3, 4	2, 3, 4	2, 3, 4
*Size the conductor according to its length as described in this chapter.							

Table 5-9. Connection Methods for Bonding to the Internal Bonding System from an Item Toward Earth

From Item	Minimum Conductor Size Unless Otherwise Specified*	Toward Earth					
		Rack Bonding Busbar (RBB)	Bonding Bus Conductor	Bonding Grid	IPBB or Halo Ground Ring	Secondary Bonding Busbar (SBB)	Primary Bonding Busbar (PBB)
Cable outer metal shield (6)	16 mm^2 csa (#6 AWG)	-	-	-	-	2, 3, 4	2, 3, 4
Ancillary support item or structural metal (1, 2, 3, 4, 5, 6)	16 mm^2 csa (#6 AWG)	-	-	3, 4	3, 4	2, 3, 4	2, 3, 4
Suspended ceiling grid (1, 2, 5, 6)	16 mm^2 csa (#6 AWG)	-	-	3, 4	3, 4	2, 3, 4	2, 3, 4
Raised floor support pedestal or stringer support (5, 6)	Bonded according to "Raised Computer Floor Bonding" on page 5-120	-	-	3, 4	-	2, 3, 4	2, 3, 4
*Size the conductor according to its length as described in this chapter.							

5.9.1 Equipment and Ancillary Support Apparatus Bonding

To ensure system reliability, availability, and personnel safety, all communications equipment **shall** be bonded in accordance with the requirements in the following sections.

All equipment and supporting apparatus, including but not limited to those listed in Table 5-9, **shall** be effectively bonded to the internal bonding system with a minimum 16 mm^2 csa (#6 AWG) equipment bonding conductor unless otherwise specified here (ATIS-0600334.2019(R2024), section 7.1). Bonding to the internal bonding system can be made to any of the following:

- Primary Bonding Busbar (PBB) (see "Primary Bonding Busbar" on page 5-10)
- Secondary Bonding Busbar (SBB) (see "Secondary Bonding Busbar" on page 5-17)
- Rack Bonding Busbar (RBB) (see "Rack Bonding Busbar" on page 5-28)
- Network-Equipment Bonding Busbar (NBB) (see "Network-Equipment Bonding Busbar" on page 5-33)
- An equipment bonding bus conductor (see "Equipment Bonding Bus Conductor" on page 5-51)
- Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring (ancillary support equipment only) (see "Internal Perimeter Bonding Bus Conductor or Halo Ground Ring" on page 5-58)
- Bonding grid (see "Supplementary Bonding Network or Bonding Grid" on page 5-63)

All bonding and grounding **shall** be established as described in the following subsections:

- "Separately Derived AC Systems" on page 5-89
- "Generators (Internal)" on page 5-92
- "Generators (External)" on page 5-93
- "DC Power Systems" on page 5-94

- “Equipment” on page 5-103
- “Cabinets and Racks” on page 5-107
- “Cable Trays” on page 5-109
- “Ancillary Support Apparatus” on page 5-112
- “Metallic Building Structure and Piping Systems” on page 5-119
- “Raised Computer Floor Bonding” on page 5-120
- “Surge Protective Devices” on page 5-122

5.9.1.1 Separately Derived AC Systems

Separately derived systems are electrical sources, other than a service, with no direct connection to circuit conductors of any other electrical source except through grounding and bonding connections (NFPA 70-2026, Article 100). Separately derived AC power systems have no direct electrical connection between the incoming AC power source ground and the neutral conductor on the secondary side of the system (see Figure 5-79, Figure 5-80 and Figure 5-81).

Separately derived power systems can include isolation transformers, step-down transformers, step-up transformers, generator AC power systems that break the neutral conductor inside the automatic transfer switch (ATS), uninterruptible power supply (UPS) systems configured as separately derived systems, or AC inverters powered by a battery bank.

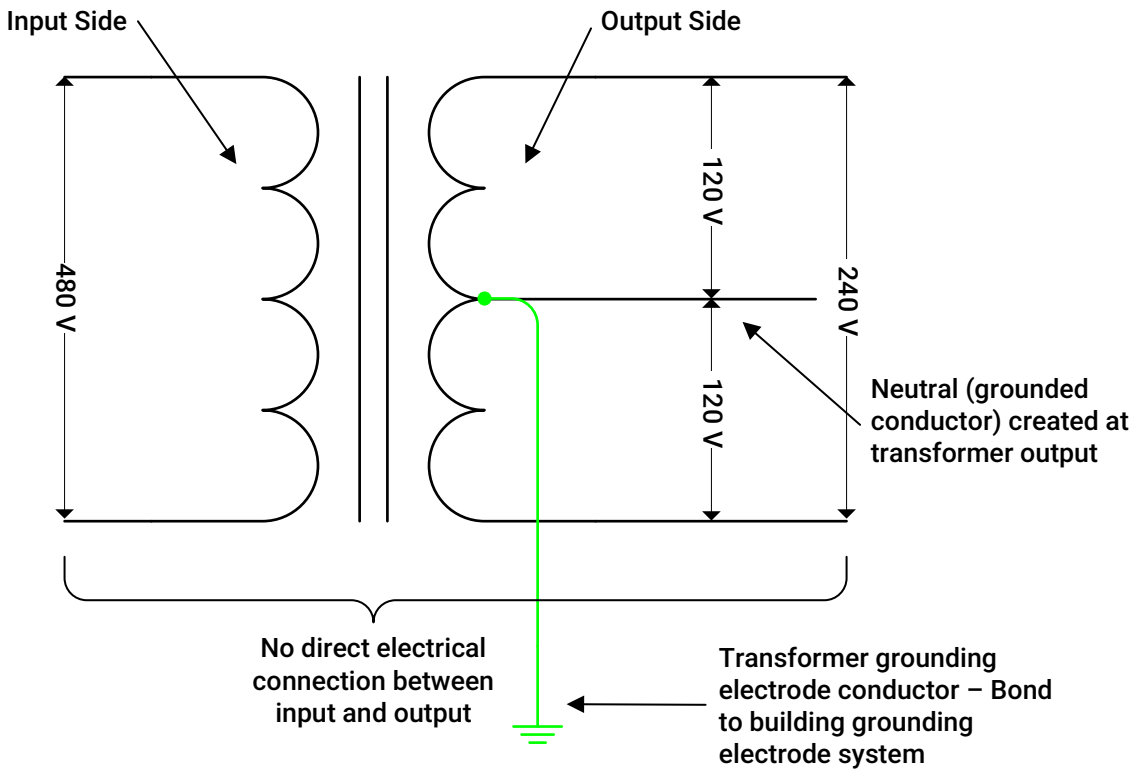


Figure 5-79. Example of Step-Down Transformer Schematic

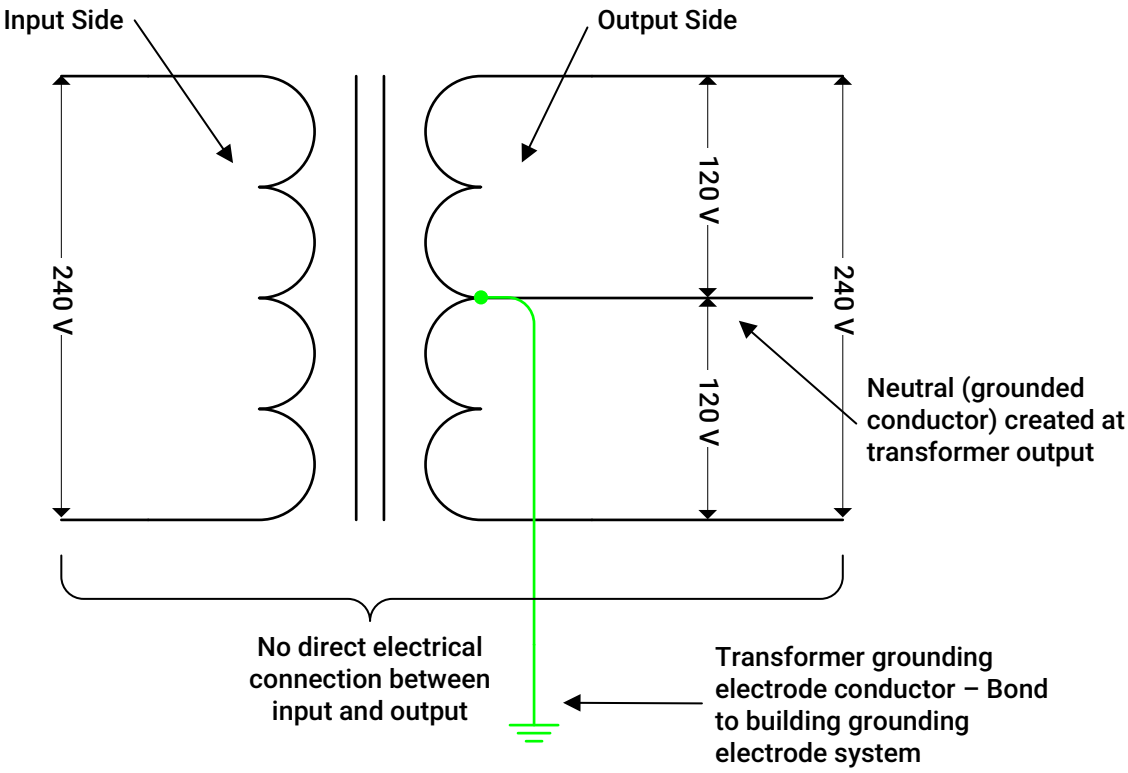


Figure 5-80. Example of Isolation Transformer Schematic



Figure 5-81. Example of Transformer

A rack-mounted, separately derived system may connect to a Rack Bonding Busbar (RBB) if the bonding conductor supplying the RBB meets the sizing requirements of Table 5-10, or a separate bonding conductor can be installed. Additionally, the conductor feeding the RBB **shall** comply with the sizing requirements of Table 5-3 on page 5-42.

Table 5-10.Grounding Electrode Conductor Sizing for Separately Derived Systems

Size of Ungrounded Conductor		Size of Grounding Electrode Conductor	
csa	**AWG**	**csa**	**AWG**
50 mm^2 or less	1/0 or less	16 mm^2	6
70 mm^2	2/0	25 mm^2	4
95 mm^2	3/0	25 mm^2	4
greater than 95 mm^2 to 177.39 mm^2	greater than 3/0 to 350 kcmil	35 mm^2	2
greater than 177.93 mm^2 to 304.025 mm^2	greater than 350 kcmil to 600 kcmil	50 mm^2	1/0
greater than 304.025 mm^2 to 557.4 mm^2	greater than 600 kcmil to 1100 kcmil	70 mm^2	2/0
greater than 557.4 mm^2	greater than 1100 kcmil	95 mm^2	3/0
Derived from NFPA 70-2026, Table 250.66 and other industry standards.			

5.9.1.1.1 Transformers, Inverters and UPS Systems (Containing Isolation Transformer)

If a separately derived AC power system exists at the site, a grounding electrode conductor at the neutral-to-ground bond on the secondary side of the unit **shall** be bonded to the nearest practicable location of the internal bonding and grounding system (for example, the Primary Bonding Busbar, a Secondary Bonding Busbar, a bonding backbone conductor, or structural building metal) with a 16 mm^2 csa (#6 AWG) or larger, green-jacketed conductor. The grounding conductor **shall** also be sized according to Table 5-10 (see NFPA 70-2026, Article 250.66 for more information). The connection **shall** be made according to the manufacturer's requirements.

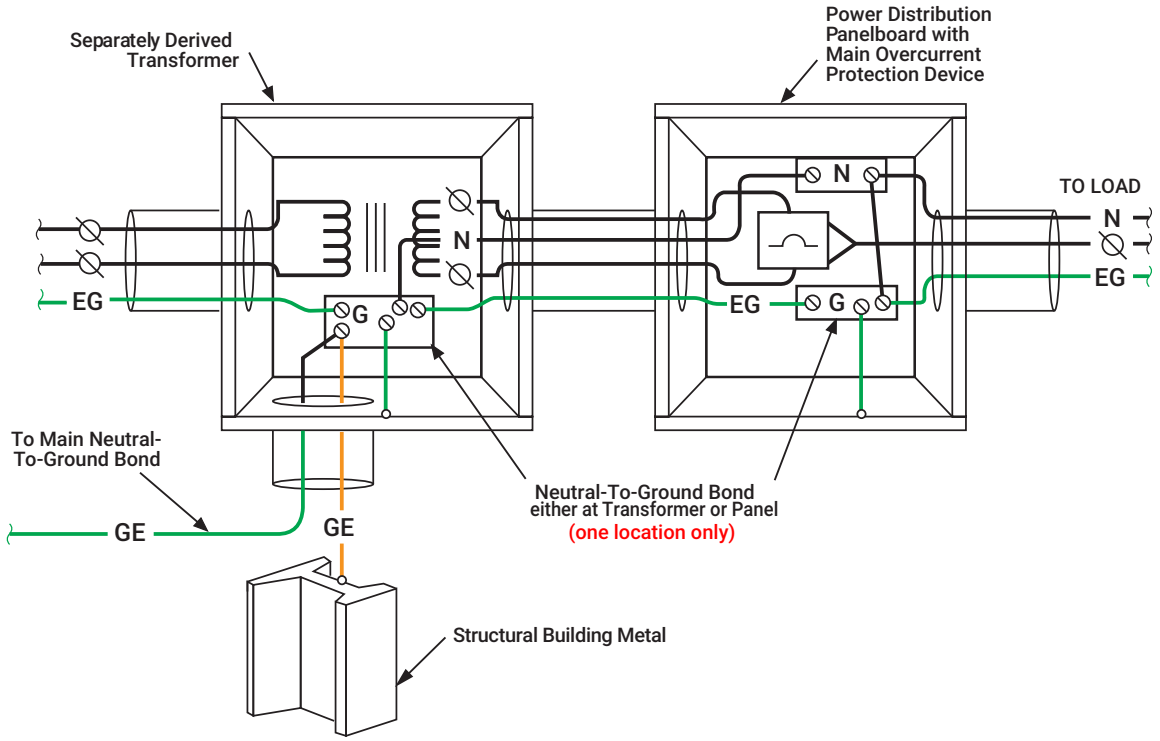


Figure 5-82. Grounding of a Dry Type Isolation Transformer

5.9.1.2 Generators (Internal)

If the generator is not configured as a separately derived system, the generator frame **shall** be bonded to the nearest point of the internal bonding and grounding system (such as the Primary Bonding Busbar, a Secondary Bonding Busbar, the IPBB or Halo Ground Ring) with a 16 mm² csa (#6 AWG) or larger, green-jacketed conductor using the methods described in this chapter. See Figure 5-83 for an example of an internal generator frame bonding using an existing frame hole.



TOP VIEW **SIDE VIEW**

Figure 5-83. Internal Generator Frame Bonding Example

If a generator is configured as a separately derived system (the Automatic Transfer Switch (ATS) breaks the neutral during switching), the generator frame **shall** be bonded as described in the previous paragraph. Additionally, a grounding electrode conductor at the neutral-to-ground bond in either the generator or the ATS **shall** be bonded to the nearest point of the internal bonding and grounding system (such as the Primary Bonding Busbar or a Secondary Bonding Busbar) with a 16 mm² CSA (#6 AWG) or larger, green-jacketed conductor (see Figure 5-84). The grounding conductor **shall** also be sized according to Table 5-10 (refer to NFPA 70-2026, Article 250.66 for more details).

Figure 5-85 shows an example of a transfer switch that does not break the neutral; therefore, is not a separately derived system.

IMPORTANT: Generators are often shipped from the factory with a neutral-to-ground bond established within the generator unit. If the generator Automatic Transfer Switch (ATS) is not configured for a separately derived system, this factory-installed bonding conductor must be removed.

NOTE: If an ATS is configured for a separately derived system, the neutral (grounded) conductor will be switched (see Figure 5-84).

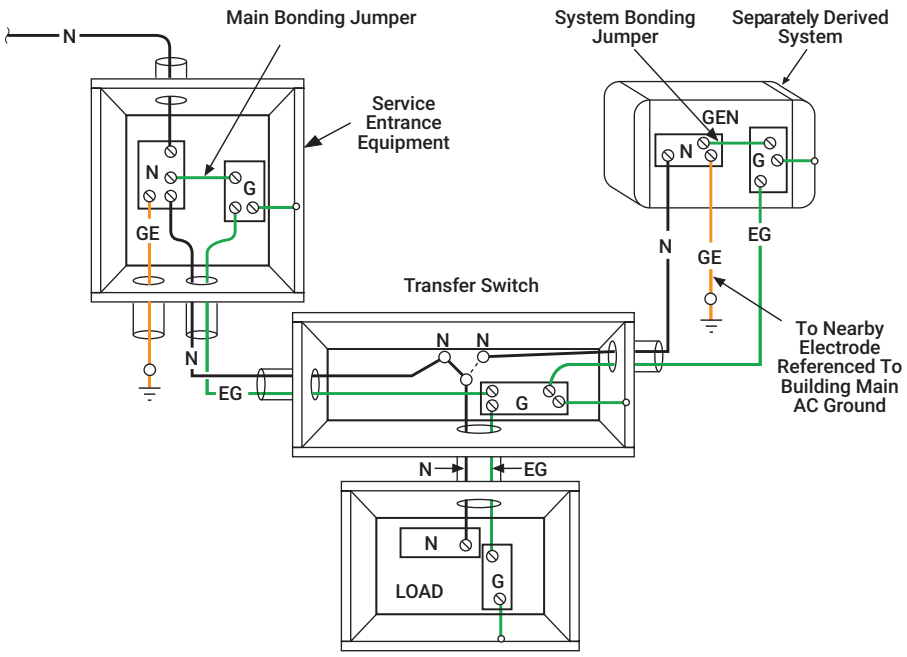


Figure 5-84. Generator System with Switched Neutral

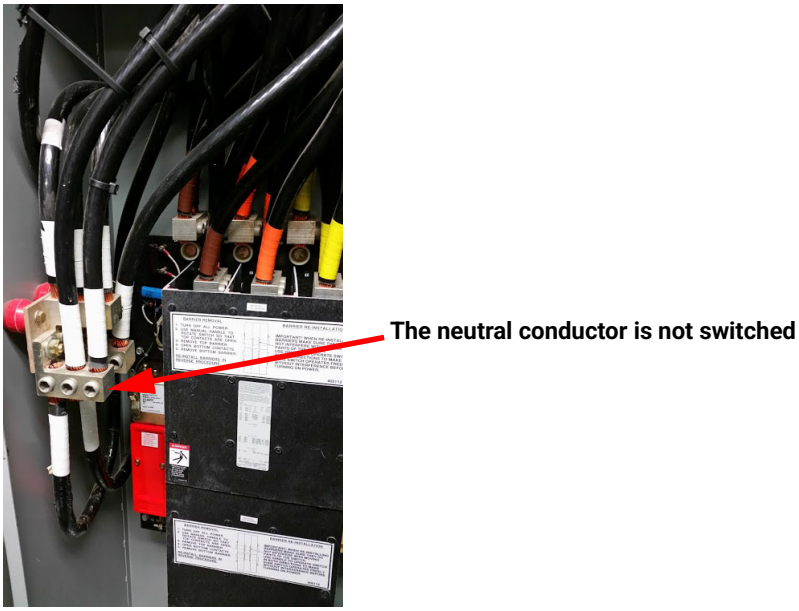


Figure 5-85. Generator Transfer Switch - Neutral Not Switched

5.9.1.3 Generators (External)

See Chapter 4, “External Grounding (Earthing) and Bonding”, for bonding and grounding requirements.

5.9.1.4 DC Power Systems

A DC power system is typically installed in a separate cabinet or rack. It often includes storage batteries to supply backup power in the event of a utility failure. The power system can be configured as either a two-wire or three-wire system, depending on the type of communication equipment it supports. The purpose of the grounding system is to protect personnel and equipment and to provide a fault clearing path (ATIS-0600311.2017(R2023), section 6.1).

IMPORTANT: DC power system bonding and grounding may require assistance from an engineer or certified R56 Auditor Subject Matter Expert (SME).

IMPORTANT: For optimal bonding and grounding, the DC power system should be installed as close to the Primary Bonding Busbar (PBB) as practical. If a DC power system is installed more than 30.5 m (100 ft) from the PBB, the bonding and grounding requirements should be specified by an engineer and/or certified R56 Auditor SME.

A DC power system generally has six main segments based on equipment function (see Figure 5-86) (ATIS-0600311.2017(R2024), section 5.2):

- Rectifier/chargers
- Storage batteries
- Charge bus
- Discharge bus
- Primary power distribution
- Secondary power distribution

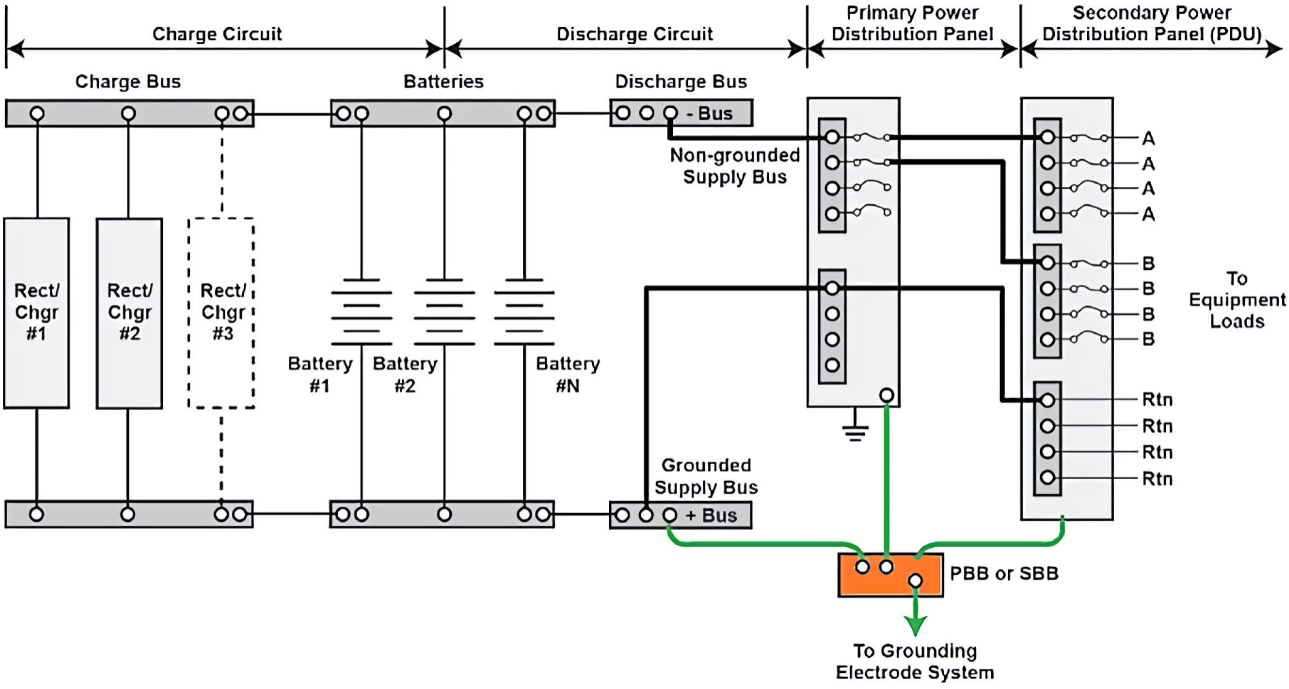


Figure 5-86. Typical Wiring Details for Isolated Ground-Type System (-48V System Example)

NOTE: Individual DC power supplies for control stations and similar devices are not classified as DC power systems as long as their wiring is not part of a premises wiring system, such as distributed in a cable tray system.

When a DC power system is installed at a communications site, it **shall** comply with the following bonding and grounding requirements:

- DC power systems **shall** comply with the grounding and bonding requirements of NFPA 70-2026, Article 250 Part VIII, and other sections of Article 250 not explicitly intended for AC systems (NFPA 70-2026, Article 250.160).
- Grounding of the electrical power system and bonding of surge protective devices and normally non-current-carrying metal parts of equipment **shall** be installed and arranged in a manner that will prevent objectionable current (NFPA 70-2026, Article 250.6).
- If a DC power system is required to be installed as a grounded system, an isolated ground-type system **shall** be installed to help prevent objectionable current. See installation requirements in “Installation Requirements for Isolated Ground-Type System” on page 5-95.
- Bonding **shall not** depend on incidental paths through equipment racks, cabinets, cable trays, or other conductive surfaces (see ATIS-0600311.2017(R2023), section 6.1, for additional information).
- Frames, cabinets, racks, and so on **shall** be bonded and grounded according to “Frames, Cabinets and Racks as Part of DC Systems” on page 5-98.

The following types of DC power systems **shall** be installed as grounded systems:

- DC power systems used in the telecommunications industry within the range of 0 to 160 volts (ATIS-0600311.2017(R2023), section 5).
- A DC system with an output exceeding 150 W (ATIS-0600333.2013(S2023), section 7.1). This applies to all battery systems, converter systems, and all converters installed in equipment frames, cabinets, or other enclosures, regardless of whether the DC source serves loads located in the same enclosure.
- A two-wire, DC system supplying premises wiring and operating at greater than 60 volts but not greater than 300 volts (NFPA 70-2026, Article 250.162(A)).
- All three-wire, DC systems supplying premises wiring (NFPA 70-2026, Article 250.162(B)).

5.9.1.4.1 Installation Requirements for Isolated Ground-Type System

To help prevent objectionable current, the DC power system **shall** be bonded to the facility's single-point bonding location in an isolated ground-type system configuration. In an isolated ground-type system, the DC power system return conductors are bonded to the internal bonding system at only one point. Under normal operating conditions, the internal bonding and grounding system does not carry DC in this configuration. Any DC on the internal bonding and grounding system typically results from one or more of the following: a fault condition, incorrectly configured equipment (for example, not configured for isolated grounding), or installation errors. See ATIS-0600311.2017(R2023) and ATIS-0600333.2013(S2023) for additional information.

The requirements listed below **shall** be met to establish an isolated ground-type system for the DC power system:

- A Primary Bonding Busbar (PBB) **shall** be installed at the site according to “Primary Bonding Busbar” on page 5-10.
- If the DC Power System is installed in a separate room away from the PBB, a Secondary Bonding Busbar (SBB) **shall** be installed in the DC Power System room according to “Secondary Bonding Busbar” on page 5-17.
  - The bonding conductor between the SBB and PBB **shall** be sized according to “Sizing of SBB-to-PBB Conductor Where Part of a DC System” on page 5-103
- All DC-powered equipment (such as racks of base station repeaters and associated devices) **shall** be bonded to the internal bonding and grounding system (for example, PBB, SBB, RBB, or equipment bonding bus conductor) as described in this chapter.

- The DC power system main return busbar or the primary distribution panel main return bus terminal (one or the other) **shall** be bonded to the facility's single point bonding location (see Figure 5-87 and Figure 5-88).
  - The single-point bonding location **shall** be the facility's Primary Bonding Busbar (PBB) or a designated Secondary Bonding Busbar (SBB) that serves as the single-point bonding busbar for a separate location.

NOTE: The conductor that connects the DC system's main return bus or primary distribution panel's main return busbar/terminal to the facility's single-point bonding location is called the DC System Bonding Jumper (see NFPA 70-2026, Article 250.168).

IMPORTANT: The DC power system return **shall** be bonded to the internal bonding and grounding system at only one point. Bonding at multiple points can cause objectionable DC currents to flow on the internal bonding and grounding system.

IMPORTANT: When installing a DC power system, the internal bonding and grounding system **shall** be tested for the presence of objectionable DC current after all equipment is installed. See "DC Current Testing" on page 5-145 for testing details.

- The DC return bus conductor (DC system bonding jumper) **shall** only be used for bonding the DC power system. This conductor **shall not** be used for bonding other equipment.
- When a secondary Power Distribution Unit (PDU) is installed, the return bus conductors **shall** be insulated from the PDU enclosure and from the cabinet or rack support framework. This is to prevent objectionable DC current.
- The DC power plant grounding/bonding conductor (DC System Bonding Jumper) **shall** be bonded to both busbars using an irreversible compression-type two-hole listed lug, as described in this chapter.

The following equipment installation requirements **shall** be met for an isolated ground-type system:

- All supplied equipment and components **shall** be approved for use in an isolated ground-type system. Third-party certified equipment and components **shall** be listed for the purpose (ATIS-0600311.2017(R2023), section 7.2).
- When a DC-to-DC converter is installed, the unit's return bus conductors **shall** be insulated from the unit's enclosure and the supporting framework of the cabinet or rack. This is to prevent objectionable DC current.
- If a DC-to-DC converter's rated output exceeds 150 Watts, it **shall** be installed as a grounded system (ATIS-0600333.2013(S2023), section 7.1).
  - All requirements for installing an isolated ground-type system **shall** apply.
  - A rack-mounted unit can be connected to a Rack Bonding Busbar (RBB) if the bonding conductor supplying the RBB meets the sizing requirements of "Sizing of DC System Bonding Jumper" on page 5-100, or a separate bonding conductor may be installed.
  - A unit may be bonded to the bonding backbone system or to an equipment bonding bus conductor if the conductor meets the sizing requirements of "Sizing of DC System Bonding Jumper" on page 5-100, or a separate bonding conductor may be installed.
- If a DC-to-AC inverter is installed, it **shall** be installed as a grounded system in accordance with the requirements of "Separately Derived AC Systems" on page 5-89.

See Figure 5-87 for an example of bonding the DC return bus in an isolated ground-type system.

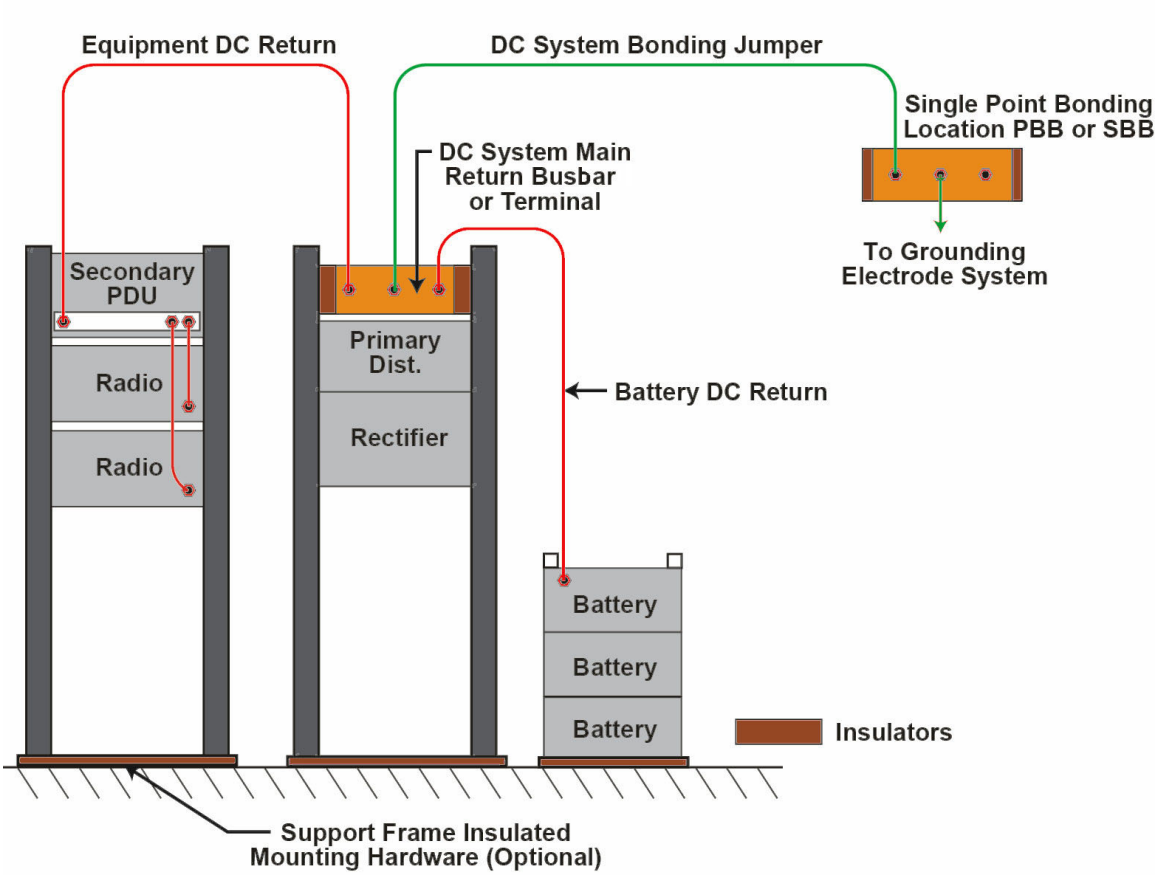


Figure 5-87. Bonding of DC Return Bus in Isolated Ground-type System

5.9.1.4.2 DC Return Bonding Conductor

The DC return bonding conductor connects the DC system return bus to the site's internal bonding and grounding system (PBB or SBB) and to the site's grounding electrode system. This conductor is also known as the DC System Bonding Jumper (see NFPA 70-2026, Article 250.168).

The DC return bonding conductor **shall** be sized at a minimum in accordance with “Sizing of DC System Bonding Jumper” on page 5-100.

IMPORTANT: The DC System Bonding Jumper **shall not** be used for bonding battery frames, cabinets, racks, or other equipment.

IMPORTANT: The DC System Bonding Jumper **shall not** contain a splice (NFPA 70-2026, Article 250.168).

NOTE: It is a common practice to size the DC return bonding conductor (System Bonding Jumper) equal to the largest current-carrying conductor in the DC system.

5.9.1.4.3 Battery Racks

Metallic battery racks or enclosures **shall** be bonded with a minimum 16 mm² csa (#6 AWG) conductor (see ATIS-0600311-2017(R2023), section 6.3.5) and **shall** meet the size requirements of "Equipment Bonding Conductor Specifications" on page 5-48. A minimum 35 mm² csa (#2 AWG) bonding conductor is recommended (see FAA-STD-019G, section 4.5.4.1). See Figure 5-88 for an example.

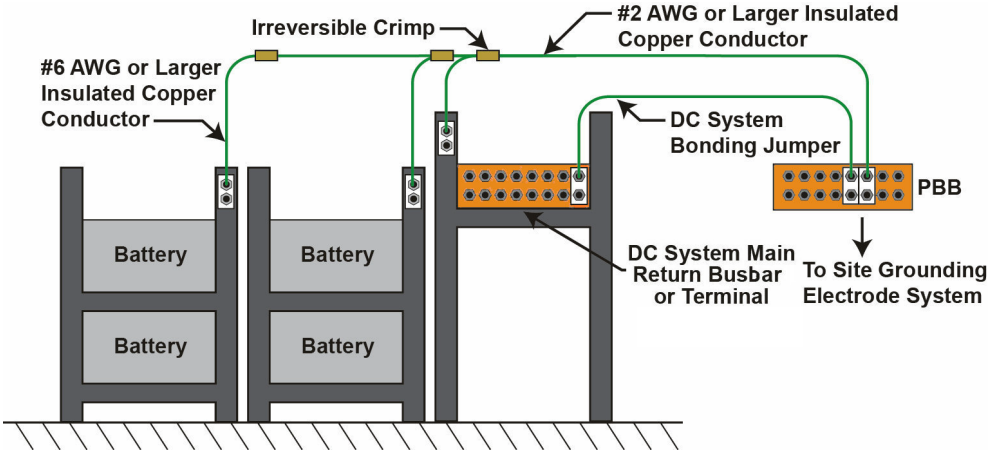


Figure 5-88. DC Power Plant and Frame Grounding

NOTE: A 16 mm² csa (#6 AWG) conductor **shall** be increased in size if the conductor length exceeds 4 m (13 ft). Refer to Table 5-4 for more information.

5.9.1.4.4 Cable Tray Systems Supporting DC Conductors

Cable tray systems that support DC conductors **shall** be bonded according to "Cable Trays" on page 5-109. In addition, the bonding conductor(s) **shall** be minimally sized using the same procedure and calculations used for the DC System Bonding Jumper as required in "Sizing of DC System Bonding Jumper" on page 5-100. In this calculation, the bonding conductor length is used, measured from the cable tray to the respective PBB or SBB.

For example, in a 48V, 200A DC system, a 16mm² (#6 AWG) conductor can be used for cable tray bonding, provided the total conductor length does not exceed 16 m (52.5 ft) (see Table 5-11). The bonding conductor shall also be minimally sized based on conductor length, as specified in Table 5-4. See "Cable Tray Installation Requirements" on page 9-40 for DC power conductor cable tray installation requirements.

NOTE: Cable trays listed as suitable equipment grounding conductors are recommended for supporting DC cabling. See "Cable Trays" on page 5-109 and Figure 5-101.

5.9.1.4.5 Frames, Cabinets and Racks as Part of DC Systems

Exposed normally non-current carrying metal parts of fixed equipment that are supplied by, enclosed in, or supporting electrical conductors or components likely to become energized **shall** be bonded as necessary to ensure electrical continuity and the capacity to safely conduct any fault current imposed on them (see NFPA 70-2026, Articles 250.4(A), 250.96, 250.102, 250.110, and 250.122).

All frames, cabinets, racks, and other metallic enclosures that are part of a DC system **shall** be bonded according to all of the following:

- All frames, cabinets, racks, and other metallic enclosures of a DC power system **shall** be bonded to the PBB or SBB as described in "Cabinets and Racks" on page 5-107 (see ATIS-0600333.2013(S2023), section 7.2).

- The bonding conductor(s) **shall** be minimally sized based on the size of the upstream overcurrent protection device feeding the cabinet or rack according to “Sizing of DC System Bonding Jumper” on page 5-100.
- The bonding conductor(s) **shall** also be minimally sized based on conductor length, as specified in Table 5-4.

NOTE: A bus conductor may be used for bonding all equipment (see Figure 5-89), but **shall not** be used as the DC System Bonding Jumper. The bus conductor **shall** be sized according to the largest conductor required.

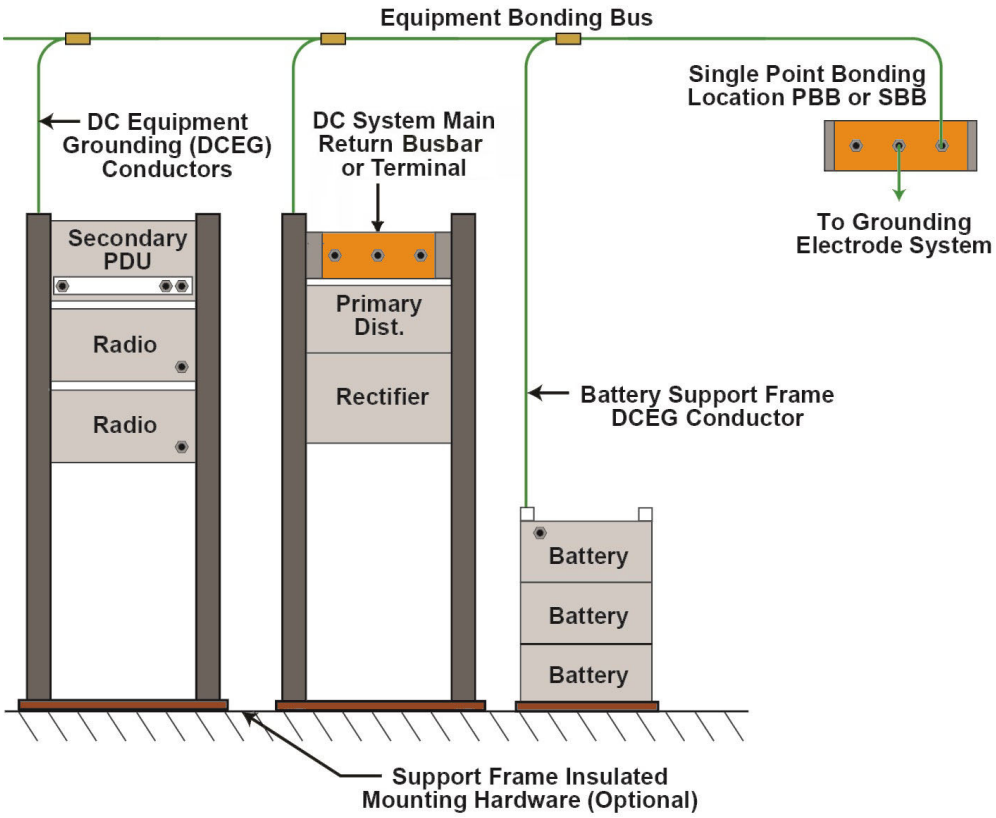


Figure 5-89. Bonding of Rack Supporting Framework

5.9.1.4.5.1. Racks, Cabinets and Equipment Supplied from DC Systems

Racks and cabinets supplied with power from a DC system are bonded in a manner similar to that described in “Frames, Cabinets and Racks as Part of DC Systems” on page 5-98. Racks and cabinets supplied with power from a DC system **shall** be bonded according to all of the following:

- All racks and cabinets supplied with power from a DC system **shall** be bonded to the Primary Bonding Busbar or Secondary Bonding Busbar (SBB) as described in “Cabinets and Racks” on page 5-107 (see ATIS-0600333.2013(S2023), section 7.2).
- The bonding conductor(s) **shall** be minimally sized based on the size of the upstream overcurrent protection device feeding the cabinet or rack according to “Sizing of DC System Bonding Jumper” on page 5-100.
- The bonding conductor(s) **shall** also be minimally sized based on conductor length according to Table 5-4.

NOTE: A rack supplied DC from a 200 A source would require a minimum 16 mm^2 csa (#6 AWG) bonding conductor, based on a maximum conductor length of 4m (13 ft). Refer to Table 5-4 and Table 5-11 for more information.

5.9.1.4.5.2. DC Powered Equipment Installed in a Rack or Cabinet

DC powered equipment installed in a rack or cabinet is bonded in a manner as described for racks and cabinets supplied with power from a DC system (see “Racks, Cabinets and Equipment Supplied from DC Systems” on page 5-99). DC-powered equipment installed in a rack **shall** be bonded according to all of the following:

- DC powered equipment installed in a rack or cabinet **shall** be bonded according to “Equipment” on page 5-103.
- The bonding conductor(s) **shall** be minimally sized according to “Sizing of DC System Bonding Jumper” on page 5-100, based on the upstream overcurrent device of the DC conductors feeding the equipment from the Power Distribution Unit (PDU).
- The bonding conductor(s) **shall** also be minimally sized based on conductor length according to Table 5-4.

NOTE: DC powered equipment installed in a rack or cabinet is typically bonded to a Rack Bonding Busbar (RBB). The RBB bonding conductor **shall** be sized the same as that described in “Racks, Cabinets and Equipment Supplied from DC Systems” on page 5-99.

NOTE: A 16 mm^2 csa (#6 AWG) equipment bonding conductor is adequate for a DC supply up to 200A, based on a maximum conductor length of 4m (13 ft). See Table 5-4 and Table 5-11 for more information.

5.9.1.4.6 Sizing of DC System Bonding Jumper

All DC bonding and grounding conductors **shall** meet the requirements of “Bonding and Grounding (Earthing) Conductors” on page 5-41. The DC system bonding jumper **shall** be sized according to all of the following:

IMPORTANT: An engineer and/or certified R56 Auditor Subject Matter Expert (SME) should be consulted for calculating the size of the DC System Bonding Jumper.

NOTE: The DC system bonding jumper should also be sized according to Table 5-4, but is not required to exceed the values given in this section. DC bonding conductors should be sized for the largest possible expansion of the DC power system at the time of installation.

1. The minimum size DC system bonding jumper **shall** be16 mm^2 csa (#6 AWG) (ATIS-0600311.2017(R2024) and ATIS-0600333.2013(S2023)).
2. DC system bonding jumpers **shall** be minimally sized according to Table 5-11, based on the largest overcurrent protective device in the circuit ahead of the equipment unless otherwise specified within this chapter (see ATIS-0600311.2017(R2024) and ATIS-0600333.2013(S2023) for additional information).
3. If the conductor length is less than or equal to the maximum distance shown in Table 5-11 for the appropriate system voltage, use the listed conductor size. If the conductor length is longer, go to step 4.

Table 5-11.Minimum Size for DC System Bonding Jumper

Overcurrent Protection Device Rating	Minimum Bonding Conductor Size	Maximum Distance (Rounded Down to Nearest 0.5 ft or 0.25 m) Before Conductor Must Be Increased in Size		
		12 V System	24 V System	48 V System
200 A or less	16 mm^2 csa (6 AWG)	4 m (13 ft)	8 m (26 ft)	16 m (52.5 ft)
300 A	25 mm^2 csa (4 AWG)	4.25 m (13.5 ft)	8.5 m (27.5 ft)	17 m (55.5 ft)
400 A	35 mm^2 csa (3 AWG)	4 m (13 ft)	8 m (26 ft)	16 m (52.5 ft)
500 A	35 mm^2 csa (2 AWG)	4 m (13 ft)	8 m (26.5 ft)	16.25 m (53 ft)
600 A	50 mm^2 csa (1 AWG)	4.25 m (13.5 ft)	8.5 m (27.5 ft)	17 m (55.5 ft)
800 A	70 mm^2 csa (1/0 AWG)	4 m (13 ft)	8 m (26 ft)	16 m (52.5 ft)
1000 A	70 mm^2 csa (2/0 AWG)	4 m (13 ft)	8 m (26 ft)	16 m (52.5 ft)
1200 A	95 mm^2 csa (3/0 AWG)	4.25 m (14 ft)	8.5 m (28 ft)	16.75 m (55 ft)
1600 A	120 mm^2 csa (4/0 AWG)	4 m (13 ft)	8 m (26 ft)	16 m (52.5 ft)
2000 A	150 mm^2 csa (250 kcmil)	3.75 m (12.5 ft)	7.6 m (25 ft)	15 m (50 ft)
Sources: •NFPA 70-2026, Table 250.122 •ATIS-0600311.2017(R2024)				

4. The DC system bonding jumper **shall** also be sized according to the allowable resistance of the fault current path (see ATIS-0600311.2017(R2024) and ATIS-0600333.2013(S2023)). The DC system bonding jumper **shall** be sized to yield a voltage drop equal to or less than 90% of the nominal source voltage while carrying a fault current equal to a minimum of 10 times the rating of the largest overcurrent device.

The following formula is used (see Table 5-12):

$$R_{max} = (0.9 \times V_{nom}) / (10\ I_{opd})$$

Where:

- R_{max} = Maximum resistance of envisaged fault current path
- V_{nom} = Nominal source voltage (V)
- I_{opd} = Current rating of overcurrent protection device

Table 5-12 provides the R_{max} values for common overcurrent protection device ratings and system voltages. Consider the following example:

- V_{nom} = -48 V
- I_{opd} = 300 A
- Conductor length = 100 ft (30.48 m)

Considering the current rating of the upstream overcurrent protection device (300 A), Table 5-11 initially indicates that the minimum size conductor is 25 mm^2 csa (# 4 AWG), but only for a conductor length up to 55.5 ft (17 m). Based on the 100 ft (30.48 m) conductor length in this example, Step 4 is now required.

The purpose of Step 4 is to calculate the maximum allowable fault current resistance (R_{max}) (see Table 5-12 for completed R_{max} calculations for the different voltage systems):

- $R_{max} = (0.9 \times 48) / (10 \times 300) = 0.0144\Omega$

A maximum resistance of 0.0144Ω for 100 feet of conductor corresponds to 0.000144Ω (or 0.144mΩ) per conductor foot.

Table 5-12.R_{max} Calculated Values (Ω)

Overcurrent Protection Device Rating	R_{max}		
	12 V	24 V	48 V
200 A or less	0.0054 Ω	0.0108 Ω	0.0216 Ω
300 A	0.0036 Ω	0.0072 Ω	0.0144 Ω
400 A	0.0027 Ω	0.0054 Ω	0.0108 Ω
500 A	0.00216 Ω	0.00432 Ω	0.00864 Ω
600 A	0.0018 Ω	0.0036 Ω	0.0072 Ω
800 A	0.00135 Ω	0.0027 Ω	0.0054 Ω
1200 A	0.0009 Ω	0.0018 Ω	0.0036 Ω
1600 A	0.000675 Ω	0.00135 Ω	0.0027 Ω
2000 A	0.000504 Ω	0.00108 Ω	0.00216 Ω
Resistance per conductor foot = R_{max} / Conductor Length (ft)			

Completing the calculation using the equation in the table, (0.0144Ω / 100) = 0.000144Ω. A conductor size with a maximum resistance of 0.000144Ω/ft (or 0.144 mΩ/ft) is required. Table 5-13 indicates that a 50 mm^2 csa (# 1 AWG) conductor is the closest match.

NOTE: A mΩ equals 1/1000th of an ohm (Ω).

Table 5-13.Resistance of Copper Conductors at 25° C

Bonding Conductor Size (csa)	Resistance	Bonding Conductor Size (AWG)	Resistance
16 mm^2	0.3574 mΩ/ft	6	0.411 mΩ/ft
25 mm^2	0.2259 mΩ/ft	4	0.258 mΩ/ft
35 mm^2	0.1629 mΩ/ft	3	0.205 mΩ/ft
50 mm^2	0.1203 mΩ/ft	2	0.162 mΩ/ft
70 mm^2	0.0833 mΩ/ft	1	0.129 mΩ/ft
95 mm^2	0.0600 mΩ/ft	1/0	0.102 mΩ/ft
120 mm^2	0.0476 mΩ/ft	2/0	0.081 mΩ/ft
150 mm^2	0.0385 mΩ/ft	3/0	0.0642 mΩ/ft
185 mm^2	0.0314 mΩ/ft	4/0	0.051 mΩ/ft
240 mm^2	0.0241 mΩ/ft	250 kcmil	0.0431 mΩ/ft
400 mm^2	0.0145 mΩ/ft	350 kcmil	0.031 mΩ/ft
500 mm^2	0.0114 mΩ/ft	500 kcmil	0.021 mΩ/ft
630 mm^2	0.0088 mΩ/ft	750 kcmil	0.0144 mΩ/ft
Source: ATIS-0600333.2013(S2023), Table D.2 and IEC 60228 Class 2 Resistance Table.			

5.9.1.4.6.1. Sizing of SBB-to-PBB Conductor Where Part of a DC System

IMPORTANT: If the DC power system is installed in the same room or area as the Primary Bonding Busbar (PBB), it should be bonded to the PBB rather than to a Secondary Bonding Busbar (SBB).

When a DC power system is bonded to a Secondary Bonding Busbar (SBB), the SBB to Primary Bonding Busbar (PBB) conductor (or bonding backbone conductor) **shall** be appropriately sized for the DC power system, as follows (ATIS-0600333.2013(S2023), section 9.1.4):

- The conductor **shall** be at least 50 mm^2 csa (1/0 AWG).
- The conductor **shall** be sized at 6561 circular mils per linear meter (2000 circular mils per linear foot), according to Table 5-3 (see TIA-607-E, Table 1).
  - The conductor is not required to be larger than 400 mm^2 csa (750 kcmil).

If structural metal (a metal frame or framework) is used as the bonding backbone conductor or PBB-to-SBB bonding conductor, the SBB **shall** be bonded to the structural metal (the metal frame or framework) using a bonding conductor minimally sized as described above in this section and the same as the DC system bonding jumper (see “Sizing of DC System Bonding Jumper” on page 5-100).

Before utilizing structural metal, building plans (including as-builts as applicable) and specifications **shall** be reviewed to ensure the structural metal is electrically continuous or can be made so (TIA-607-E, section 6.3.6.1). Additionally, the two-point continuity test (see TIA-607-E, section 9.1) or equivalent should be performed on the structural metal to verify electrical continuity and acceptable resistance along the paths used as bonding conductors (TIA-607-E, section 6.3.6.1).

5.9.1.4.6.2. DC System Grounding Electrode Conductor

Where the DC power system is installed in a standard communications-type building or shelter, the DC system grounding electrode conductor requirements are met where a Primary Bonding Busbar (PBB) is installed according to “Primary Bonding Busbar” on page 5-10 and the associated subsections. Refer to NFPA 70-2026, Article 250.166, for more information.

Where the DC power system is installed in a larger and/or multi-story building that contains a bonding backbone (see “Bonding Backbone and Bonding Backbone Conductor” on page 5-55 and associated subsections), the PBB **shall** be bonded to the electrical service equipment (power) ground using a conductor of the same size or larger, as the bonding backbone conductor (TIA-607-E, section 6.3.3).

5.9.1.5 Equipment

An equipment bonding conductor **shall** be attached to the equipment bonding or grounding terminal, chassis, or frame using methods described in this chapter. If equipment has a ground stud or connection point provided by the manufacturer that is sized or located such that a 16 mm^2 csa (#6 AWG) conductor cannot be reasonably attached, then the 16 mm^2 csa (#6 AWG) equipment bonding conductor **shall** be connected to the equipment mounting screw or another suitable attachment point.

Where a terminal strip or other type of connection point is an integral part of the equipment (for example, a PC board terminal) and must be connected to ground, a jumper sized according to the manufacturer's instructions **shall** be installed between this point and the equipment bonding conductor. Installation instructions from the manufacturer regarding bonding and grounding **shall** be followed in all cases unless the manufacturer specifies a bonding or grounding conductor smaller than 16 mm^2 csa (#6 AWG); in such cases, a 16 mm^2 csa (#6 AWG) equipment bonding conductor **shall** be used. If the manufacturer has not provided specific bonding and grounding instructions, the guidelines in this paragraph **shall** apply.

Exception for Type A sites: Dedicated communications equipment that is electrically isolated and lacks external metallic connections (e.g., a desktop control station utilizing an antenna installed entirely within the building) does not require a dedicated equipment bonding conductor if a bonding busbar is not present in the immediate area. In these specific applications, grounding achieved through the electrical code-required Equipment Grounding Conductor (EGC) within the AC power cord is considered adequate.

NOTE: See “Equipotential Grounding (Earthing) of the Network Operator Position” on page 5-138 for specific exceptions to the 16 mm^2 csa (#6 AWG) equipment bonding conductor requirement.

Bonding can be made to any of the following:

- Rack Bonding Busbar (RBB). See “Rack Bonding Busbar” on page 5-28.
- Secondary Bonding Busbar (SBB). See “Secondary Bonding Busbar” on page 5-17.
- Primary Bonding Busbar (PBB). See “Primary Bonding Busbar” on page 5-10.
- Bonding grid (see “Supplementary Bonding Network or Bonding Grid” on page 5-63)
- An equipment bonding bus conductor. See “Equipment Bonding Bus Conductor” on page 5-51.

Manufacturer's installation instructions (if available) **shall** be followed when bonding to equipment. Two-hole lugs **shall** be used instead of single-hole lugs where practicable.

IMPORTANT: Electronic equipment **shall not** be bonded the Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring. Only ancillary equipment **shall** be bonded to the IPBB or Halo Ground Ring.

NOTE: Bonding and grounding communication equipment through the Alternating Current (AC) power cord does not meet the requirements of this standard or other related industry standards. Although the AC power cord usually includes an Equipment Grounding Conductor (EGC), the low impedance integrity of the EGC ground path in the electrical distribution system to the main power ground cannot be easily verified (see TIA-607-E, section 7.1, and IEEE 1100-2005 for more information).

NOTE: Many types of equipment lack an attachment point for bonding conductors. Equipment that lacks attachment points for external bonding conductors may be bonded via the equipment rail. If the equipment cannot be bonded through the rail, such as IT equipment on sliding trays, it may be bonded through the power cord. Bonding through the power cord is acceptable if the cord contains an EGC and the electrical receptacle housing, conduit, or Power Distribution Unit (PDU) to which the cord connects is bonded with an equipment bonding conductor. In this case, the shortest practical power cord **shall** be used. Consult the manufacturer's documentation for guidance. Refer to TIA-607-E, section 7.1, for additional information.



Figure 5-90. Example of Equipment Bonding: Antenna Combiner

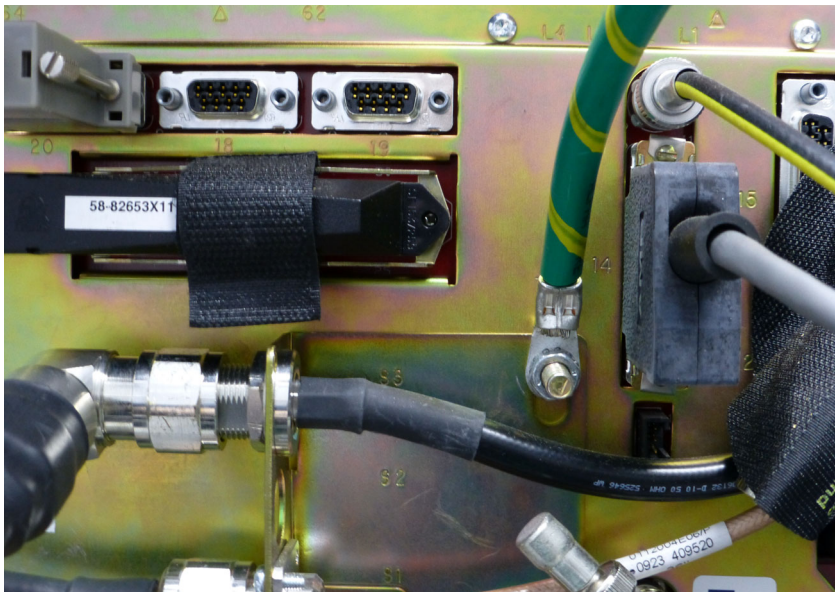


Figure 5-91. Example of Equipment Bonding: Base Station/Repeater

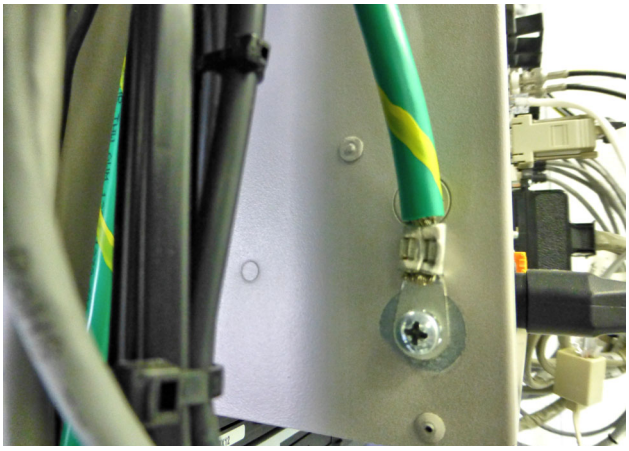


Figure 5-92. Example of Equipment Bonding: Channel Bank

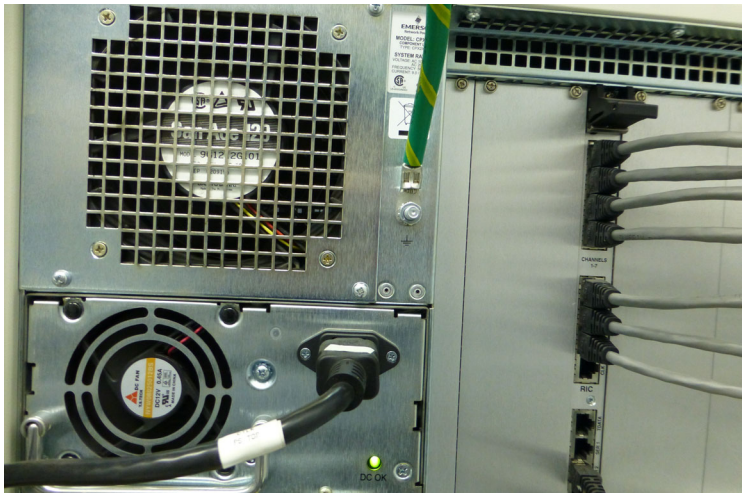


Figure 5-93. Example of Equipment Bonding: Trunking Controller

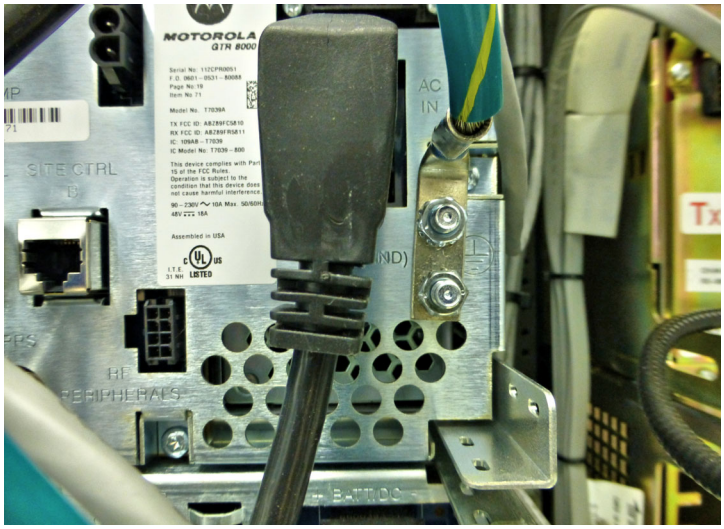


Figure 5-94. Example of Equipment Bonding: Base Station/Repeater

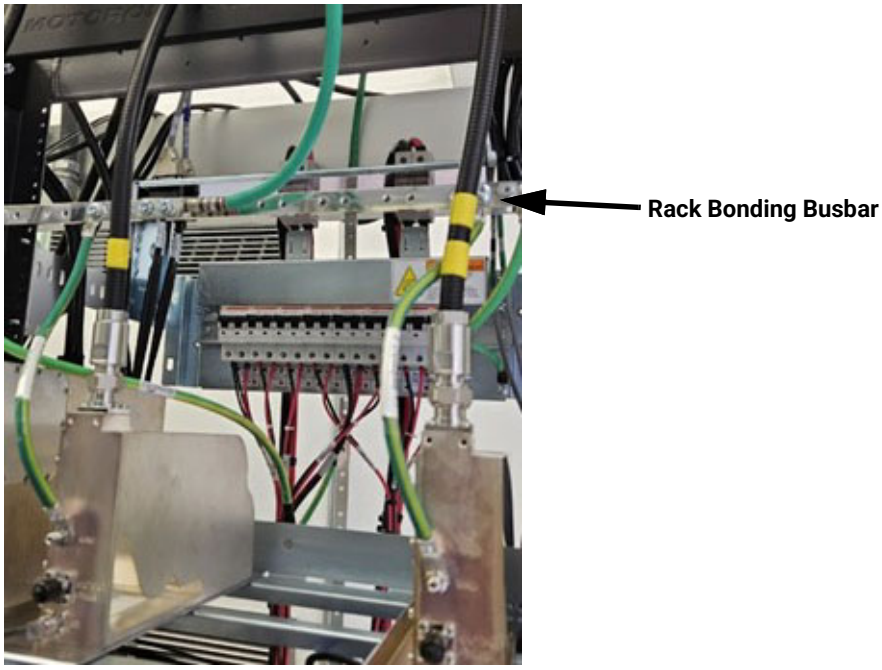


Figure 5-95. Example of Equipment Bonding: RBB on Multi-Carrier Site Rack



Figure 5-96. Example of Site Router Bonding

5.9.1.6 Cabinets and Racks

Cabinets and racks **shall** be effectively bonded to the internal bonding system with a minimum 16 mm^2 csa (#6 AWG) equipment bonding conductor unless otherwise specified.

Bonding conductor connections to cabinets and racks **shall** be made at the designated ground connection point or ground "pad." Connections to cabinets and racks without a designated connection point or ground pad **shall** be made to the equipment mounting rail using bonding methods described in this chapter.

Racks or cabinets equipped with a Rack Bonding Busbar (RBB) **shall** have an independent bonding jumper installed between the rack or cabinet grounding connection point and the RBB (see Figure 5-97). If it is not practical to install a rack bonding jumper directly to the RBB, the jumper may instead be installed between the rack bonding/grounding connection point and the 35 mm^2 csa (#2 AWG) (or larger) RBB bonding bus conductor, following the methods described in this chapter. All equipment within the rack or cabinet **shall** be bonded to the RBB using an equipment bonding conductor, according to the methods outlined in this chapter.

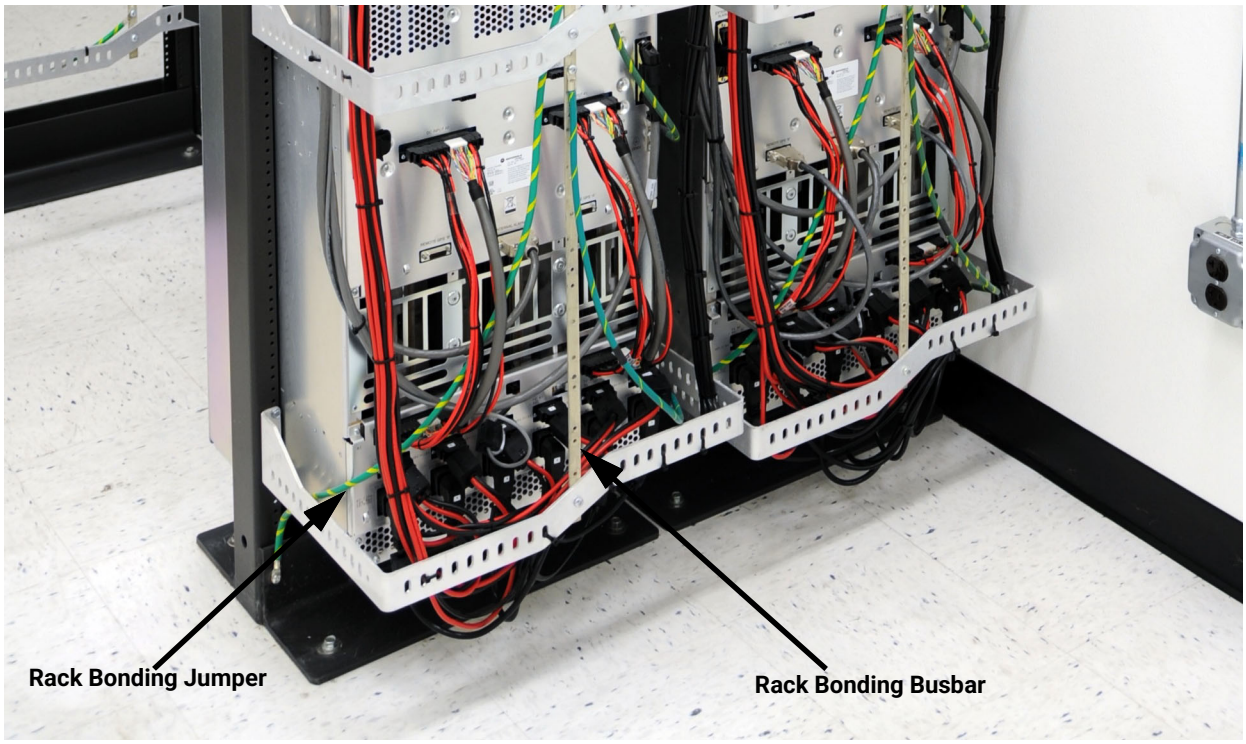


Figure 5-97. Example of Rack Bonding Jumper to Rack Bonding Busbar

IMPORTANT: If a cabinet or rack is supplied with DC power, see “Racks, Cabinets and Equipment Supplied from DC Systems” on page 5-99 for additional bonding requirements.

5.9.1.6.1 Structural Bonding of Cabinets and Racks

For cabinets and racks with welded construction, the welds serve as the method of bonding the structural members of the cabinet/rack together (see TIA-607-E, section 7.7).

For bolted cabinets and racks, bonding continuity **shall not** be assumed through the use of normal frame bolts unless the cabinet or rack is specifically designed and tested for integral bonding (see manufacturer specifications). These cabinets or racks use bonding hardware (e.g., bolts, washers, nuts, and screws) that are specifically engineered to provide integral bonding of the assembly. Refer to TIA-607-E, section 7.7, for more details.

If a cabinet or rack is not designed explicitly for integral bonding, it can be retrofitted using one of the options below (see TIA-607-E, section 7.7 for more details):

- Installing bonding jumpers between adjoining sections.
- Removing the paint from all bonding contact areas to ensure electrical continuity (per manufacturer recommendations).

NOTE: For integral bonding, welded racks are preferred over bolted racks.

All detachable metallic parts of equipment cabinets (such as the frame, door, side panels, top panel, etc.) **shall** be bonded. Bonding can be achieved using bonding jumpers or through bolted connections to the cabinet frame, contact fingers, or other manufacturer-approved bonding methods (see BICSI N3-20, section 8.7.3, and TIA-607-E, section 7.7, for more details).

If a detachable metallic panel of a cabinet is bonded with a jumper, the jumper **shall** have a minimum cross-sectional area (csa) of 4 mm² (#12 AWG), be constructed from a high-strand-count insulated copper conductor, and have a green or green with yellow stripe jacket. The bonding jumper should feature an easily visible quick connect to allow for quick detachment and attachment of the panel or door (see Figure 5-98). Refer to TIA-607-E, section 7.7, for further information.

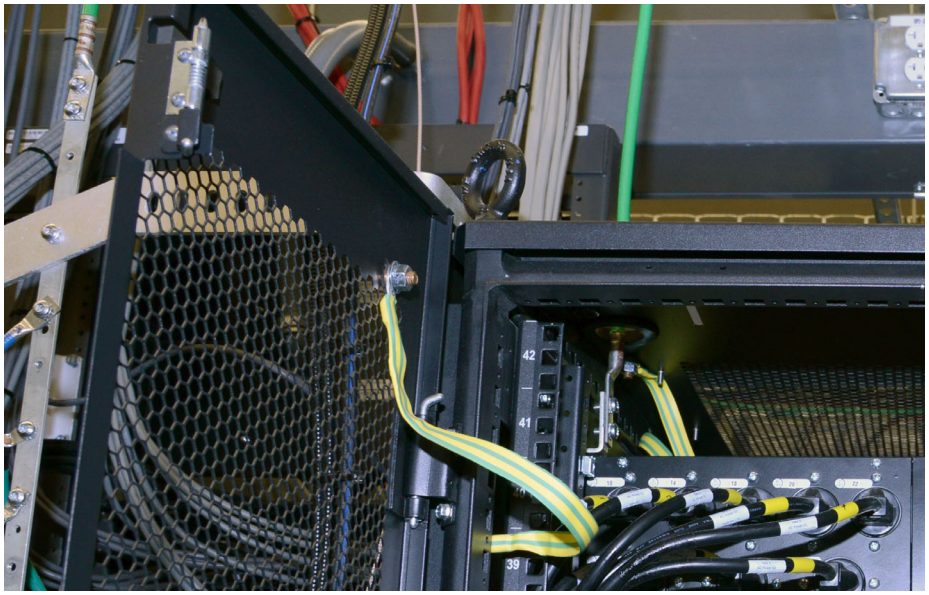


Figure 5-98. Example of Removable Cabinet Door Bonding

5.9.1.7 Cable Trays

A cable tray system **shall** be grounded appropriately as follows (see NFPA 70-2026, Article 250.96 and Part IV of Article 250 for additional information):

- A cable tray system **shall** be effectively bonded to the Primary Bonding Busbar (PBB) using a bonding conductor no smaller than 16 mm^2 csa (#6 AWG).
- The cable tray bonding conductor **shall** also be sized according to length as shown in Table 5-4.
- If the PBB is not located inside the equipment room or area, the cable tray system **shall** be bonded to the main Secondary Bonding Busbar (SBB) within that room or area using the bonding methods described here.
- Cable trays installed beneath a raised computer floor may be bonded to the bonding grid if installed.
- Bonding conductor attachment to the PBB or SBB **shall** be made using bonding methods specified in this chapter (see Figure 5-100).
  - Typically, a listed two-hole lug.
  - See “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69.
  - See Table 5-1 and Table 5-2.
- Bonding conductor attachment to the cable tray **shall** be accomplished using approved connection methods:
  - Typically, a listed two-hole lug.
  - Using a cable tray manufacturer-designed bonding method.
  - See “Connection Methods for Internal Bonding and Grounding (Earthing) System” on page 5-69.
- See “Cable Tray Systems Supporting DC Conductors” on page 5-98 for additional bonding requirements for cable tray systems supporting DC conductors.

IMPORTANT: If a cable tray supports DC conductors, see “Cable Tray Systems Supporting DC Conductors” on page 5-98 for additional bonding requirements.

Where a cable tray system has a single section running perpendicular to the PBB or SBB, the cable tray section closest to the bonding busbar **shall** have an equipment bonding conductor installed between one of its side rails and the PBB or SBB. The bonding conductor **shall** follow the shortest, straightest practicable route. See Figure 5-99 for an example of this configuration.

Where a cable tray system has been installed with a U-shaped section routed perpendicular to the PBB or SBB, each cable tray section nearest to the bonding busbar **shall** have an equipment bonding conductor installed between the cable tray side rail and the PBB or SBB. Each bonding conductor **shall** be installed along the shortest, straightest route practicable. See Figure 5-99 for an example of this configuration type.

Where a cable tray has been installed parallel to the PBB or SBB, the section of the cable tray nearest the bonding busbar **shall** have two equipment bonding conductors installed to ensure a bi-directional flow path to the PBB or SBB. Each bonding conductor **shall** be installed along the shortest, straightest route practicable. See Figure 5-99 for an example of this configuration type

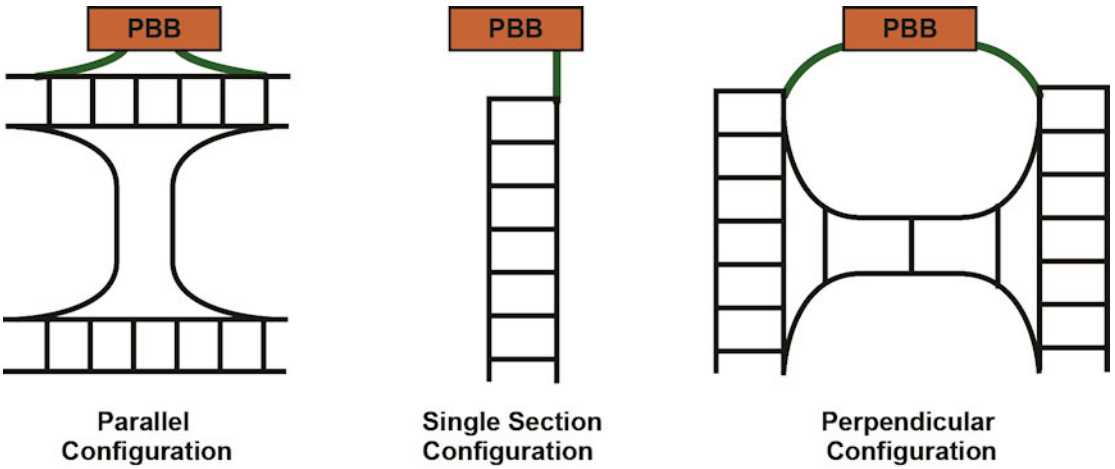


Figure 5-99. Cable Tray Bonding Configurations

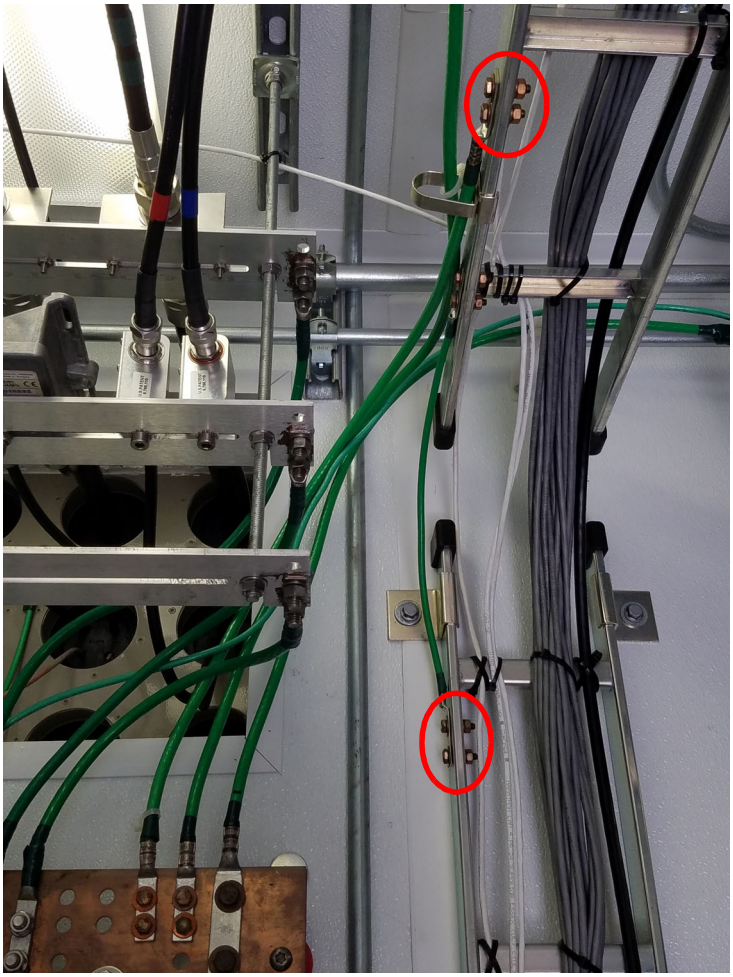


Figure 5-100. Example of Cable Tray Bonding to Primary Bonding Busbar

Bonding jumpers **shall** be installed at all cable tray splices and connection points unless the cable tray is labeled as suitable for use as an equipment grounding conductor and complies with NFPA 70-2026, Article 392.60(B) (see Figure 5-101). These types of cable trays have bolted splices, and the connection points use splined shoulder bolts that bite into the side rail of the cable tray to ensure a solid bond between sections. All bolts **shall** be installed at each splice in the cable tray system following the manufacturer's instructions. It is essential to ensure a continuous electrical path. Bonding jumpers are required at discontinuities, such as expansion splice plates and hinged splice plates.



Figure 5-101. Cable Tray Listed as an Equipment Grounding Conductor

IMPORTANT: Cable trays **shall not** be used as bonding bus conductors for equipment or support apparatus.

A bonding jumper **shall** be installed between each cable tray section and between each piece of metallic non-current-carry support hardware to ensure an effective current flow path to the PBB or SBB (BICSI N3-20, section 8.6.1). All bonding jumpers **shall** be as short and straight as practicable. Where a bend is required in the bonding jumper, it **shall** comply with the 203 mm (8 in.) minimum bending radius requirement. Cable trays with painted or aluminum anodized finishes **shall** have the protective coating completely removed down to the bare metal at each bonding connection point, and this point **shall** be treated with the appropriate conductive antioxidant compound before establishing the connection. Refer to Figure 5-102 and Figure 5-103 for examples of cable tray bonding jumpers.



Figure 5-102. Example of Bonding Jumper Installed on Cable Tray System

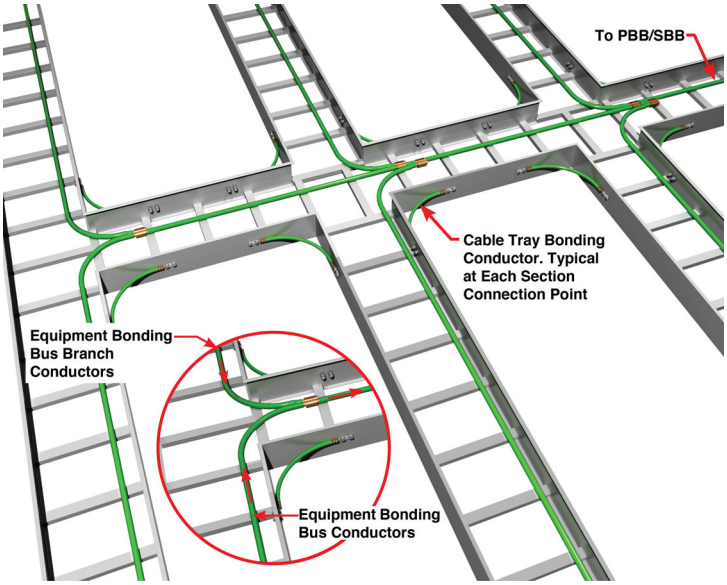


Figure 5-103. Example of Bonding Jumpers Installed on Cable Tray System (Top View)

5.9.1.8 Ancillary Support Apparatus

To ensure equal potential throughout a site or equipment room, all metallic ancillary support apparatus **larger than 10 cm² (4 in.²)** (see list in this section) within an equipment shelter, room, or specific equipment area **shall** be bonded to the internal bonding and grounding system, using a bonding conductor as described in "Equipment Bonding Conductor" on page 5-48 and related subsections. See Telcordia GR-3171-CORE.i02, section 10.10 for more information.

Bonding can be made to any of the following:

NOTE: In buildings or equipment rooms with high ceilings, ancillary equipment mounted above 2.44 m (8 ft) may be exempt from bonding and grounding, provided the equipment is not subject to contact by persons and has a horizontal clearance of at least 1.52 m (5 ft) from grounded metallic objects.

The system engineer or system owner should consider increasing these vertical clearances in high lightning areas, particularly within dispatch centers and occupied buildings, to further mitigate risks from sideflashing or induced surges.

- Primary Bonding Busbar (PBB) (see "Primary Bonding Busbar" on page 5-10)
- Secondary Bonding Busbar (SBB) (see "Secondary Bonding Busbar" on page 5-17)
- Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring (see "Internal Perimeter Bonding Bus Conductor or Halo Ground Ring" on page 5-58)
- Bonding grid (see "Supplementary Bonding Network or Bonding Grid" on page 5-63)

Follow the manufacturer's installation instructions (if available) when bonding ancillary support equipment to the site's bonding and grounding system. Make connections to the designated terminal or another suitable point on the apparatus. Use two-hole lugs instead of single-hole lugs whenever possible.

Metallic ancillary support apparatus that **shall** be bonded includes, but is not limited to, the following (see ATIS-0600334.2019(R2024), section 7.1):

- Ventilation louvers (see Figure 5-110)
- Exhaust fans (see Figure 5-109)
- Door frames and doors (see Figure 5-114)

- Electrical panels and panelboards (TIA-607-E, section 7.2.2, 7.3.3, and Figures 2 and 3) (see Figure 5-108)
- Switchboards
- Automatic and manual transfer switches.
- Exposed structural steel (ATIS-0600333.2013(S2023), section 5.2.1.2)
- Storage cabinets and desks
- Battery racks
- Window frames
- Ceiling grids
  - Bonding to the main ceiling support in at least two locations on opposite sides of the room is adequate for typical communications shelters/buildings (or equivalent) (see Figure 5-11 for an example). Larger equipment rooms should consider a bond on all sides.
  - The bond may be made to the PBB, SBB, IPBB, or Halo Ground Ring.
- Raised flooring systems (see “Raised Computer Floor Bonding” on page 5-120)
- HVAC grilles, ducts, units, motors, motor controllers, control panels, junction and terminal boxes (see Figure 5-106 and Figure 5-107)
- Dehydrators (see Figure 5-112)
- Unused entry panels (see Figure 5-113)
- Transformers and UPS units (see “Transformers, Inverters and UPS Systems (Containing Isolation Transformer)” on page 5-91)
- Metallic housing of AC power surge suppressor devices
- Primary surge suppressor ground terminals (bond per manufacturer instructions)
- Support apparatus, including metallic conduits, within an equipment shelter/room, a generator or power distribution room, or specific equipment area and located within 2.4 m (8 ft) vertically or 1.5 m (5 ft) horizontally of ground or grounded metal objects and subject to contact by persons (NFPA 70-2026, Article 250.110 and Parts V and VI).
- Electrical conduits (typically bonded to the IPBB or Halo Ground Ring near the terminating electrical panel). See Figure 5-104 and Figure 5-105.
- Set-screw type electrical conduit connectors and couplings **shall** be bridged with a bonding jumper. Set-screw-type couplings should be avoided (IEEE 1100-2005, section 8.4.8.2).
- Rigid Metallic Conduit (RMC) and Electrical Metallic Tubing (EMT).
  - **Exception:** If the conduits are effectively joined with a threaded coupling, threadless coupling, or threadless compression connector, that terminate in bonded metallic enclosures, they may be considered adequately bonded and do not require additional bonding (ATIS-0600334.2019(R2024), section 7.7).
  - If a conduit does not meet the above specifications (such as set-screw type couplings), the electrical conduits **shall** be bonded (typically to the IPBB or Halo Ground Ring).

NOTE: Multiple conduits may be bonded with a single continuous 16 mm^2 csa (#6 AWG) bonding conductor using removable saddle clamps or other clamps that specifically permit the use of a single continuous conductor for bonding multiple runs of conduits (Telcordia GR-3171-CORE.i02, section 10.10.3). If multiple conduits are bonded using a single conductor, the conductor **shall** be clamped to each conduit run such that removal of one clamp does not interrupt the path to ground for the other conduit runs. See Figure 5-104 and Figure 5-105 for examples.

Non-electrical metal cabinets, such as tool cabinets, **shall** also be bonded if mounted within 2 m (6 ft) of units that require bonding as previously specified (Telcordia GR-3171-CORE.i02, section 10.10.1).

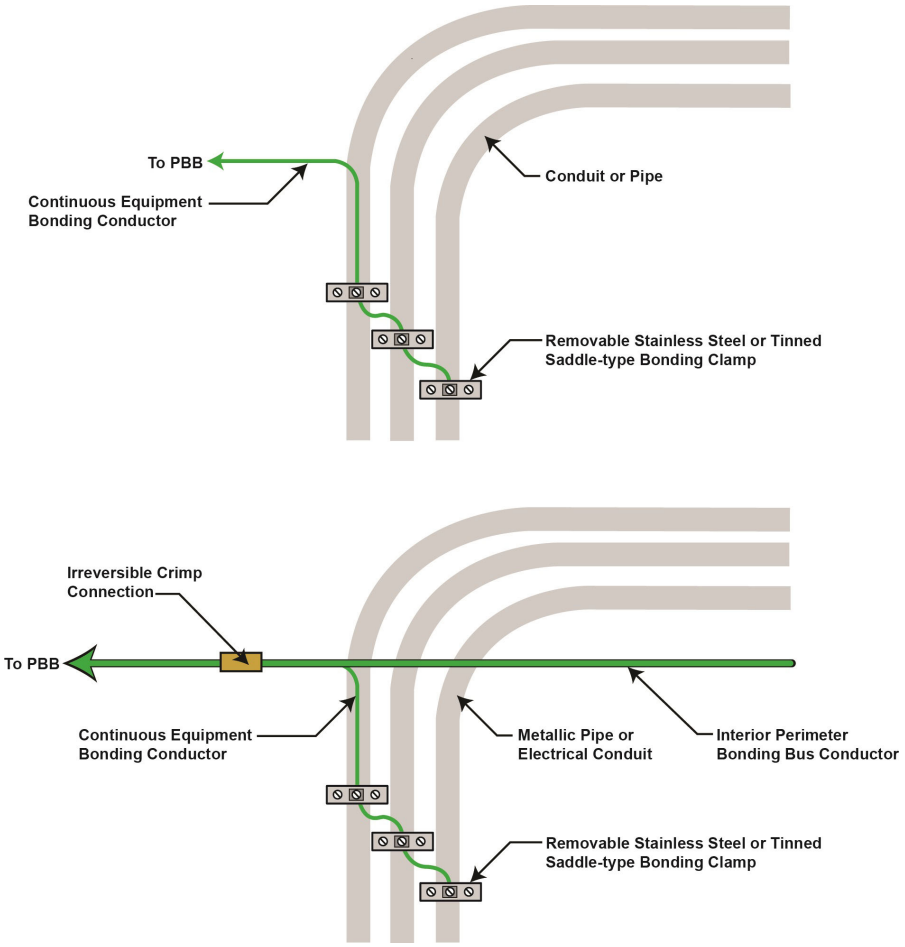


Figure 5-104. Bonding Method for Metallic Pipe or Conduit

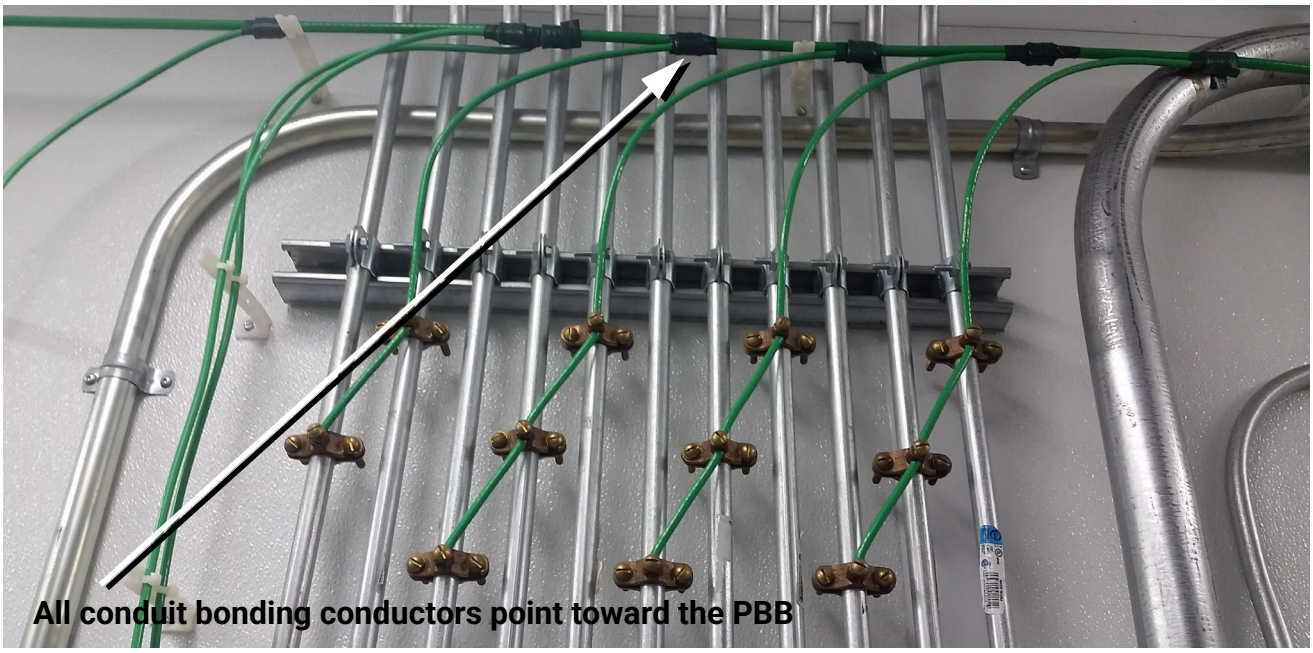


Figure 5-105. Example of Bonding Conduit to Internal Perimeter Bonding Bus or Halo Ground Ring

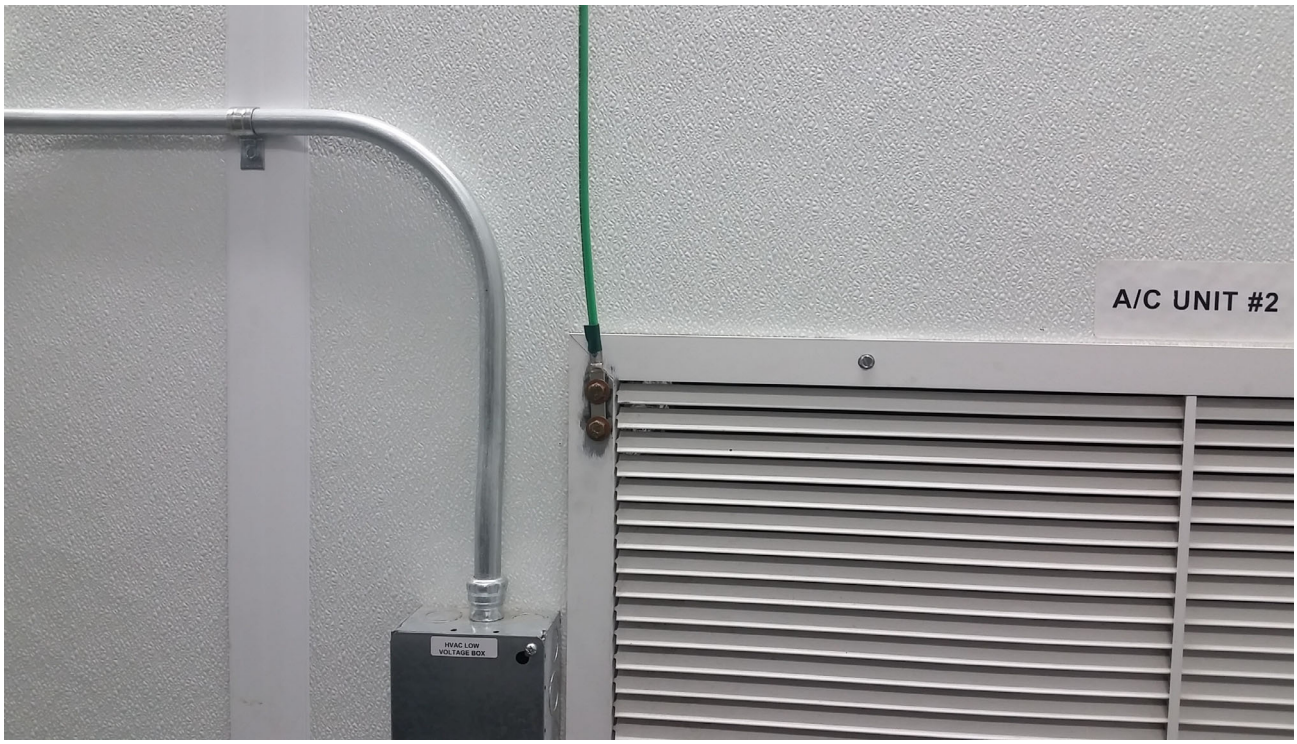


Figure 5-106. Example of HVAC Grille Bonding

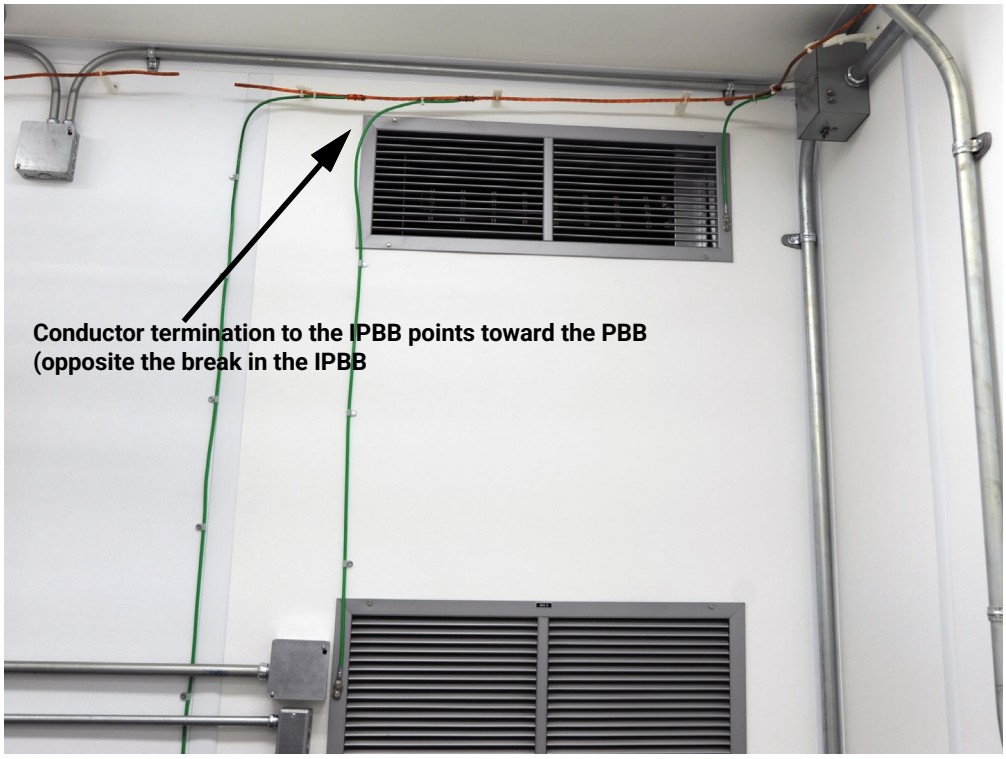


Figure 5-107. Example of Bonding HVAC Grilles to Internal Perimeter Bonding Bus



Figure 5-108. Example of Bonding Electrical Panelboard to Internal Perimeter Bonding Bus or Halo Ground Ring



Figure 5-109. Example of Bonding Exhaust Fan to Internal Perimeter Bonding Bus or Halo Ground Ring

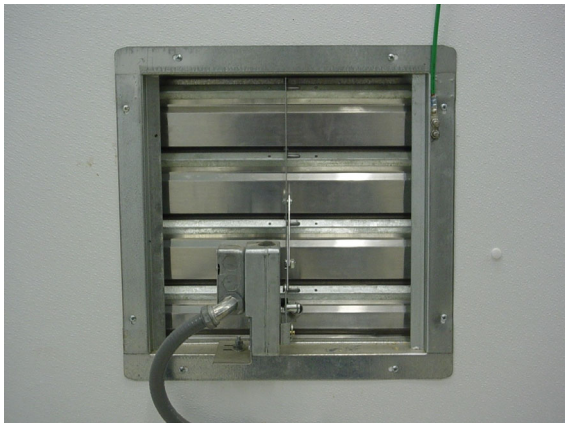


Figure 5-110. Example of Exhaust Louver Bonding



Figure 5-111. Example of Bonding Fresh Air Vent for Generator Room to Internal Perimeter Bonding Bus or Halo Ground Ring



Figure 5-112. Example of Bonding Dehydrator and Shelf to Internal Perimeter Bonding Bus or Halo Ground Ring

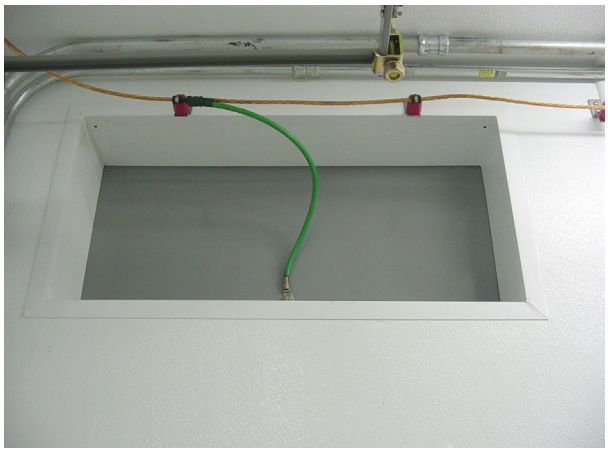


Figure 5-113. Example of Bonding Unused Entry Panel to Internal Perimeter Bonding Bus or Halo Ground Ring

IMPORTANT: Unused entry panels and similar items that are electrically continuous should be bonded either inside or outside the shelter, but not at both locations. Bonding at both locations can compromise the single-point grounding concept.

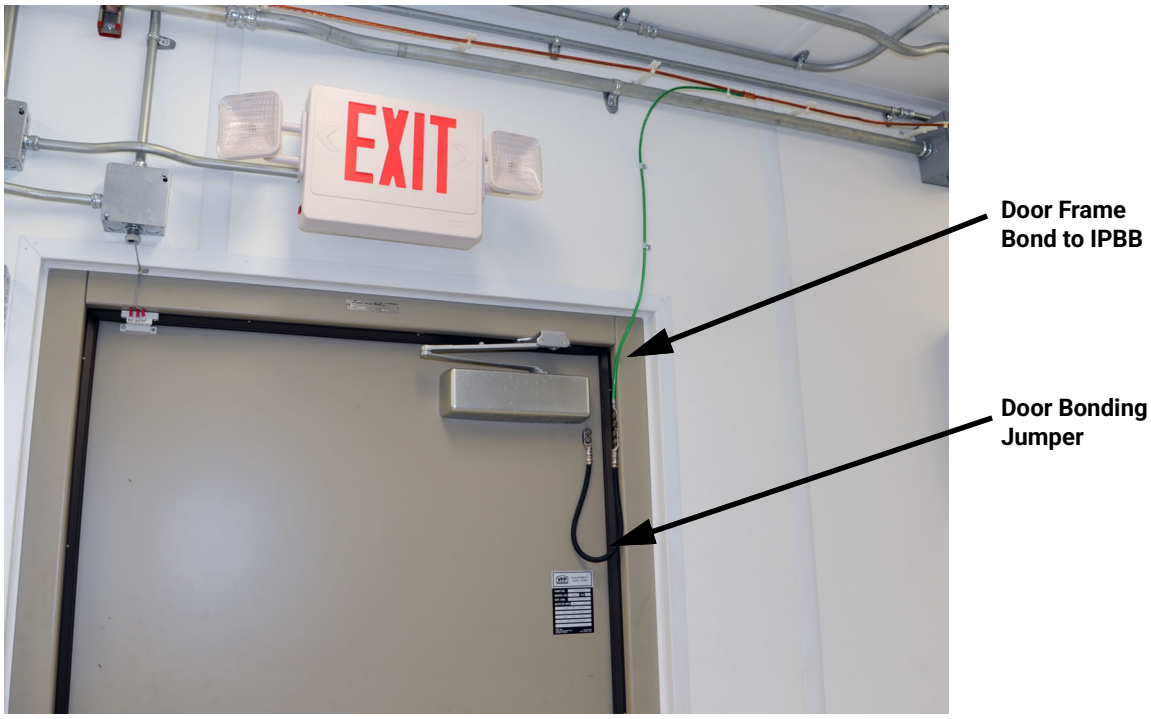


Figure 5-114. Example of Bonding Door Frame to Internal Perimeter Bonding Bus

NOTE: Doors are typically bonded using a highly flexible conductor, such as welding cable. Door bonding conductors may not be able to meet the conductor bending radius requirements due to the opening and closing of the door.

5.9.1.9 Metallic Building Structure and Piping Systems

Metallic building structures and piping systems, steel roof trusses, exposed support beams and columns, drop ceiling grids, raised floor support structures, and any metallic exposed building support structures and building frames located within 2.4 m (8 ft) vertically or 1.5 m (5 ft) horizontally of the communications equipment **shall** be bonded to the Primary Bonding Busbar (PBB), a Secondary Bonding Busbar (SBB), Internal Perimeter Bonding Bus (IPBB), Halo Ground Ring, or Bonding Grid using one of the conductors and methods described within this chapter. See Figure 5-115.

Series or daisy chain connections **shall not** be used. Each peripheral device **shall** be bonded with a separate equipment bonding conductor.

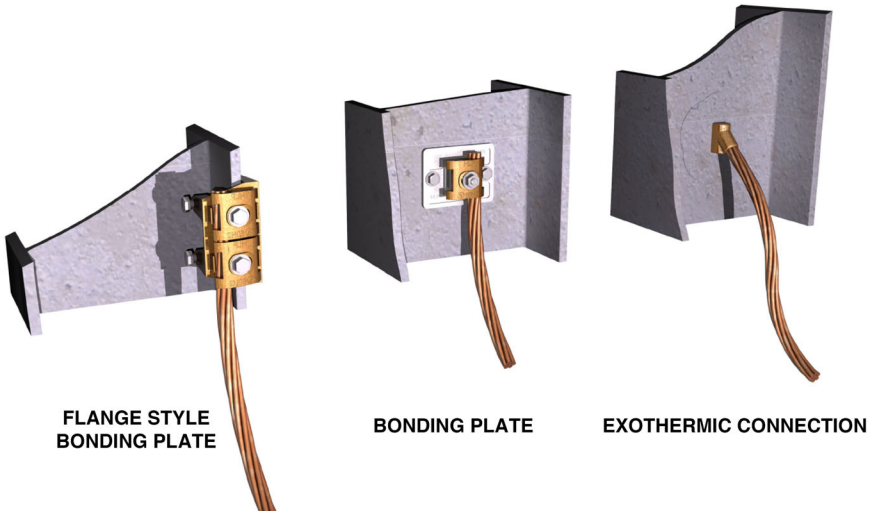


Figure 5-115. Examples of Acceptable Structural Building Steel Bonding Connections

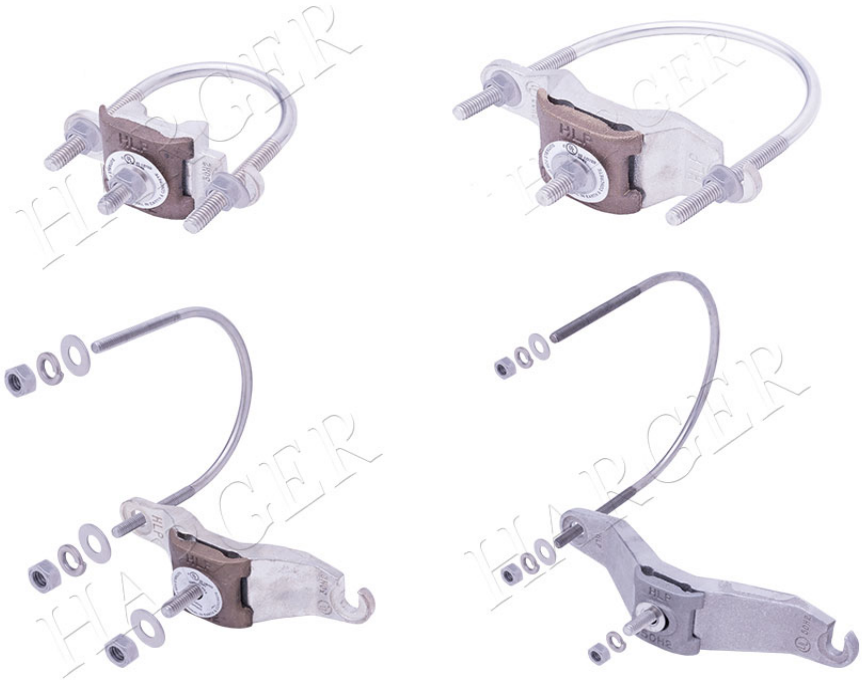


Figure 5-116. Examples of Pipe Bonding Clamps

5.9.1.10 Raised Computer Floor Bonding

To help ensure equal potential throughout a computer room, IT room, or dispatch area, a raised computer floor **shall** be bonded to the internal bonding and grounding system as described in the following subsections.

5.9.1.10.1 Raised Computer Floors Designed with Integrated Bonding

Some raised computer floors are designed to ensure electrical continuity throughout the system (see manufacturer specifications). These systems may include one or more of the following:

- Stringers designed to ensure electrical continuity
- Bonding/grounding clips designed to ensure electrical continuity
- A specific construction designed to ensure electrical continuity



IMPORTANT: See “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137 for further bonding requirements at these locations.

Raised computer floor systems of this type **shall** be bonded to the internal bonding system as follows:

- Each computer room, IT room, or dispatch area **shall** have at least one Secondary Bonding Busbar (SBB) (TIA-607-E, section 7.1.3).
- If the facility has a bonding backbone with more than one vertical riser or horizontal backbone conductor, the computer/IT room and/or dispatch area **shall** contain at least two SBBs (one SBB for each respective vertical riser or horizontal backbone conductor) as practicable.
  - The SBBs **shall** be installed horizontally, opposed to each other as much as practicable, and near each respective bonding backbone conductor.
  - Each SBB **shall** be bonded to the closest point on the bonding backbone.
- Bonding of the floor to the SBB(s) **shall** be performed in at least four locations within the computer/IT room and/or dispatch area (see ATIS-0600321.2020, section 7.7.2). The corners are the preferred bonding locations.
- The minimum size floor bonding conductor **shall** be a 16 mm^2 csa (#6 AWG) (ATIS-0600333.2013(S2023), section 5.6.2). Bonding conductor size **shall** also comply with the requirements of “Bonding and Grounding (Earthing) Conductor Length and Gauge Requirements” on page 5-41.
- Bonding to the floor **shall** be done at the manufacturer-provided or recommended bonding locations, if applicable. Otherwise, bonding **shall** be made to nearby floor pedestals using approved bonding hardware (see Figure 5-117 and Figure 5-118).
- Bonding conductors **shall** meet the requirements of “Bonding and Grounding (Earthing) Conductors” on page 5-41 and all relevant subsections.

If a bonding grid is not installed at the site, the following **shall** apply:

- The preferred method of bonding all corners is to install a bonding conductor around the floor’s perimeter and connect each end to opposite sides of the SBB, creating a floor bonding loop. If more than one SBB is present, each one **shall** be bonded to the floor bonding loop.
  - Bond each corner area of the floor system to this conductor with the correct hardware (see Figure 5-117).
  - The minimum size for this bonding conductor **shall** be a 16 mm^2 csa (#6 AWG).
  - The bonding conductor size **shall** also meet the requirements of “Bonding and Grounding (Earthing) Conductor Length and Gauge Requirements” on page 5-41, with the following exception: the conductor length can be doubled for a given conductor gauge. For example, a 16 mm^2 csa (#6 AWG) can be used for a floor bonding loop up to 8 m (26 ft), because the conductor is installed in a loop, creating two paths.
  - The bonding conductor can be either bare or jacketed. If it is bare, it **shall** be adequately secured to prevent incidental contact with the concrete floor and/or other metallic objects (see Figure 5-117 and Figure 5-118).

If a bonding grid is installed at the site (see “Supplementary Bonding Network or Bonding Grid” on page 5-63), the following **shall** apply:

- Bond each corner area of the floor system to the grid using appropriate hardware (see Figure 5-117 and Figure 5-118).
- Bond at least every four (4) to six (6) floor pedestals in each perpendicular direction (TIA-607-E, section 7.8.1). See Figure 5-117 and Figure 5-118.
- If applicable, bond each dispatch/network operator position SBB to the bonding grid (see “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137.

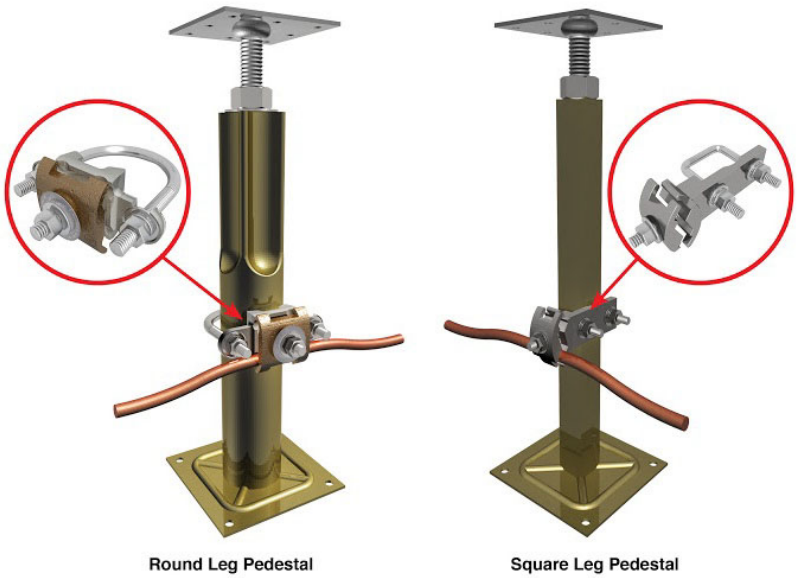


Figure 5-117. Acceptable Raised Flooring Bonding Connections

5.9.1.10.2 Raised Computer Floors Not Designed with Integrated Bonding

Some raised computer floors are not designed to ensure electrical continuity throughout the system (see manufacturer specifications). These systems **shall** be made electrically continuous through bonding and grounding.

Bonding and grounding are achieved by installing a supplementary bonding network in the form of a bonding grid under the floor, which may be referred to as a mesh-bonding network or mesh-BN (see TIA-607-E, section 7.1.3 for more details). This bonding grid is used to bond the floor system, electronic equipment, ancillary support equipment, and dispatch position Secondary Bonding Busbars. See “Supplementary Bonding Network or Bonding Grid” on page 5-63.

IMPORTANT: See “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137 for additional bonding requirements at these locations.

A bonding grid system (mesh-BN) **shall** be installed beneath the raised computer floor as follows:

- Install a bonding grid according to “Supplementary Bonding Network or Bonding Grid” on page 5-63.
- Bond each corner area of the floor system to the bonding grid using appropriate hardware (see Figure 5-117 and Figure 5-118) (ATIS-0600321.2020, section 7.7.2).
- Bond at least every four (4) to six (6) floor pedestals in each perpendicular direction (TIA-607-E, section 7.8.1 and Figure 5-118).

- Bond each dispatch/network operator position SBB to the bonding grid, if applicable (see “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137.

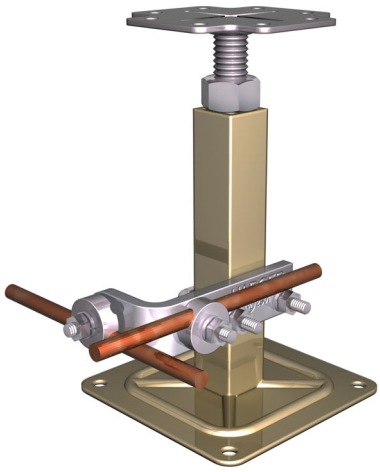


Figure 5-118. Bonding Conductors Suspended on Raised Flooring Pedestals

5.9.1.11 Surge Protective Devices

All surge protective devices (SPDs) and outside telecommunication cable metallic shields, including but not limited to the following items, **shall** be effectively bonded to the internal bonding and grounding system as described within this section:

- “RF Surge Protective Devices” on page 5-122
- “Primary Surge Protective Devices” on page 5-124
- “Secondary Surge Protective Devices” on page 5-125
- “Telecommunication Cable Metallic Shields” on page 5-127

5.9.1.11.1 RF Surge Protective Devices

RF coaxial cables **shall** be protected using an SPD as described in chapter 7, “Surge Protective Devices.”
RF coaxial cables **shall** be grounded and bonded as described in Chapter 4, “External Grounding (Earthing) and Bonding.”

RF SPDs **shall** be bonded to the Primary Bonding Busbar (PBB) or an Entry Point Secondary Bonding Busbar (SBB) within 610 mm (24 in.) of entry into the equipment shelter, room, or area. Each SPD should have its own bonding conductor connected to the PBB or SBB. RF coaxial SPDs can also be bonded directly to the PBB, an SBB, or a copper integrated entry panel using appropriate securing hardware. Refer to Figure 5-119 through Figure 5-123.

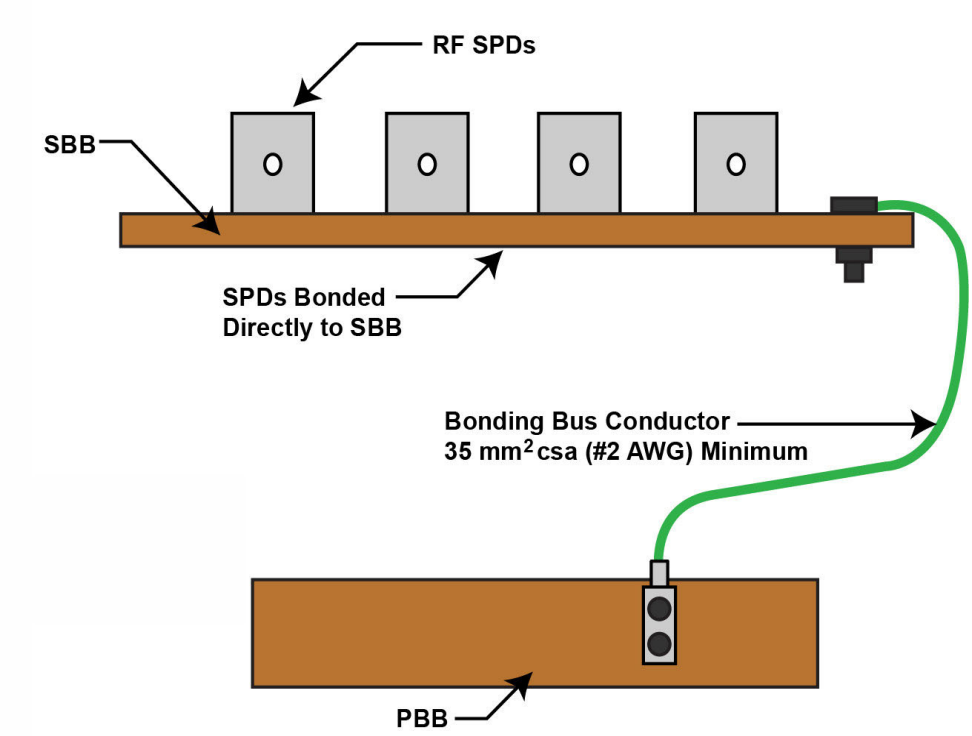


Figure 5-119. RF Surge Protective Device Bonding to Secondary Bonding Busbar with Bonding Bus Conductor

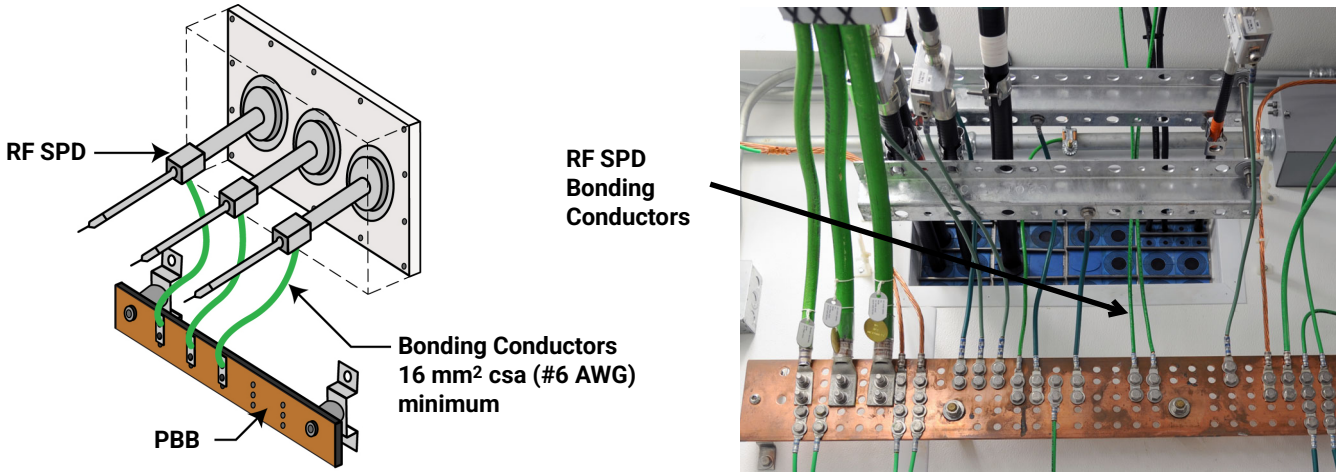


Figure 5-120. Example of RF Surge Protective Devices Bonding to Primary Bonding Busbar with Separate Bonding Conductors

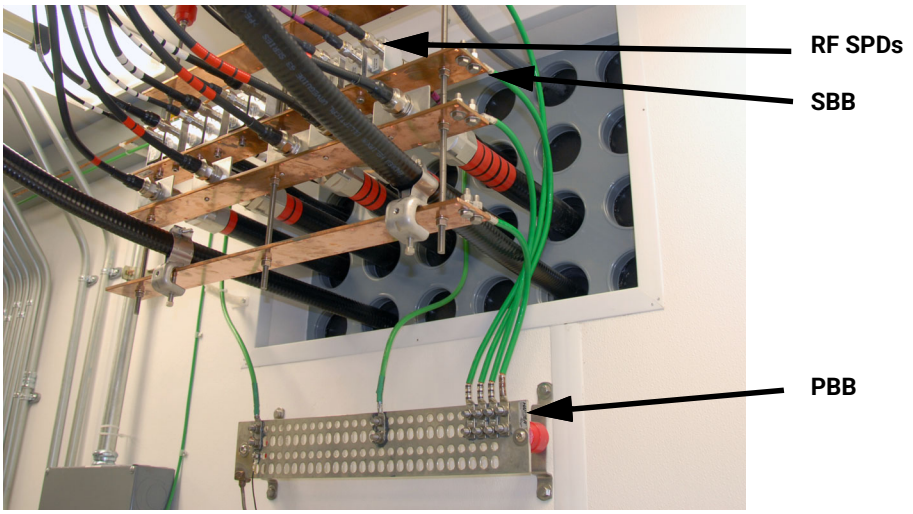


Figure 5-121. Example of RF Surge Protective Devices Bonding Directly to Secondary Bonding Busbars

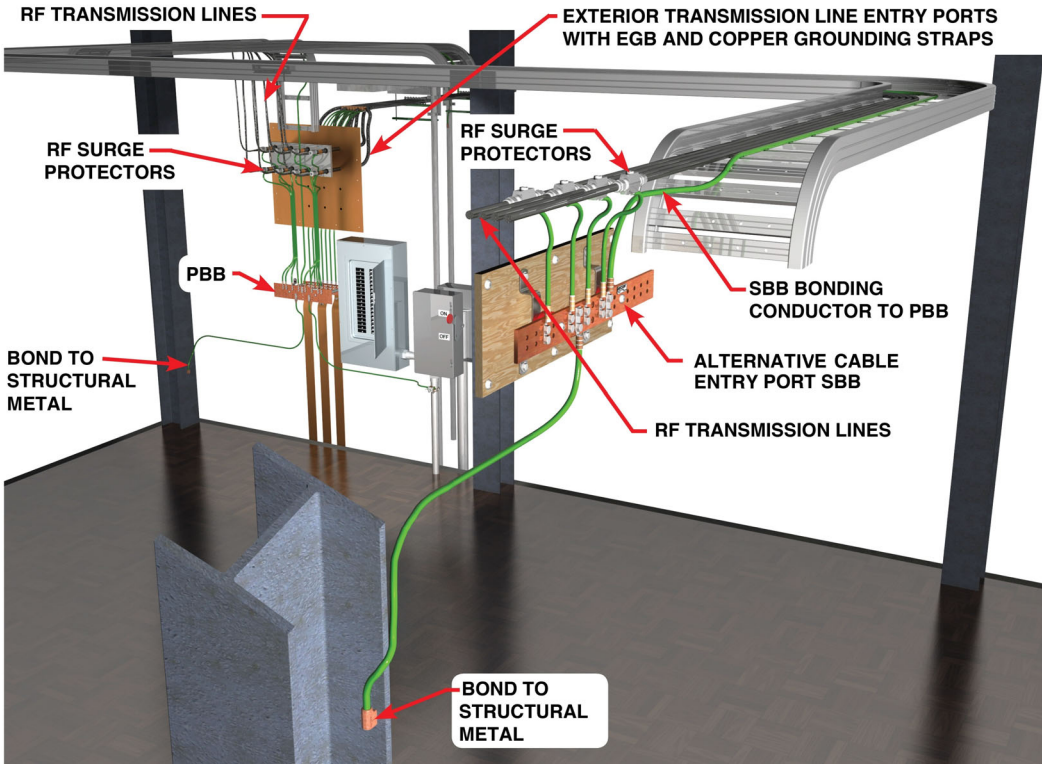


Figure 5-122. Alternative RF Entry Point Using Entry Point SBB

5.9.1.11.2 Primary Surge Protective Devices

Primary Surge Protective Devices (SPDs) for telephone, data, and control circuits **shall** have the ground terminal bonded to the Primary Bonding Busbar (PBB), a Secondary Bonding Busbar (SBB), or a dedicated bonding bus conductor with an equipment bonding conductor, using methods outlined in this chapter. The minimum size for a bonding conductor for a single-line primary SPD **shall** be 6 mm² (#10 AWG); for multiple-line primary SPDs, it **shall** be 16 mm² (#6 AWG) (see ATIS-0600318.2021, section 7.1.3.3; ATIS-0600321.2020, section 7.2; and NFPA 70-2026, Article 750 for more details). The bonding conductor **shall** also comply with the size requirements specified in Table 5-4.

Where a primary SPD is installed at an entry point other than next to the PBB and that point is more than 6.1 m (20 ft) away from the PBB's grounding electrode, a grounding electrode conductor **shall** be installed between the primary SPD grounding terminal or its SBB and the nearest accessible point on the common grounding electrode system, as specified in NFPA 70-2026, Article 750. See Figure 5-123 for an example of this type of grounding configuration.

In both cases, the bonding or grounding electrode conductors **shall** maintain at least 0.3 m (1 ft) of separation between cables of different groups, even where the conductor is installed in rigid metallic conduit (TIA-607-E, section 7.2.2).

NOTE: All conductor sizes given in Figure 5-123 represent the minimum size.

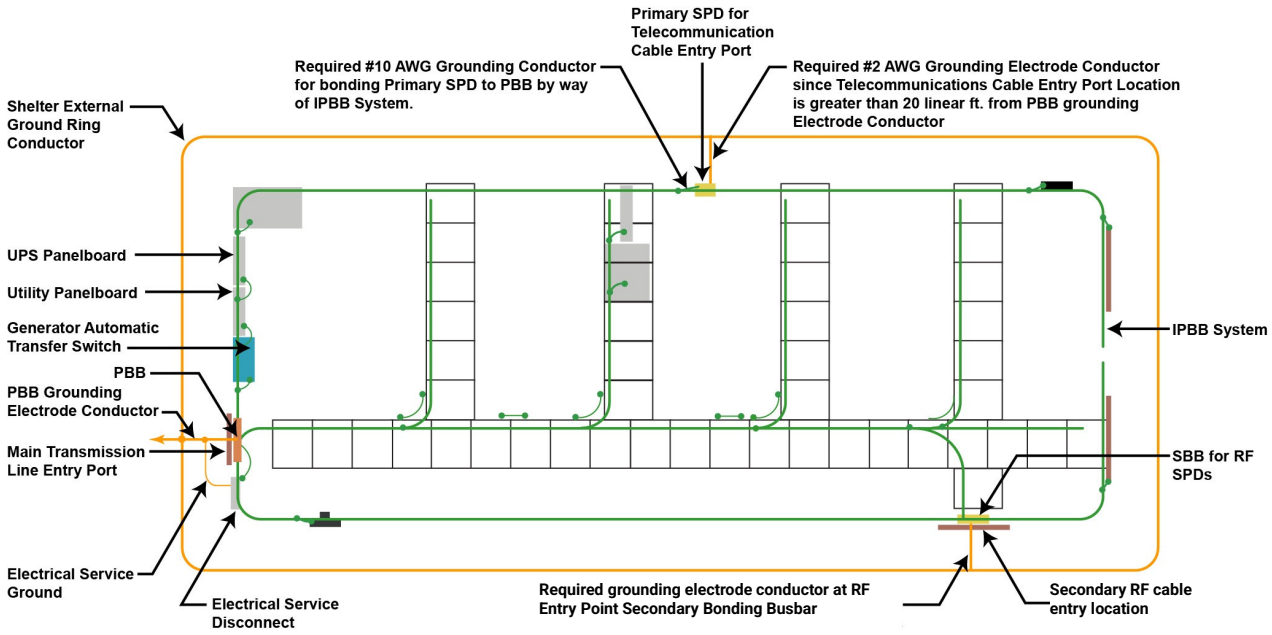


Figure 5-123. Telco Cable Entry Greater Than 6.1 Linear Meters (20 Linear ft) from PBB Grounding Electrode System

5.9.1.11.3 Secondary Surge Protective Devices

All secondary SPDs for telephone, data, and control circuits **shall** be installed as close as practicable to the equipment they protect, as outlined in Chapter 7, "Surge Protective Devices". Each secondary SPD grounding conductor or ground terminal **shall** be bonded separately to the Primary Bonding Busbar (PBB), a Secondary Bonding Busbar (SBB), a Rack Bonding Busbar (RBB), or a bonding bus conductor that serves the related equipment. The minimum size of the bonding conductor for a single-line secondary SPD is 6 mm² csa (#10 AWG). For multiple-line secondary SPDs, the minimum size is 16 mm² csa (#6 AWG) (see ATIS-0600318.2021, section 7.1.3.3; ATIS-0600321.2020, section 7.2; and NFPA 70-2026, Article 750 for more information). The bonding conductor must also meet the size requirements listed in Table 5-4.

Where several secondary SPDs are installed at an equipment rack or cabinet, they should be positioned centrally within the rack or cabinet to allow bonding to the equipment rack or cabinet RBB or to a separately installed RBB. If a dedicated RBB is used for the SPDs, it must be bonded to the equipment bonding bus system using the methods described in this chapter. See Figure 5-124.



Figure 5-124. Surge Protective Devices Installed at Equipment Rack or Cabinet

IMPORTANT: To prevent transients from coupling onto the protected cable, the protected and unprotected cables **shall** be kept physically separated as much as practicable, with a minimum distance of 100 mm (4 in.). The best practice is to run the unprotected cable along one side of the rack and the protected cable along the other. See Figure 5-125 for an example.

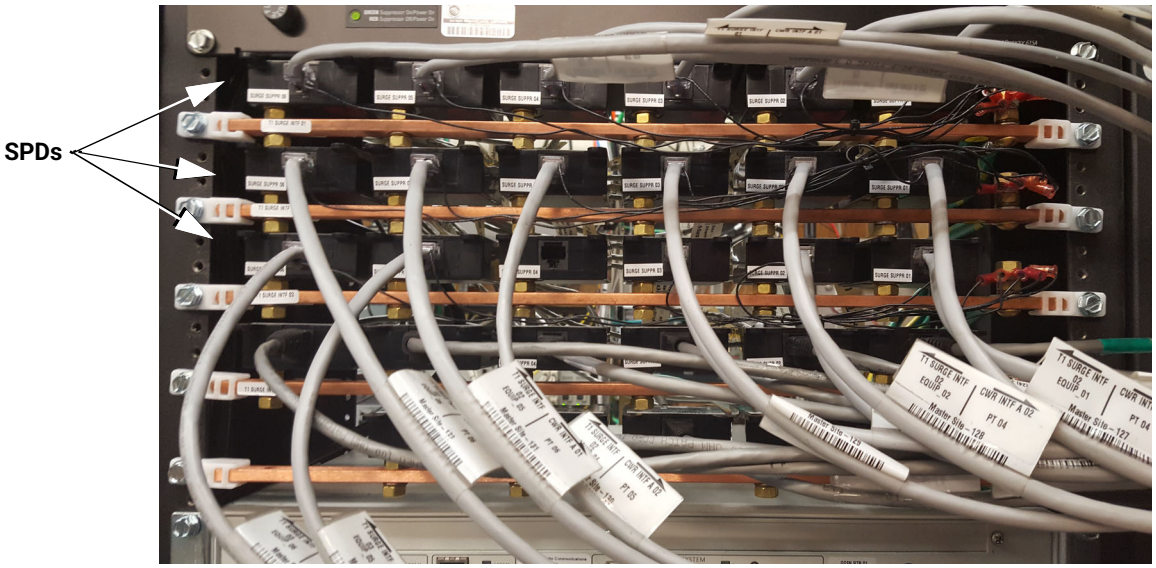


Figure 5-125. Example of Multiple Line Secondary Surge Protective Device

5.9.1.11.4 Telecommunication Cable Metallic Shields

Telecommunication cable metallic shields **shall** be bonded to the site's grounding electrode system as described in Chapter 4, "External Grounding (Earthing) and Bonding" or bonded according to this section. If outside facility telecommunication cables are configured for a standard entrance, all incoming telecommunication cables' metallic members (for example, the shield or drain), including paired-conductor and optical fiber cables, **shall** be bonded to the Primary Bonding Busbar (PBB), either directly or via a Secondary Bonding Busbar (SBB) at the facility's entrance point. Each metallic member **shall** be effectively bonded to the grounding point using a 16 mm^2 csa (#6 AWG) or larger green-jacketed conductor or a transmission line ground kit as practicable, following the methods outlined in this chapter. See Figure 5-126.

Where the internal bonding and grounding system is configured for functional categories 0 - 7 or PANI, the metallic members **shall** be bonded to reference point 0 or P. See "PANI Method" on page 5-81 and ATIS-0600313.2019(R2024) for more information.

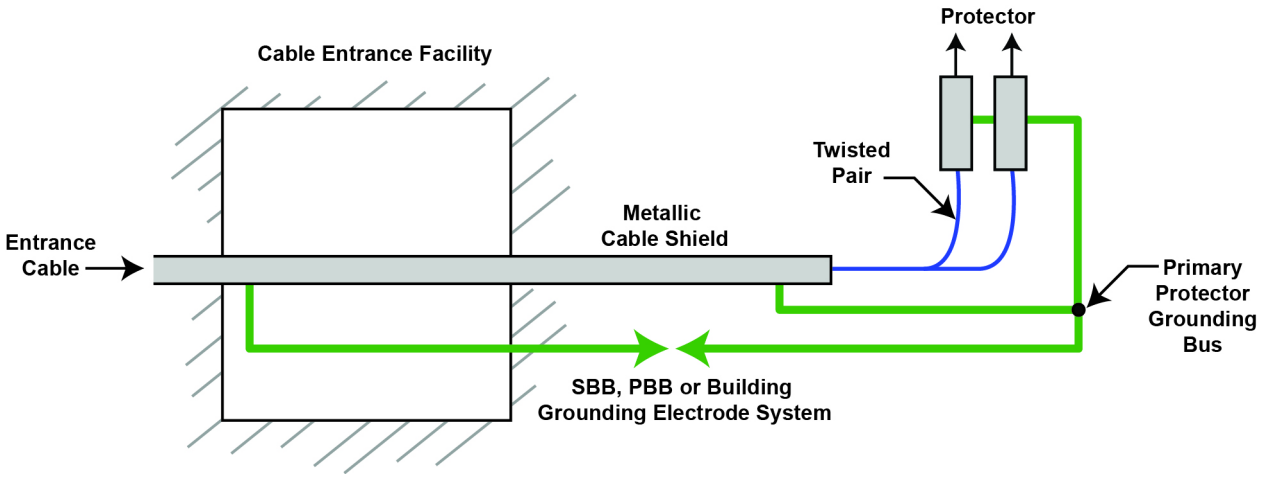


Figure 5-126. Standard Telecommunications Cable Entry Location

Where outside facility telecommunication cables are configured for an isolation entrance, the metallic member on the field side of the isolation gap **shall** be bonded to the PBB, either directly or through an SBB at the facility's entrance point (see Figure 5-127). The bonding connection point for a PANI configured bonding busbar will be reference point P. The metallic member on the facility side of the isolation gap **shall** only be grounded at the primary SPD grounding terminal, which is bonded to the SBB or to the PBB at the PANI reference point P. In this type of environment, the metallic members of all telecommunication cables entering the facility **shall** be isolated with a minimum 76 mm (3 in.) isolation gap. The isolation gap **shall** be sealed and insulated to prevent moisture penetration and flashovers during high voltage events. The grounding conductor for each side of the metallic member **shall** be a 16 mm^2 csa (#6 AWG) or larger and green-jacketed. The grounding conductor **shall** be effectively bonded to the referenced grounding point using bonding methods described within this chapter. See "PANI Method" on page 5-81 and ATIS-0600313.2019(R2024) for more information.

NOTE: Isolation gaps, which interrupt the metallic members of all cables, may be installed in some locations as a protective measure against high lightning incidence. This method should be used with caution because it tends to compensate for deficiencies in electrical protection in the outside plant (ATIS-0600313.2019(R2024), section 8.2.2). Consultation with an engineer is recommended in these instances.

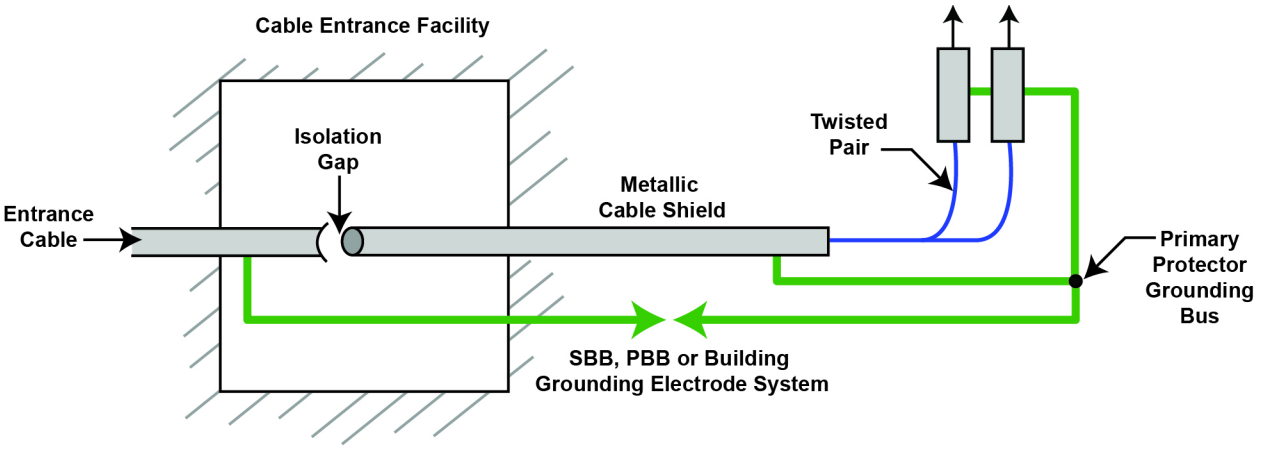


Figure 5-127. Isolation Type Telecommunications Cable Entry Location

Where outside facility telecommunication cables are configured with an insulated entrance, the metallic members **shall** be bonded on both sides of the insulating joint (see Figure 5-128). The facility side of the insulating joint **shall** be bonded to the PBB, either directly or through an SBB at the facility's entrance point. The bonding point for a PANI-configured busbar will be reference point P. The grounding conductor for each metallic member on the facility side of the insulating joint **shall** be a 16 mm² csa (#6 AWG) or larger, green-jacketed, and effectively bonded to the referenced grounding point using bonding methods described in this chapter. On the field side of the insulating joint, all metallic members and associated metals are intentionally isolated from the site's common grounding electrode system. Insulating joints are bridged with capacitors to permit alternating currents and lightning surges to flow to ground. Refer to “PANI Method” on page 5-81 and ATIS-0600313.2019(R2024) for more information.

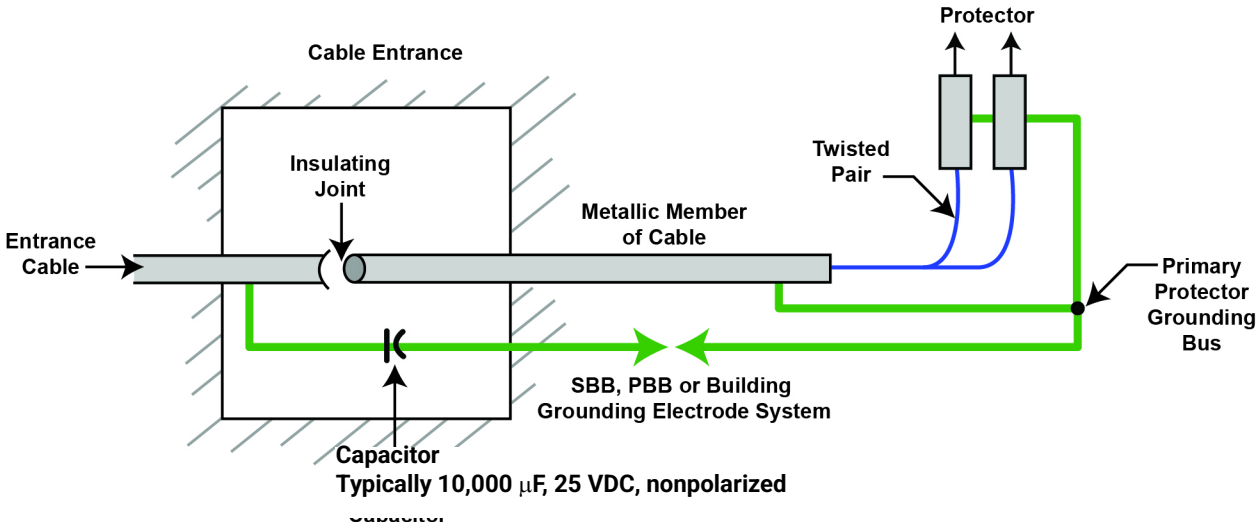


Figure 5-128. Insulating Type Telecommunications Cable Entry Location

Where internal building backbone telecommunication cables contain a shield or metallic member, the shield or metallic member **shall** be effectively bonded to the closest PBB or SBB using a 16 mm² csa (#6 AWG) or larger, green-jacketed grounding conductor at the point where cables terminate or are broken out. Refer to TIA-607-E, section 7.1, for more information.

5.10 Bonding and Grounding (Earthing) for Specific Site Types

Bonding and grounding of communications equipment are essential for personnel safety, system reliability, and system availability. As circuit density increases and lower-voltage integrated circuit devices become common, communications and electronic equipment become more vulnerable to damage from lightning activity, power line anomalies, and electrostatic discharge. Inadequate or incorrect equipment bonding and grounding can create an electrical potential difference between system components, which may cause injury to personnel, system failure, and equipment damage.

IMPORTANT: Bonding and Grounding (Earthing) alone are not enough to adequately protect a communications site. Appropriate Surge Protective Devices (SPDs) and external grounding **shall** be incorporated at a communications site to provide adequate protection. See Chapter 4, "External Grounding (Earthing) and Bonding", and Chapter 7, "Surge Protective Devices", for details and requirements.

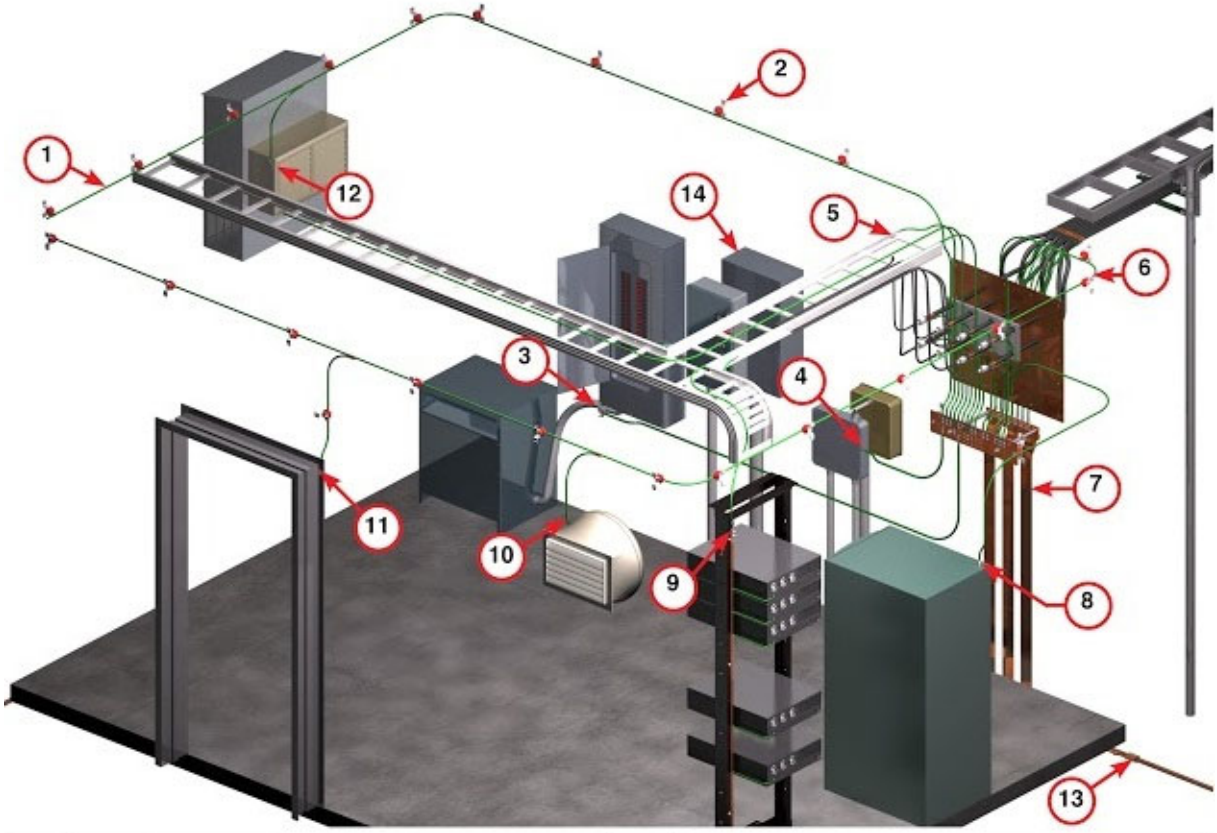
NOTE: This section provides a summary of internal bonding and grounding requirements for various types of communications sites, based on the requirements of this chapter. This summary is not exhaustive; all relevant sections in this chapter **shall** be followed

5.10.1 Bonding and Grounding Requirements for Stand-Alone Shelters

Stand-alone equipment shelters are typically located next to a communications tower or atop a large building to house communications system equipment. The bonding and grounding requirements for stand-alone equipment shelter installations listed below **shall** be met:

- Installation of a grounding electrode system as appropriate for the site, as described in Chapter 4, "External Grounding (Earthing) and Bonding".
- Grounding of the electrical service per local codes and bonding to the common grounding electrode system. See "Electrical Service Grounding and Entrance Point" on page 5-8 and Chapter 6, "Power Sources" for more information.
- Bonding of all grounding electrode systems together as described in Chapter 4, "External Grounding (Earthing) and Bonding", and in "Common Grounding (Earthing)" on page 5-6.
- Installation of a Primary Bonding Busbar (PBB) as described in "Primary Bonding Busbar" on page 5-10 or an integrated panel as described in "Integrated Cable Entry Grounding Systems and Cable Entry Panels" on page 5-15.
- Installation of Secondary Bonding Busbars (SBB) as applicable, as described in "Secondary Bonding Busbar" on page 5-17.
- Installation of an Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring as described in "Internal Perimeter Bonding Bus Conductor or Halo Ground Ring" on page 5-58. See Figure 5-129 and Figure 5-1 on page 5-4 for IPBB bonding examples and see Figure 5-56 for a Halo Ground Ring example.
- Installation of equipment bonding bus conductors as described in "Equipment Bonding Bus Conductor" on page 5-51. See Figure 5-130 and Figure 5-131 for examples.
- Bonding of all ancillary support apparatus as described in "Ancillary Support Apparatus" on page 5-112.
- Bonding of all cable tray systems as described in "Cable Trays" on page 5-109.
- Bonding of equipment as described in "Equipment" on page 5-103.
- Bonding of cabinets and racks as described in "Cabinets and Racks" on page 5-107.
- Bonding of all power systems (for example, separately derived AC systems, generators, and DC power systems) as described in "Equipment and Ancillary Support Apparatus Bonding" on page 5-88 and applicable subsections.
- Bonding of all surge protective devices as described in "Surge Protective Devices" on page 5-122.

- Bonding of telecommunications cable metallic shields as described in “Telecommunication Cable Metallic Shields” on page 5-127.



1	#2 AWG INTERNAL PERIMETER BONDING BUS CONNECTED TO THE PBB AT ONE END	8	UPS EQUIPMENT GROUND CONDUCTOR TO THE PBB
2	STANDOFF CLAMP WITH INSULATOR	9	EQUIPMENT BONDING BUS TO THE PBB
3	BOND AC ELECTRICAL SERVICE TO THE PBB	10	BOND EXHAUST FANS AND AIR VENTS TO THE INTERNAL PERIMETER BONDING BUS
4	BOND TELCO GROUND TO THE PBB	11	BOND DOOR FRAME TO THE INTERNAL PERIMETER BONDING BUS
5	BOND CABLE TRAY TO THE PBB	12	BOND HVAC TO THE IPBB
6	BOND IPBB TO THE PBB	13	SHELTER GROUND RING
7	ENTRANCE PANEL GROUND STRAPS EXOTHERMICALLY WELDED TO THE SHELTER GROUND RING	14	AC ELECTRICAL METER BOX

Figure 5-129. Example of Stand-Alone Equipment Shelter Bonding and Grounding

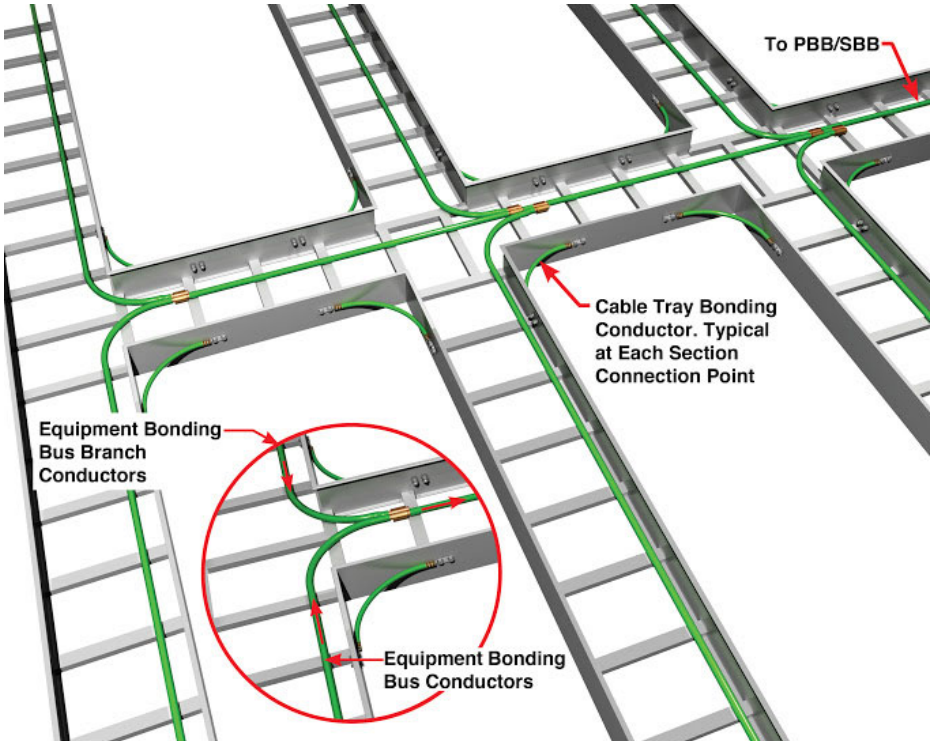


Figure 5-130. Example 1 of Equipment Bonding Bus Conductors

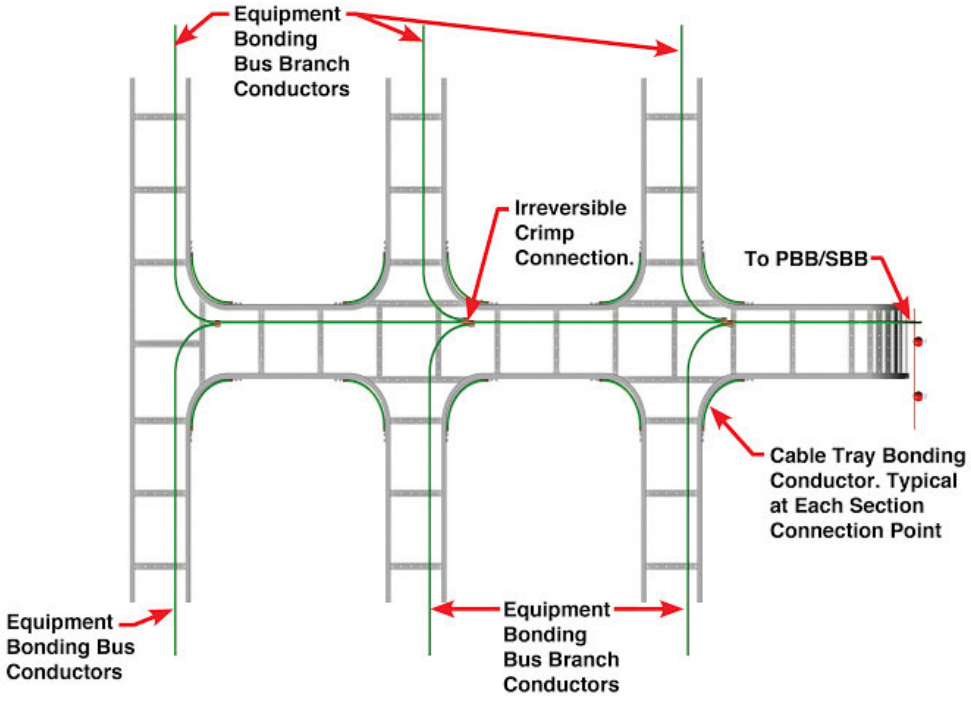


Figure 5-131. Example 2 of Equipment Bonding Bus Conductors

5.10.2 Bonding and Grounding for Small Commercial Building Installations

A small commercial building installation is typically one in a commercial or office building, where the communications equipment is located in the same general area as the electrical service entrance (common in small dispatch centers). See Figure 5-132 for an example.

This type of installation has the same general requirements as a stand-alone shelter once the Primary Bonding Busbar (PBB) is established. The following PBB installation requirements apply:

- The PBB **shall** be installed in a location that minimizes the conductor length between the PBB and the electrical service ground (PBB grounding electrode conductor), while also allowing convenient bonding of electronic equipment, building structural metal, metallic water pipes, and other grounding electrodes. See “Primary Bonding Busbar” on page 5-10 and Figure 5-132 for more information.
- The PBB grounding electrode conductor **shall** meet the requirements of “Primary Bonding Busbar Grounding Electrode Conductor” on page 5-13.
- The PBB **shall** serve as the central bonding location for all other grounds at the site (e.g., telco ground, building structural metal, water pipes, supplemental grounding electrodes, and so on).
- The PBB may bond to the electrical service equipment ground (see Figure 5-133) or may bond directly to the building's common grounding electrode system.
- Electrical panelboards in the telecommunications entrance facility/equipment room **shall** be bonded to the PBB as shown in Figure 5-132 (TIA-607-E, section 7.2.2). See “Ancillary Support Apparatus” on page 5-112.

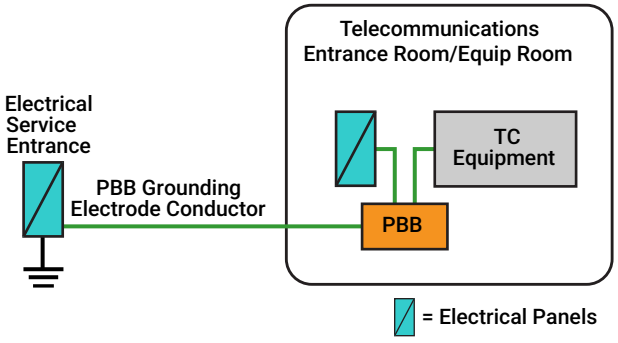


Figure 5-132. Example of Internal Bonding and Grounding System for Single-story Smaller Commercial Building

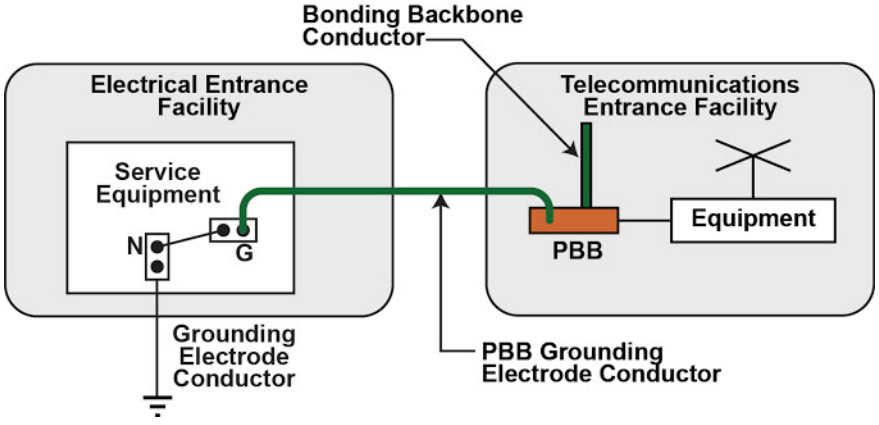


Figure 5-133. Example of Bonding to the Electrical Service (Power) Ground

IMPORTANT: Where accessible structural metal is in the same room as the PBB or SBB, the PBB or SBB **shall** be bonded to the structural metal using a conductor sized according to Table 5-3 (see TIA-607-E, section 7.1.6).

NOTE: If the existing grounding electrode system is unknown or cannot be verified (see Appendix D, "Testing/Verification of Grounding (Earthing) Electrode System and Bonding Continuity"), a supplemental grounding electrode system should be installed (see Chapter 4, "External Grounding (Earthing) and Bonding" and Figure D-16). This supplemental grounding electrode system **shall** be bonded to the electrical service ground (typically at the PBB).

5.10.3 Bonding and Grounding for Large and Multi-Story Commercial Building Installations

A large commercial building installation generally refers to an installation in a commercial or office building where the communications equipment is situated separately from the electrical service entrance (common for large dispatch centers) and/or there are multiple equipment rooms. This type of installation can be in a single-story building (see Figure 5-134) or a multi-story building (see Figure 5-135).

Large and/or multi-story buildings require the installation of a bonding backbone as described in "Bonding Backbone and Bonding Backbone Conductor" on page 5-55. The bonding backbone interconnects all equipment room Secondary Bonding Busbars (SBB) to the building's Primary Bonding Busbar (PBB). See Figure 5-134 and Figure 5-135.

Requirements for bonding and grounding in large and multi-story commercial buildings are as follows:

- The PBB **shall** be installed in a location that minimizes the conductor length between the PBB and the electrical service ground (PBB grounding electrode conductor), while also allowing convenient bonding of the bonding backbone conductors, building structural metal, metallic water pipes, and other grounding electrodes. See "Primary Bonding Busbar" on page 5-10, Figure 5-134, and Figure 5-135 for more information.
- The PBB **shall** be bonded to the electrical service equipment (power) ground using a conductor of the same size or larger, as the bonding backbone conductor (TIA-607-E, section 6.3.3).
- Each equipment room **shall** contain an SBB. This SBB functions as the PBB equivalent for each respective equipment room.
- The SBB **shall** be installed as close as practicable to the electrical panel serving that equipment room and **shall** be installed to maintain clearances required by applicable electrical codes (TIA-607-E, section 7.3.1).
- Where an electrical panel for the equipment room is not installed in the same room or space, that room's SBB should be located near the backbone cabling and associated terminations (TIA-607-E, section 7.3.1).
- Where an electrical panel serving the equipment room is not located in the same room or space as the SBB, that SBB should be bonded to the electrical panel, using bonding conductors sized according to Table 5-4 (TIA-607-E, section 7.3.3).
- Bonding and grounding within each equipment room follows the general requirements summarized in "Bonding and Grounding Requirements for Stand-Alone Shelters" on page 5-129. The PBB referenced on page 5-129 is now an SBB (bonded to a bonding backbone) that serves as the PBB for each equipment room.
- Electrical panels in each equipment room **shall** be bonded to that room's respective SBB as shown in Figure 5-134 and Figure 5-135. See "Ancillary Support Apparatus" on page 5-112.
- All metallic pathways for telecommunications cabling located within the same room or space as the SBB **shall** be bonded to the SBB (TIA-607-E, sections 7.2.2 and 7.3.3).

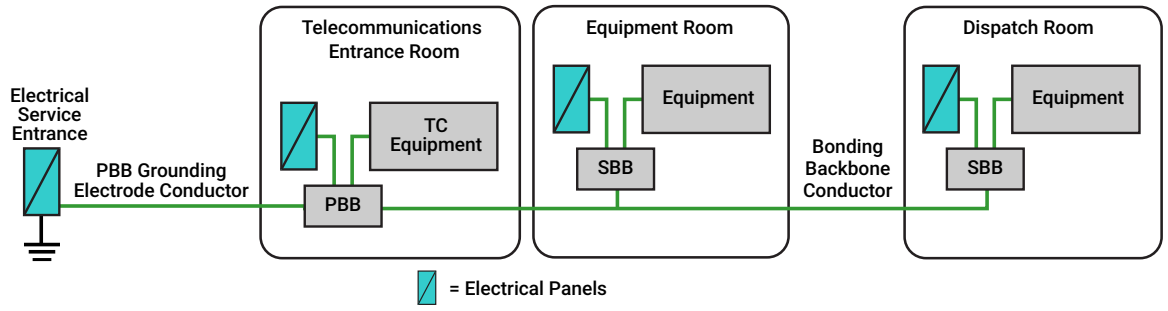


Figure 5-134. Example of Internal Bonding and Grounding System for Single-Story Large Commercial Building

IMPORTANT: The PBB grounding electrode conductor **shall** be the same size as or larger than the bonding backbone conductor (TIA-607-E, section 6.3.3).

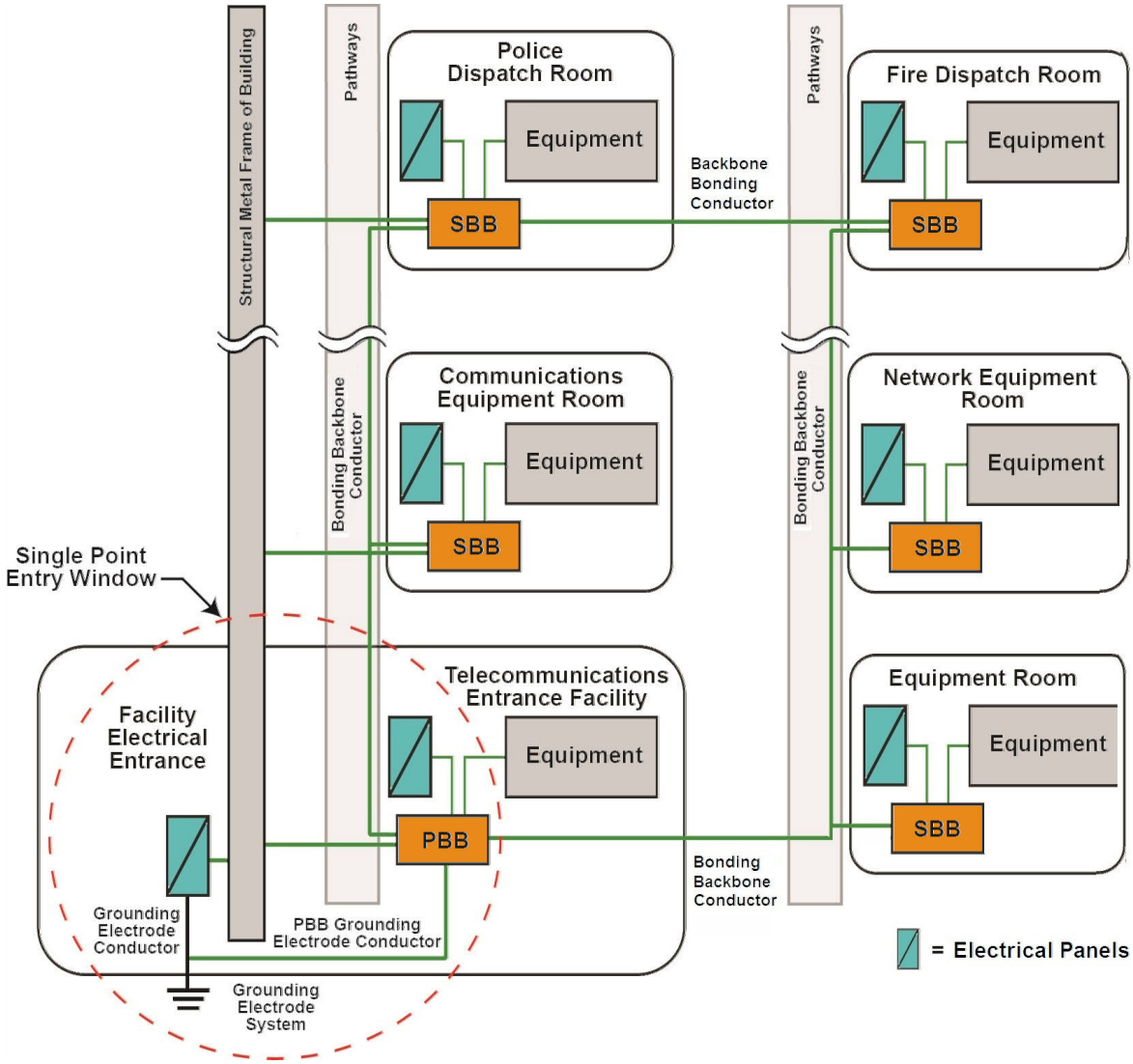


Figure 5-135. Example of Internal Bonding and Grounding System for Multi-Story Commercial Building

IMPORTANT: Concrete reinforcing steel, water piping systems, cable shields, metallic pathways, and conduits **shall not** be used as a bonding backbone conductor (TIA-607-E, sections 6.3.6.1 and 7.5.4).

NOTE: Buildings or campuses with more than one electrical service entrance, each serving the communication system, require special design considerations that are beyond the scope of this document. Consulting with Motorola Solutions Engineering or an engineering firm is recommended in these situations.

Where external antenna cables and other communications cables enter the building in a location other than the single point entry window, that point of entry **shall** be provided with an Entry Point Secondary Bonding Busbar as described in “Secondary Bonding Busbar Serving an Entry Point” on page 5-26.

5.10.4 Bonding and Grounding for Integrated and Rooftop Communication Sites

A communications site integrated within a high-rise building has the same general requirements as described for a multi-story building in “Bonding and Grounding for Large and Multi-Story Commercial Building Installations” on page 5-133. Using structural metal as the bonding backbone conductor is preferred and is usually more practical than installing a separate conductor (see Figure 5-136). For more information, see “Bonding Backbone and Bonding Backbone Conductor” on page 5-55. See Figure 5-137 and Figure 5-138 for examples of high-rise building installations.

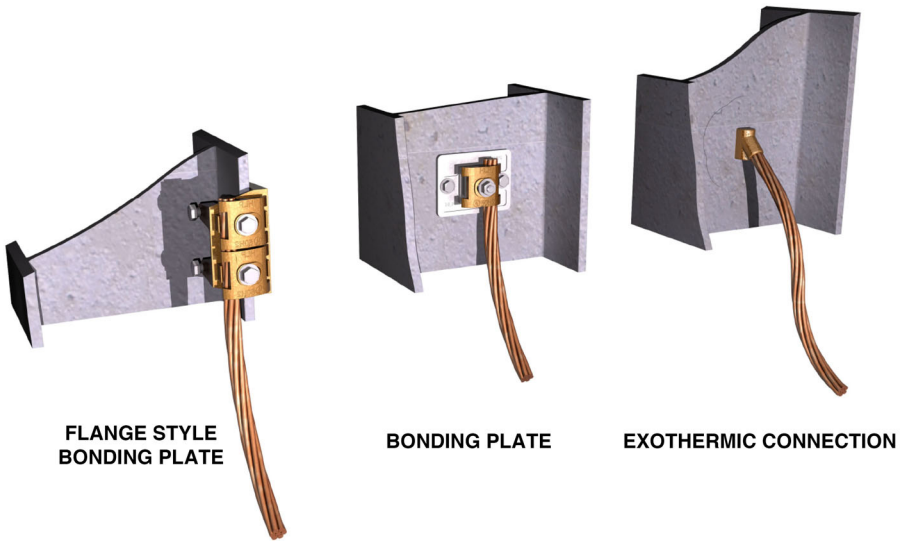


Figure 5-136. Examples of Acceptable Structural Building Steel Bonding Connections

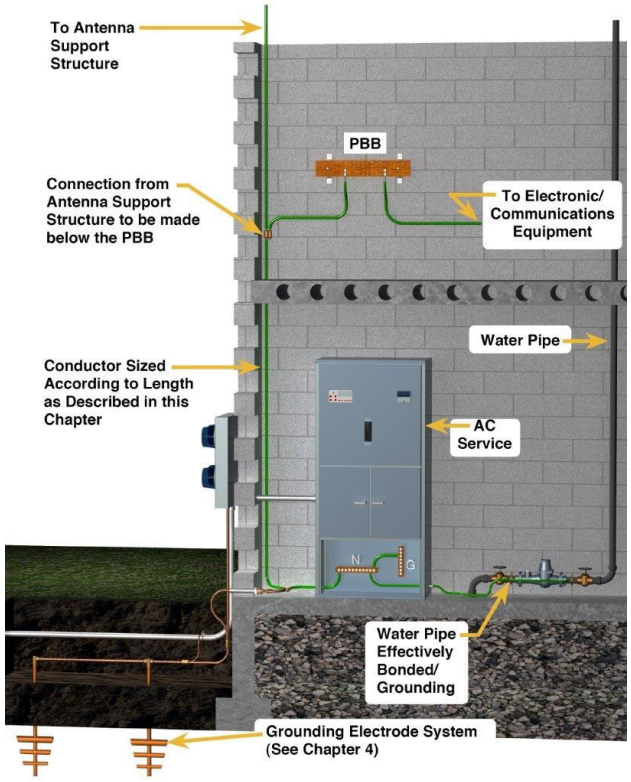


Figure 5-137. Integrated Site Bonding Where Building Steel Is Not Available

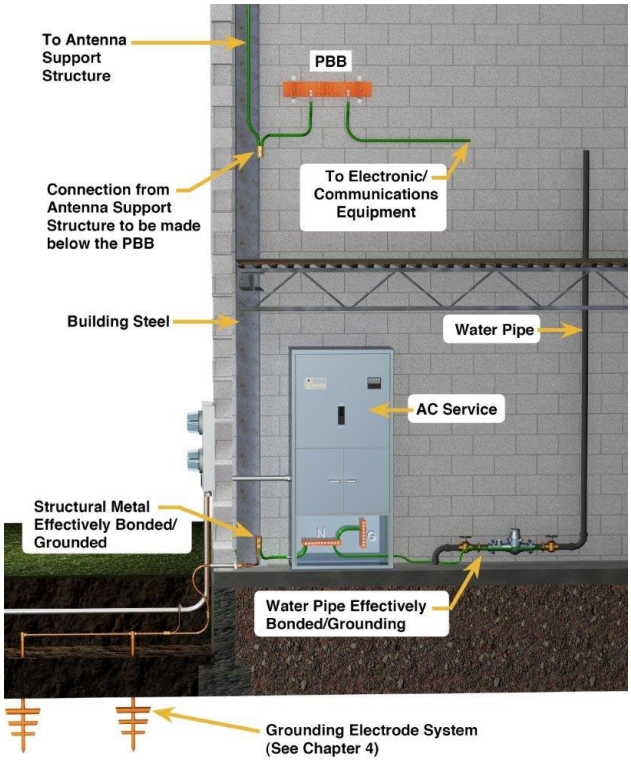


Figure 5-138. Integrated Site Bonding Where Building Steel Is Available

A rooftop communications site is a shelter or building installed on a rooftop, or penthouse used to house communications equipment. The rooftop shelter, building, or penthouse equipment room **shall** contain an internal bonding and grounding system with all equipment bonded and grounded as described in this chapter and summarized above for integrated sites. The inside of the site is bonded and grounded as described in “Bonding and Grounding Requirements for Stand-Alone Shelters” on page 5-129.

The rooftop communications site internal bonding and grounding system and external ground busbar (where applicable) **shall** be bonded to earth using methods described in “Rooftop Communications Sites” on page 4-149. See TIA-607-E, section D.2.6, for more information. Refer to Figure 5-139 and Figure 5-140 for rooftop site examples.

IMPORTANT: Concrete reinforcing steel, water piping systems, cable shields, metallic pathways and conduits **shall not** be used as a bonding backbone conductor (TIA-607-E, sections 6.3.6.1 and 7.5.4).

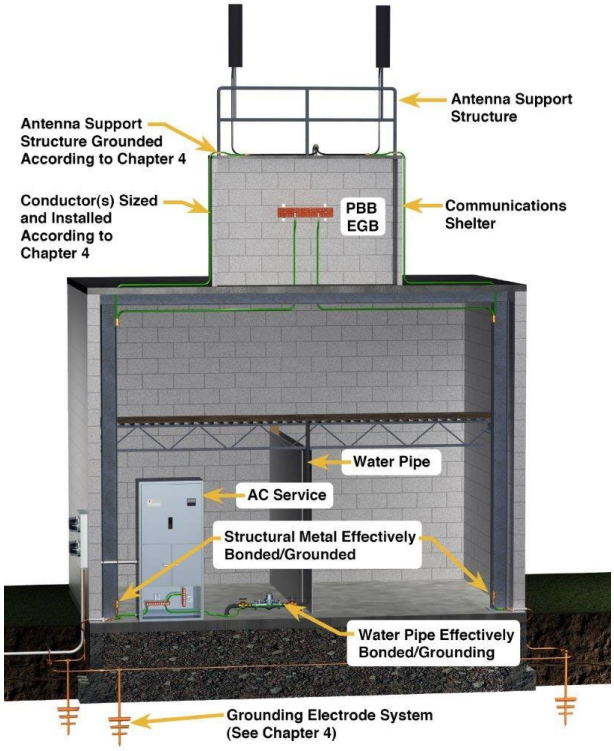


Figure 5-139. Rooftop Site Bonding Where Building Steel Is Available

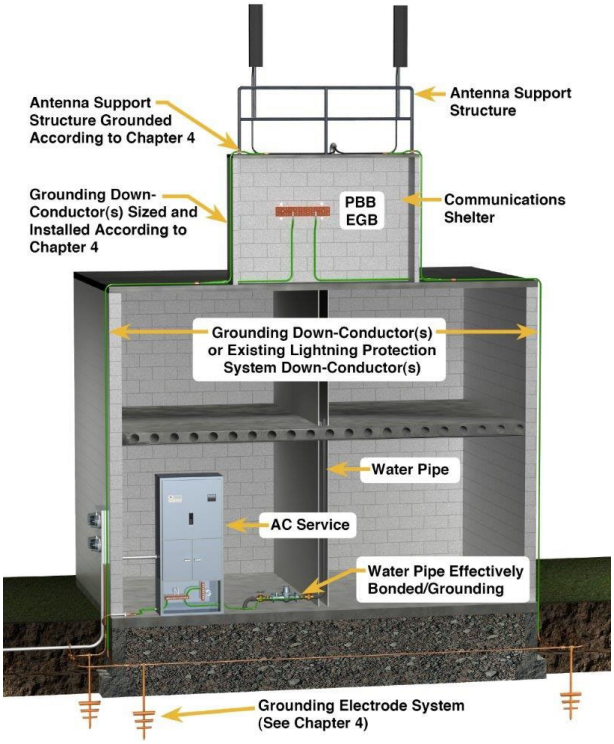


Figure 5-140. Rooftop Site Bonding Where Building Steel Is Not Available

5.10.5 Bonding and Grounding for Dispatch Centers and Network Operator Positions

Equal potential (equipotential) bonding at the network operator position is crucial to ensuring personnel safety and equipment reliability. A dispatch or network operator position typically includes a headset, headset interface equipment, and other electronic devices such as consoles, computers, video displays, small emergency radios, and workstation furniture (see ATIS-0600321.2020, section 1). Workstations are often grouped in clusters within a dispatch room, with the operator equipment interconnected with other communication system components located throughout the building. In these cases, it is essential not only to establish equipotential bonding at the operator position but also to ensure bonding between any adjacent stations. The ground potential **shall** also be equalized among interconnected communication systems within the building that are powered by the same electrical service.

Electrical disturbances may appear at dispatch/network operator-type equipment positions, arising from Electrostatic Discharge (ESD) or from internal or external sources, such as lightning or AC power disturbances (see ATIS-0600321.2020, section 1).

IMPORTANT: All grounding electrodes at the site **shall** be bonded together as described in “Common Grounding (Earthing)” on page 5-6 and its subsections.

Dispatch centers, especially those co-located with a communications tower, require special protection measures due to the critical nature of their operations and the inherent risk to personnel from lightning strikes. For optimal protection of a dispatch center, the following **shall** be adhered to:

- Site design recommendations given in “Design Considerations to Help Reduce Effects of Lightning” on page 2-16.

- External grounding and bonding as defined in Chapter 4, “External Grounding (Earthing) and Bonding”.
- External grounding as defined in “Dispatch Centers Co-Located With Communications Towers” on page 4-135, if applicable.
- Surge protection as defined in Chapter 7, “Surge Protective Devices”.
- Electrostatic discharge (ESD) precautions as defined in Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”.
- Internal bonding and grounding as defined in this chapter for the appropriate site type(s). See “Bonding and Grounding (Earthing) for Specific Site Types” on page 5-129 and the appropriate subsections for details.
- Installation of a supplementary bonding network (bonding grid) in the dispatch room/area as described in “Supplementary Bonding Network or Bonding Grid” on page 5-63.
- Raised computer floor bonding as described in “Raised Computer Floor Bonding” on page 5-120 and applicable subsections.
- Equal potential (equipotential) bonding at the network operator position as described in “Equipotential Grounding (Earthing) of the Network Operator Position” on page 5-138 and associated subsections.

5.10.5.1 Equipotential Grounding (Earthing) of the Network Operator Position

Equal potential (equipotential) bonding at dispatch or network operator-type equipment locations should be incorporated into the position equipment itself whenever possible. This approach will significantly reduce the need to add bonding conductors for each installation. All furniture, telecommunications cable shields, data cable shields, and the AC electrical ground **shall** be bonded together at the position Secondary Bonding Busbar (SBB) or within the equipment (see Figure 5-142 and Figure 5-146 on page 5-142). Refer to ATIS-0600321.2020, section 7.

All dispatch/network operator equipment including, but not limited to, the items listed in this section, **shall** be effectively bonded to an Operator Position Secondary Bonding Busbar (SBB) using methods described within this chapter (see Figure 5-143). See ATIS-0600321.2020 and the following subsections for additional information.

- Equipment supplied with a ground connection point
- Mounting rails or support brackets intended for mounting equipment on or within the furniture
- Metallic parts of network operator furniture
- Telecommunication cable shields
- Data cable shields
- Voltage limiting secondary surge protective devices
- AC Power ground

A Secondary Bonding Busbar (SBB) **shall** be installed at the network operator position area (see Figure 5-143 for an example). If several network operator positions are clustered, a single SBB can be shared within the cluster if it is adequately sized and the equipment bonding conductor length restrictions are met. Refer to ATIS-0600321.2020, section 7.1, for additional details.

NOTE: Equal potential bonding may be simplified and improved using surge suppressed power strips with an external grounding point. When bonded to the position SBB, this device helps maintains equal potential between the electrical ground and adjacent equipment. See Figure 5-141. See “Dispatch Operator Position Type 3 SPD Power Strip Additional Requirements” on page 7-27 for additional information.



Image courtesy of Transtector. Copyright ©2026, Infinite Electronics, Inc.

Figure 5-141. Example of Dispatch Operator Position SPD Power Strip

NOTE: An SBB at a network operator position may be referred to as a Position Bonding Terminal (PBT) in some standards.

NOTE: For optimal equal potential (equipotential) bonding in a dispatch room or area, installing a bonding grid beneath the computer floor as described in "Supplementary Bonding Network or Bonding Grid" on page 5-63 is recommended. See Figure 5-144.

Each network operator position SBB **shall** be bonded to internal bonding and grounding system as outlined in "Secondary Bonding Busbar" on page 5-17 and relevant subsections. Network operator position SBB bonding can also be connected to a bonding backbone described in "Bonding Backbone and Bonding Backbone Conductor" on page 5-55 or to a bonding grid detailed in "Supplementary Bonding Network or Bonding Grid" on page 5-63.

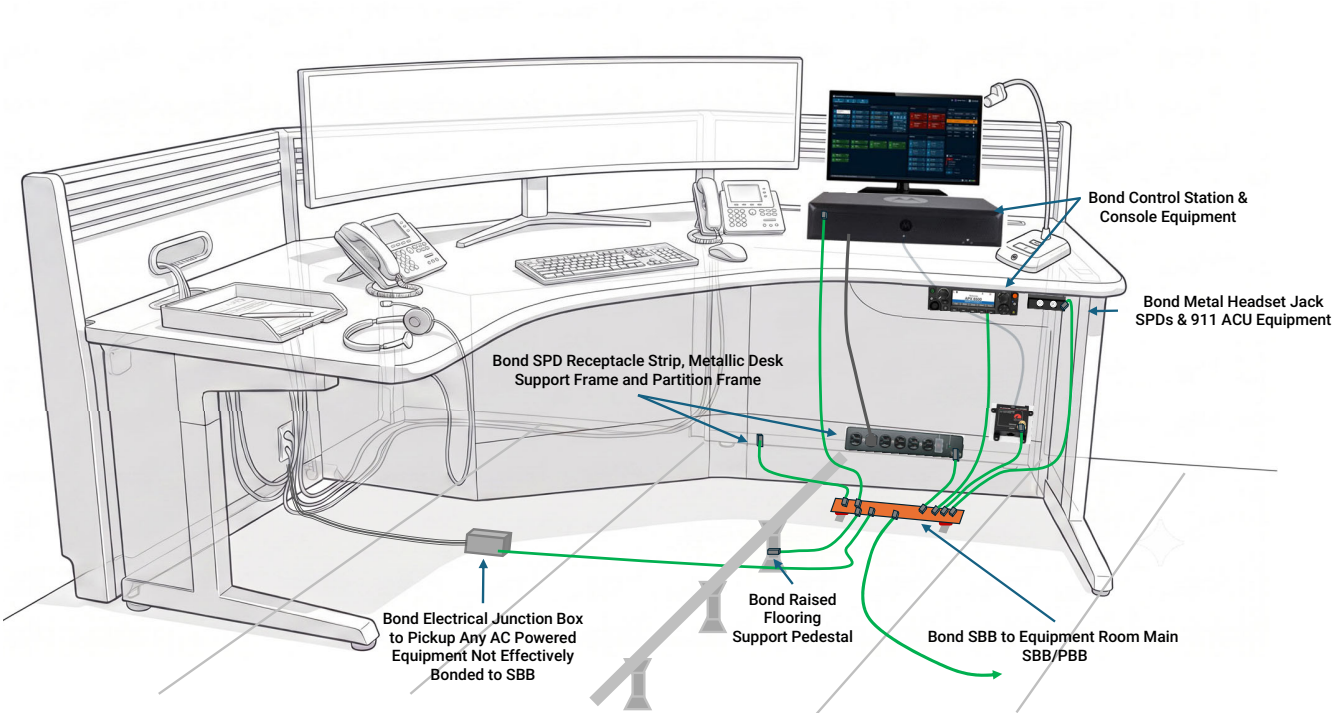


Figure 5-142. Example of Operator Position Bonding

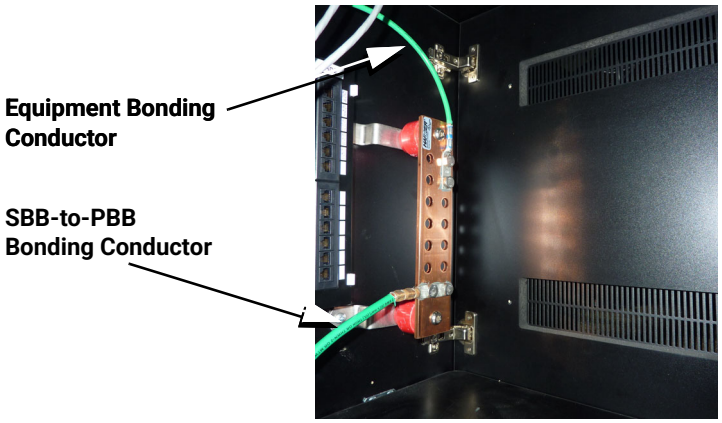


Figure 5-143. Example of Secondary Bonding Busbar at Operator Position

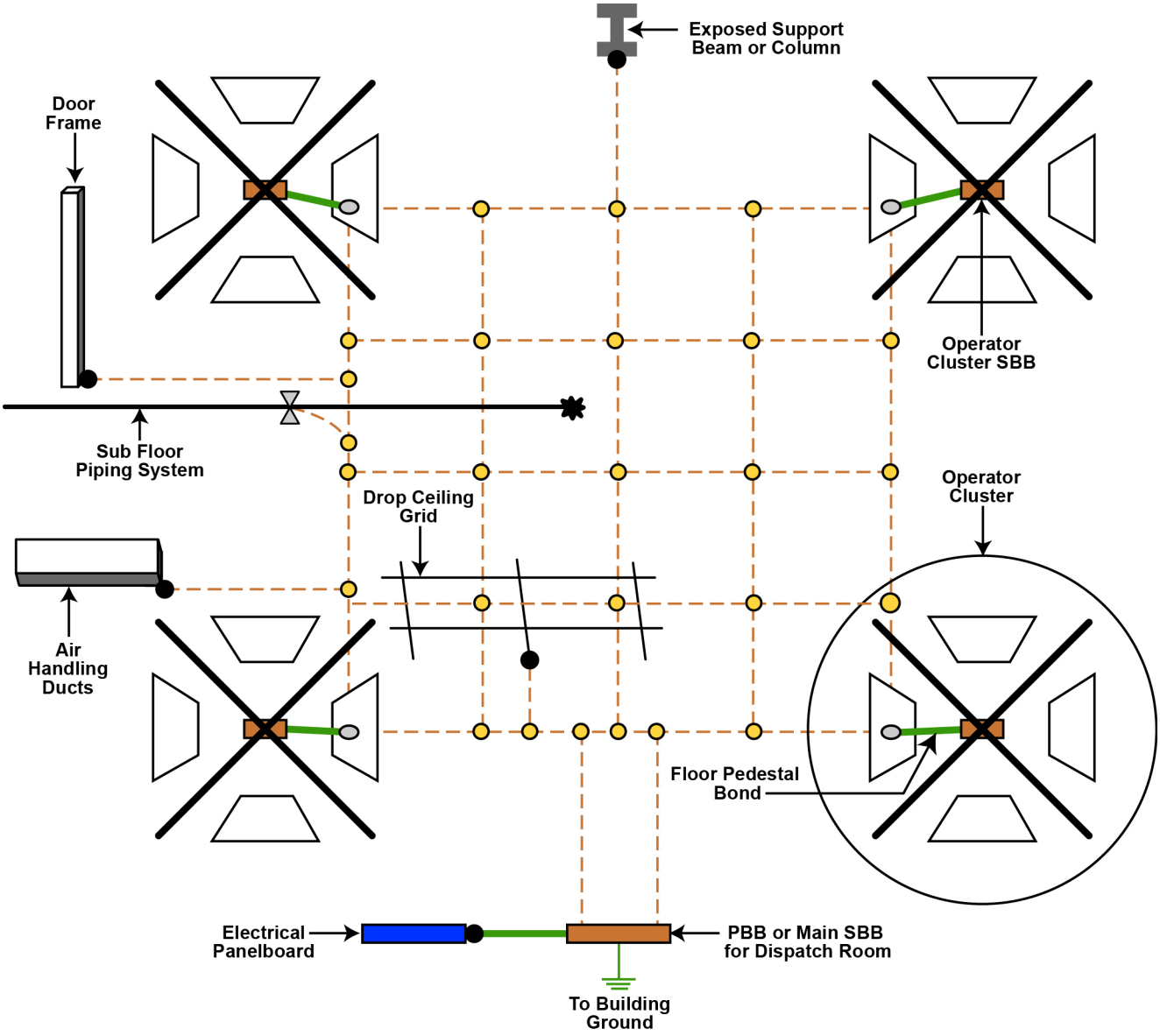


Figure 5-144. Example of Bonding Grid in Dispatch Area

A dispatch room or area may contain a main SBB to serve as a collection point for the operator position SBBs (see Figure 5-145). Where installed, the main SBB **shall** be located to allow convenient bonding of all network operator position SBBs and to provide the shortest path to the internal bonding and grounding system. The main SBB **shall** be bonded to the internal bonding and grounding system using conductors sized according to this chapter (Table 5-3). Bonding conductors from the main SBB to the network operator position SBBs **shall** be sized based on the length between the two bonding busbars.

NOTE: A main Secondary Bonding Busbar (SBB) used in a dispatch room or area is considered part of the bonding backbone. See “Bonding Backbone and Bonding Backbone Conductor” on page 5-55.

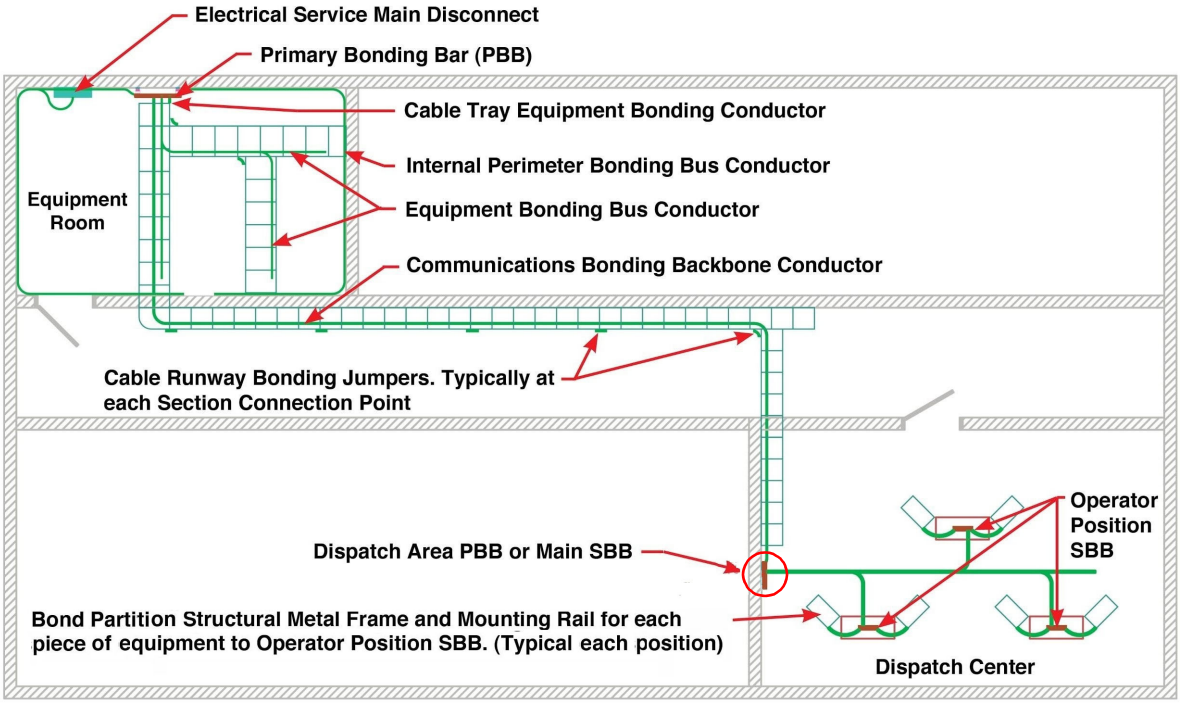


Figure 5-145. Example of Main Secondary Bonding Busbar in Dispatch Area

5.10.5.1.1 Bonding of Equipment and Furniture at the Operator-Type Equipment Position

All metallic equipment enclosures, frames, chassis, mounting rails, operator position furniture (other than chairs) and other items with a designated bonding/grounding point **shall** be effectively bonded to the Operator Position SBB using bonding conductors as follows:

- 6 mm^2 csa (#10 AWG) for lengths not exceeding 3 m (10 ft).
- 16 mm^2 csa (#6 AWG) for lengths not exceeding 3.9 m (13 ft).
- If a longer length is required, the equipment bonding/grounding conductor **shall** be sized according to Table 5-4. Ensure the SBB is installed at the optimum location.
- See Figure 5-146 for an example.

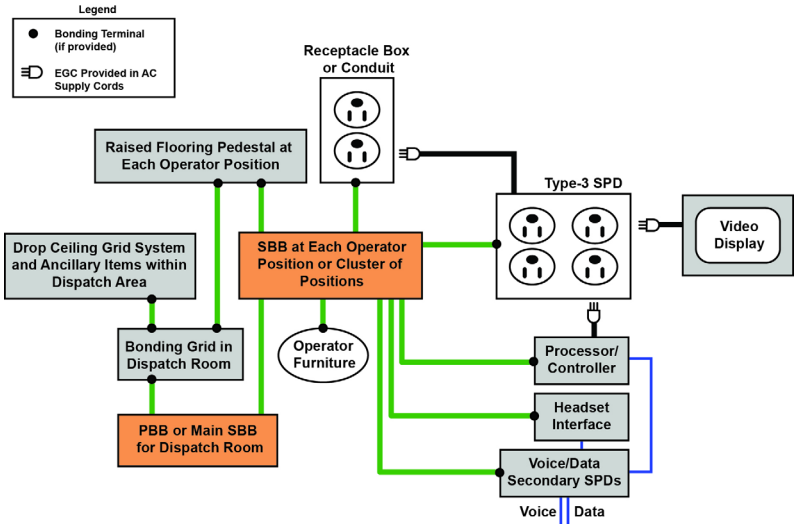


Figure 5-146. Example of Network Operator Position Bonding

5.10.5.1.2 Bonding to Power at the Operator-Type Equipment Position

Where AC power is available at a network operator position, the AC power receptacle housing(s), metallic conduit(s), or equipment grounding conductor(s) (EGC) **shall** be bonded to the Operator Position SSB using a bonding conductor as follows:

- 6 mm^2 csa (#10 AWG) for lengths not exceeding 1 m (3 ft)
- 16 mm^2 csa (#6 AWG) for lengths not exceeding 3.9 m (13 ft).
- If a longer length is required, the equipment bonding conductor **shall** be sized according to Table 5-4.

Furthermore, if a Power Distribution Unit (PDU) or a Type 3 Surge Protective Device (SPD) is installed at the operator position (see Figure 5-141 on page 5-139), it **shall** be bonded to the SBB as described in this section or according to the manufacturer's recommendations.

The conduit or raceway serving the receptacle box **shall not** be relied upon as the sole AC equipment grounding conductor at that location. A separate, insulated AC equipment grounding conductor **shall** be run with the branch circuit supply conductors and bonded to the metallic receptacle box, conduit, or armored cable, as required by NFPA 70-2026. See Chapter 6, “Power Sources” and ATIS-0600321.2020, section 7.3, for more information.

The equipment grounding conductors of AC branch circuits serving network operator equipment positions **shall not** be electrically isolated from the building’s bonding and grounding network in any way. Due to the required bonding of the AC equipment grounding conductor to the SBB and the necessity for a single common ground potential, isolated ground receptacles (orange in color) **shall not** be used (see Figure 5-147) (ATIS-0600321.2020, section 7.3). For additional details, see “AC Receptacle Requirements” on page 6-14.

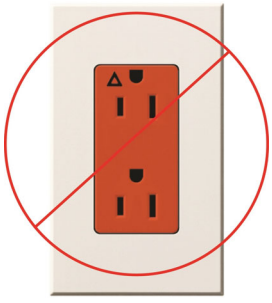


Figure 5-147. Example of Unapproved Isolated Ground Receptacle (Orange Colored)

5.10.5.1.3 Bonding of Telecommunications Cable Metallic Members

Outer shields of telecommunication cables serving the network operator position or cluster of positions (to or from a different location) **shall** be bonded directly to the SBB or by using bonding conductors as follows:

- 6 mm^2 csa (#10 AWG) for lengths not exceeding 1.8 m (6 ft).
- 16 mm^2 csa (#6 AWG) for lengths not exceeding 3.9 m (13 ft).

The outer shield ground/bond is automatically provided where the cable connector includes a shield-to-chassis connection. See ATIS-0600321.2020, sections 7.2 and 7.5 for more information.

5.10.5.1.4 Bonding of Nearby Metallic Objects

Exposed metallic objects within 2.4 m (8 ft) vertically or 1.5 m (5 ft) horizontally of the operator position **shall** be effectively bonded to the Operator Position Secondary Bonding Busbar (SBB) or bonding grid, using a minimum 16 mm^2 conductor (#6 AWG) of the shortest and straightest length practical (see ATIS-0600321.2020, Figure 1 and section 7.6, for more details). Metallic objects include, but are not limited to, the following (which may be above or below a raised flooring system):

- Building steel or structural metal
- Ventilation ducts
- Metallic plumbing
- Raised flooring system pedestal

At least one nearby raised flooring system pedestal **shall** be bonded to the Operator Position SBB. If the SBB supports more than one operator position, at least one raised floor system pedestal **shall** be bonded to the SBB near each operator position.

NOTE: The bonding requirements for the floor pedestal in this section go beyond those outlined in “Raised Computer Floor Bonding” on page 5-120. If a nearby floor pedestal is already bonded to a bonding grid, another nearby floor pedestal **shall** be bonded to the Operator Position SBB.

Other items, such as electrical panels, metallic water fountains, metallic plumbing, metallic ventilation ducts, and other metallic ancillary support items, **shall** be bonded to the nearest bonding grid conductor or SBB, with a minimum 16 mm^2 csa (#6 AWG) copper conductor of the shortest length practicable.

5.10.5.1.5 Interposition Bonding

To enhance interposition bonding for multi-cluster network operator-type equipment positions, a bonding grid, as described in “Supplementary Bonding Network or Bonding Grid” on page 5-63, is recommended. Interposition bonding helps ensure equal potential between different clusters. This is especially important if an operator approaches a position in a neighboring cluster while still connected to their own position. See ATIS-0600321.2020, section 7.7 for more information.

If a bonding grid is not installed, all Operator Position Secondary Bonding Busbars (SBB) should be interconnected in a grid pattern and also bonded to the area's primary or main SBB. This is in addition to the existing bonding bus conductors that connect each Operator Position SBB to the main area SBB or Primary Bonding Busbar (PBB). See Figure 5-148.

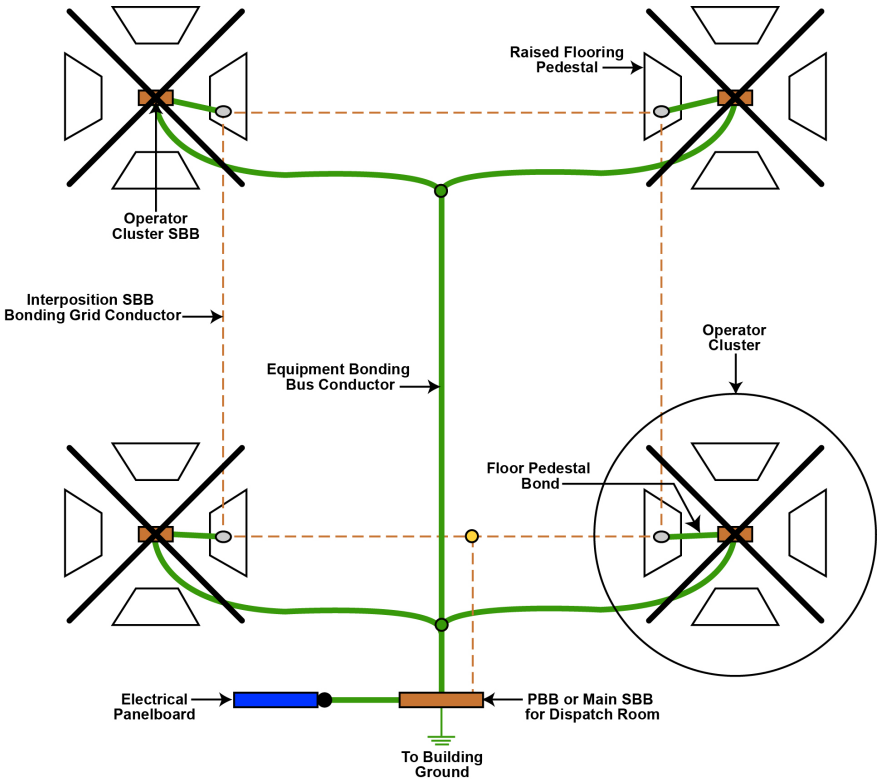


Figure 5-148. Example of Interposition Bonding

5.10.5.1.6 Surge Protective Devices

Surge Protective Devices (SPDs) **shall** be installed on all AC power, telephone, and data communication cables at every network operator position or cluster, as outlined in Chapter 7, "Surge Protective Devices". SPDs help reduce voltages between communication conductors and conductive surfaces. When SPDs are installed, they **shall** be directly bonded to the SBB or connected using bonding conductors as follows:

- Secondary SPDs for telephone circuits, data circuits and control circuits as described in "Secondary Surge Protective Devices" on page 5-125.
- AC power SPD as follows:
  - 6 mm^2 csa (#10 AWG) for lengths not exceeding 1 m (3 ft).
  - 16 mm^2 csa (#6 AWG) for lengths not exceeding 3.9 m (13 ft).

5.11 Testing the Internal Bonding and Grounding (Earthing) System

The internal bonding and grounding system **shall** be tested as described in the following subsections.

5.11.1 Bonding Continuity

The internal bonding and grounding system continuity **shall** be tested as described in "Clamp-on Ohmmeter Bonding Continuity Testing" on page D-30. Bonding continuity **shall** be tested at the Primary Bonding Busbar (PBB), Secondary Bonding Busbars (SBB), Rack Bonding Busbars (RBB), bonding bus conductors, and similar components. See Figure 5-149 for an example of a clamp-on ohmmeter.



Figure 5-149. Example of Clamp-on Ammeter/Ohmmeter

5.11.2 Current Testing

The internal bonding and grounding system **shall** be tested for objectionable current (AC and DC). As indicated in the Glossary, page H-8, “Objectionable Current” is defined as: “Any current flow over conductors not designed to normally carry current. For example, an equipment grounding conductor is not intended to carry current, except during a fault condition.”

Per NFPA 70-2026, Article 250.6, “The grounding of electrical systems, circuit conductors, surge arresters, surge protective devices and conductive normally non-current-carrying metal parts of equipment **shall** be installed and arranged in a manner that will prevent objectionable current.”

Objectionable current (especially objectionable AC neutral current) can lead to the following:

- Shock hazard
- Fire hazard
- Erratic operation of electronic equipment (due to the EME field created by the objectionable current)

See the Mike Holt Enterprises, Inc. (www.MikeHolt.com) publication “Understanding the National Electrical Code,” section 250.6, for more information.

Identifying and isolating objectionable current (AC or DC) may require a power quality engineer and/or certified R56 Auditor Subject Matter Expert (SME).

5.11.2.1 DC Current Testing

To help prevent objectionable DC current on the internal bonding and grounding system, DC systems **shall** be configured as an Isolated Ground-type System as described in “DC Power Systems” on page 5-94 and “Installation Requirements for Isolated Ground-Type System” on page 5-95. In this configuration, and under normal operating conditions, the internal bonding and grounding system should not carry DC current. Any significant DC current on the internal bonding and grounding system will typically result from one or more of the following: a fault condition, incorrectly configured equipment (for example, not configured for isolated grounding), faulty equipment, equipment not designed for isolated ground (for example, DC return having an internal bond to the chassis), installation errors, or other issues.

IMPORTANT: Many DC Power Distribution Units (PDU) are jumper configurable for the type of grounding used. Ensure the PDU is jumpered/configured for isolated grounding.

IMPORTANT: Be aware of the meter's measurement limitations. Many DC current clamp meters have a resolution of 0.1A (100 mA). This means a value between 350 mA and 450 mA may be displayed as 400 mA, and accurate readings below 100 mA are not possible.

Where a DC power system is installed, the internal bonding and grounding system **shall** be tested to determine whether or not objectionable DC current is present after all equipment is installed and powered on. Testing **shall** be completed using an appropriate clamp-on DC ammeter (see Figure 5-150). Typically, the easiest location to test for objectionable DC current is on the DC System Bonding Jumper (see “DC Power Systems” on page 5-94) near the DC power system. If a significant level of DC current is measured (see the following paragraph), the source **shall** be identified and corrected as practicable.

While industry codes and standards do not provide guidance, Motorola Solutions recommends 500 mA as the threshold for triggering an investigation for objectionable DC current on the Communications Bonding Network. A value less than 500 mA may be considered insignificant, and an investigation is not required. The investigation **shall** include verification that the DC power system and equipment are configured for an isolated ground-type system. The investigation may require an Engineer and/or R56 Auditor Subject Matter Expert (SME) to determine the root cause and nature of the current.

NOTE: 500 mA is not a Pass/Fail threshold; it is the recommended maximum value that must trigger an investigation. A system-level Pass/Fail is determined by the investigation and the root causes identified. It may not always be practical to eliminate all objectionable current, depending on the equipment installed at the site.

Communications and IT equipment may exhibit minimal leakage current (e.g., 3.5 mA or more; check product specifications) during normal operation. If the investigation shows that the measured current is due to equipment leakage, the installation may be considered acceptable.



Figure 5-150. Examples of Clamp-on AC/DC Ammeters

5.11.2.2 AC Current Testing

The internal bonding and grounding system **shall** be tested for the presence of objectionable AC current after all equipment has been installed. Testing **shall** be completed using an appropriate clamp-on AC ammeter (see Figure 5-149 and Figure 5-150). Typically, the easiest location to test for objectionable AC current is where the internal bonding and grounding system bonds to the Primary Bonding Busbar (PBB). Several other locations **shall** also be tested, such as near each Rack Bonding Busbar (RBB) and Secondary Bonding Busbar (SBB).

In addition to testing the internal bonding and grounding system, electrical metallic conduits at the site **shall** be tested for current using a suitable clamp-on AC ammeter. Testing a metallic conduit may require a clamp-on meter with a large jaw (see Figure 5-150, right). The typical test locations are at the electrical panel where the conduit terminates and/or where the conduit goes around a corner (corners provide more room for the meter jaws).

Measured currents exceeding 3 A typically indicate faulty wiring, such as an incorrect neutral-ground bond or multiple bonds. Currents up to about 300 mA may result from faulty equipment, such as a defective device or component leaking current to ground; in these cases, troubleshooting is necessary to identify the specific faulty component. If any significant AC current is detected, the source **shall** be identified and corrected appropriately.

Motorola Solutions recommends a 500 mA threshold for significant objectionable AC current at a site, provided that troubleshooting outlined in the previous paragraph has been completed. However, the site owner **shall** obtain a final determination from the authority having jurisdiction (AHJ).

CHAPTER

6

Power Sources

This chapter describes power systems typically used at communications sites, outlining different types and specifies requirements. Topics covered include:

- “Safety for Power Sources” on page 6-1
- “AC Power” on page 6-2
- “Powering Equipment” on page 6-18
- “Power Quality” on page 6-22
- “Rectifier/DC Power Systems” on page 6-27
- “Uninterruptible Power Supplies” on page 6-33
- “Alternative Power Sources” on page 6-34
- “Battery Systems” on page 6-37
- “Standby Generator Systems” on page 6-45

NOTE: NFPA 70, also known as the National Electrical Code® or NEC®, is the primary electrical code referenced in this chapter. NFPA 70 has been adopted by and influences many regions worldwide, including the Americas, Caribbean, Asia-Pacific, Middle East, and North Africa. Other electrical codes also exist and must be followed as required by the authority having jurisdiction (AHJ), such as the Canadian Electrical Code in Canada, the International Electrotechnical Commission standards in Europe and other regions, and British Standards in the UK and other parts of Europe.
NFPA 70E is known as the Standard for Electrical Safety in the Workplace.

6.1 Safety for Power Sources

The following safety requirements **shall** be observed:

- All electrical work must follow applicable safety practices. These include, but are not limited to, those required by IEC, NFPA 70, NFPA 70E, NFPA 111, OSHA (or equivalent), The International Building Code®, and local codes.
- Follow all safety cautions and warnings in this chapter.
- All AC and DC power systems **shall** include a lockout/tagout provision for each circuit to ensure safety during maintenance. Refer to NFPA 70E, OSHA 29 CFR 1910.147 (in the U.S.A.), and/or the authority having jurisdiction (AHJ) for additional information. See Figure 6-1 for an example.



Figure 6-1. Example of Circuit Tagout

WARNING: Only qualified personnel SHALL open an electrical panel. Lethal voltages may be present.

WARNING: Batteries used to power equipment can present safety hazards. Always use caution and follow the battery manufacturer's safety guidelines.

6.2 AC Power

AC power systems **shall** be designed, installed, and maintained in accordance with all applicable jurisdictional standards and regulations.

For both initial equipment installation and future expansion, all site power loads must be identified. These loads, at their various site locations, will then be incorporated into the overall site electrical system design.

To ensure sufficient power capacity for communication sites, the electrical system components (wiring, panelboards, breakers, and service ratings) **shall not** operate above 80% of their capacity (APCO ANS 2.106.1-2019, section 3.13.1.3). Adhering to this standard is crucial for all parties involved in site design, including electric utilities, prefabricated shelter vendors, UPS vendors, and generator vendors.

NOTE: NFPA 70-2026, Article 100, defines a "Continuous Load" as a load where the maximum current is expected to last for three (3) hours or more.

For US installations, a minimum 200-amp service at 120/240 VAC (or 120/208 VAC) is typically required for a dedicated communications shelter. Installations outside the USA may have different service parameters.

Calculating supply capacity requires accurate sizing of AC power loads. Common power requirements include:

- HVAC system (including redundant units). Given that shelter sites are not continuously occupied, heat load calculations are not required for service personnel at most of these locations.
- Interior room lighting and exterior security lighting.

NOTE: At sites that require tower lighting to meet FAA or similar standards, a backup generator may be needed to ensure uninterrupted service.

- Tower lighting. Additional power capacity may be required for certain tower lighting systems, such as those equipped with strobes or multiple fixtures.

- Battery chargers
- Uninterruptible Power Supply (UPS) devices
- Equipment powered by rectifier systems (-48 VDC or similar).
- Utility receptacles. The number of utility receptacles required at a site is determined based on the size of the equipment room or shelter.
- The AC electrical power requirements of the communications room when all transmitters are simultaneously keyed (see NFPA 70-2026, Articles 120 and 310.15 for additional information).
- Planned future expansion.
- Consideration of unusual maximum continuous loads (e.g., trunked system failsoft operation) is necessary.

6.2.1 Critical Operations Power Systems (COPS)

6.2.1.1 COPS Definitions

Critical Operations Power Systems (COPS): Power systems for facilities or parts of facilities that require continuous operation for the reason of public safety, emergency management, national security or business continuity (NFPA 70-2026, Article 100).

Designated Critical Operations Areas (DCOA): Areas within a facility or site designated as requiring critical operations power (NFPA 70-2026, Article 100).

Supervisory Control and Data Acquisition (SCADA): An electronic system that provides monitoring and controls for the operation of the critical operations power system. This can include the fire alarm system, security system, control of the HVAC, the start/stop/monitoring of the power supplies and electrical distribution system, annunciation and communications equipment to emergency personnel, facility occupants and remote operators (NFPA 70-2026, Article 100).

6.2.1.2 COPS Requirements

NFPA 70-2026, Article 708.1, Critical Operations Power Systems (COPS) Scope, states the following:

> "This article applies to the installation, operation, monitoring, control, and servicing of the portions of the premises wiring system intended to supply, distribute, and control electricity to designated critical operations areas (DCOA) in the event of disruption to elements of the normal system.
>
> Critical operations power systems are those systems so classed by municipal, state, federal, or other codes by any governmental agency having jurisdiction or by facility engineering documentation establishing the necessity for such a system. These systems include, but are not limited to, power systems, HVAC, fire alarm, security, communications, and signaling for designated critical operations areas."

NFPA 70-2026, Article 708.1 Informational Note 1 states the following:

> "Critical operations power systems are generally installed in vital infrastructure facilities that, if destroyed or incapacitated, would disrupt national security, the economy, public health or safety; and where enhanced electrical infrastructure for continuity of operation has been deemed necessary by governmental authority."

The 2023 NEC® Handbook (ISBN 978-14559-3170-5) further explains:

> "Article 708 helps to address homeland security issues for facilities that are mission critical. These requirements go beyond those of Article 700, in that these electrical systems must continue to operate during the full duration of an emergency and beyond. Examples of facilities that would use a critical operations power system (COPS) include police stations and fire stations. Not all such facilities within an area would be designated as a COPS facility. Because power must operate continuously with a robust power supply, only those facilities that are designated as critical would be included."

Addressing the following requirements, if necessary, could significantly increase the project's cost

- **SCADA System:** Implement a SCADA system for monitoring and controlling the COPS.
- **Risk Assessment:** Conduct a documented risk assessment of the COPS, including hazard identification.

- **Mitigation Strategy:** Develop a comprehensive mitigation strategy.
- **Physical Security:** Ensure robust physical security measures are in place.
- **System Testing:** Periodically test the system, maintaining written records for comparison with initial testing.
- **Independent Wiring:** Utilize independent wiring circuits and conduits.
- **Fire-Rated Electrical Spaces:** Locate electrical systems in spaces with a two-hour fire rating.
- **Fiber Optic Cable:** Mandate fiber optic cable for inter-building connections.
- **Generator Provisions:** Include provisions for a second generator hook-up, a separate generator automatic transfer switch, and similar considerations.

Although Motorola Solutions does not require COPS standards for communication systems, new construction **shall** follow the above requirements and the rules in NFPA 70-2026, Article 708, if mandated by the authority having jurisdiction (AHJ) or the end-user (customer).

6.2.2 Electrical Service

Utility power companies generally supply service to the meter in underground installations or to the weatherhead in overhead installations. Typically, all wiring past the meter is the customer's responsibility, though primary (high-voltage) metering may be an exception. It is crucial to identify the demarcation point where the utility company's responsibility ends and the customer's begins, as this may vary by region and affect installation costs.

The following requirements **shall** be observed when specifying and installing electrical service to the site building:

- See “Safety for Power Sources” on page 6-1 for general safety requirements.
- A buried utility locator service **shall** be contacted before digging or excavating. In the USA, a “Call before you dig” service is available in all states by calling 811 or visiting www.811beforeyoudig.com. In Canada, visit https://www.clickbeforeyoudig.com. In other countries, the local utility **shall** be consulted to obtain buried utility location services.

WARNING: Failing to locate buried utilities can endanger personnel and result in penalties for noncompliance with regulations.

- Electrical installation work **shall** be carried out in accordance with the current edition of NFPA 70 and any local codes as required by the authority having jurisdiction (AHJ). Where required by the AHJ, a qualified and licensed electrical contractor **shall** be used for electrical installations.
- Underground and above-ground service entrance conductors **shall** be protected from physical damage (see NFPA 70-2026, Article 230.50 and 300.7, for additional information).
- The service entrance conductor may be a material other than copper if permitted by the AHJ.
- The site electric meter **shall** be located in a highly visible, easily accessible location for the utility power company meter readers. For sites with fencing, this may be outside the fenced area. Installations **shall** comply with NFPA 70-2026, Articles 110 and 230, and all applicable codes of the AHJ and/or requirements of the utility power company.
- A fused disconnect switch **shall** be installed before all other panels and equipment, including a generator transfer switch. See NFPA 70-2026, Article 445.18, for additional information.
- For a standalone equipment shelter, the main disconnect should be located on the same wall as the coaxial cable entry panel, the telephone entry point, and the Primary Bonding Busbar (PBB). If it is not practicable to locate these components on the same wall, they **shall** be located on an adjacent wall as close together as practicable. Refer to IEEE 1100-2005, section 8.3.2.1.2, for additional information.
- The main bonding jumper **shall** be installed between the neutral bus and the ground bus within the main service disconnect. This ensures an effective low-impedance bond between the neutral and ground, preventing ground faults from energizing metallic objects. See NFPA 70-2026, Article 250.24(C), for additional information.

- Self-tapping or sheet metal type screws **shall not** be used for attaching a ground or grounding conductor to any surface. See NFPA 70-2026, Article 250.8, for additional information and approved methods.
- Paint, enamel, lacquer, or other nonconductive coatings **shall** be removed from threads and surface areas where connections are made. See NFPA 70-2026, Article 250.12, for additional information.

6.2.2.1 Main Disconnect for Separately Derived System Feeding Equipment Room

Not all installations have the Main Disconnect in the same building as the equipment (e.g., a meter farm at a tower site); in such cases, the panel in the equipment building is considered a subpanel, not the main disconnect panel.

All sites utilize either a main service disconnect, a fused disconnect, or both. A main service disconnect might be located at a meter outside the building. If a main disconnect is within a shelter, equipment room, or equipment area, it could be supplied by a feeder circuit originating from a main service disconnect located in an electrical room elsewhere in the building or even in a separate structure. Typically, the neutral and ground conductors are bonded at the main service disconnect. If the main service disconnect is located remotely from the equipment room or area, a separately derived system should be installed in the equipment room or area. See NFPA 70-2026, Articles 250.30 and 250.32, and “Location of Neutral-Ground Bond” on page 6-5 for additional information.

A separately derived system is used to reestablish the neutral-ground bond. This action improves power quality (see “Power Quality” on page 6-22) and enhances the effectiveness of normal mode surge suppression. (see Chapter 7, “Surge Protective Devices”). See “Location of Neutral-Ground Bond” on page 6-5 for additional information.

6.2.3 Location of Neutral-Ground Bond

Typically, the neutral-ground bond is located at the main disconnect panel (first service disconnect). Unless otherwise permitted, there **shall** be only one neutral-ground bond (NFPA 70-2026). An additional neutral-ground bond may be allowed only in the case of a separately derived system.

WARNING: Except in the case of a separately derived system, having more than one neutral-ground bond can cause neutral current (objectionable current) to flow through the equipment grounding conductors, metallic conduits, and/or metal parts of the building. This can lead to electrocution and/or fire hazards.

IMPORTANT: Electromagnetic fields (EMF) can be generated by objectionable (neutral) current flowing through metal parts of the electrical system or building. This EMF may lead to operational problems or failures in sensitive electronic equipment.

For optimal performance of electronic equipment, the voltage (or noise) between the neutral and ground conductors **shall not** exceed 2V p-p (0.7 Vrms) (see “Power Quality” on page 6-22). Where the electrical service's disconnecting means (and thus the neutral-ground bond) is located remotely from the site, the voltage or noise between the neutral and ground can lead to equipment malfunction, especially during a ground potential rise at the site.

To ensure a Surge Protective Device (SPD) installed at the AC distribution panelboard functions effectively, the neutral-ground bond must be located near the SPD. This placement allows the SPD to safely redirect unwanted energy on AC power conductors to the site's grounding electrode system.

6.2.3.1 Remote Radio Shelter with Power Supplied from Other Building

If a remote radio shelter receives power from another building or H-frame (with the neutral-ground bond established) (see Figure 6-2), a neutral-ground bond **shall not** be re-established at the remote radio shelter without using an isolation transformer or another approved, separately derived system. Refer to NFPA 70-2026 for more details.

If the neutral-ground bond is located more than 15.25 m (50 ft) from the remote radio shelter, Motorola Solutions recommends installing an isolation transformer as close as possible to the shelter (see Figure 6-3). The distance recommendation **shall** consider the length of the conductor from the neutral-ground bond to the shelter's distribution panel. Even if the distance is less than 15.25 m (50 ft), installing an isolation transformer near the remote radio shelter might still be necessary to reduce neutral-to-ground voltage and noise to acceptable levels at the equipment. See “Power Quality” on page 6-22 for more information.

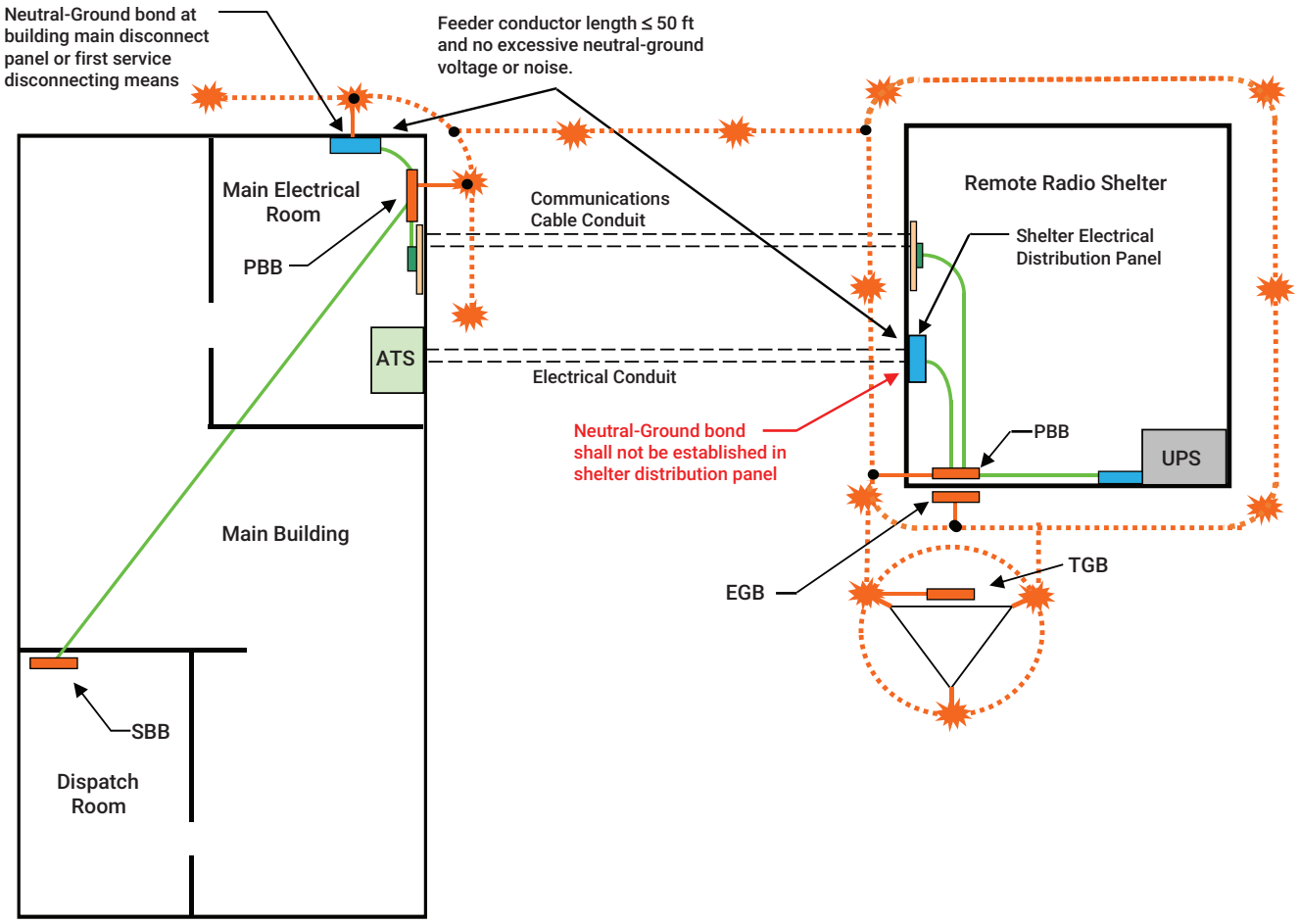


Figure 6-2. Remote Radio Shelter Less Than or Equal to 15.25 m (50 ft) From Main Disconnect

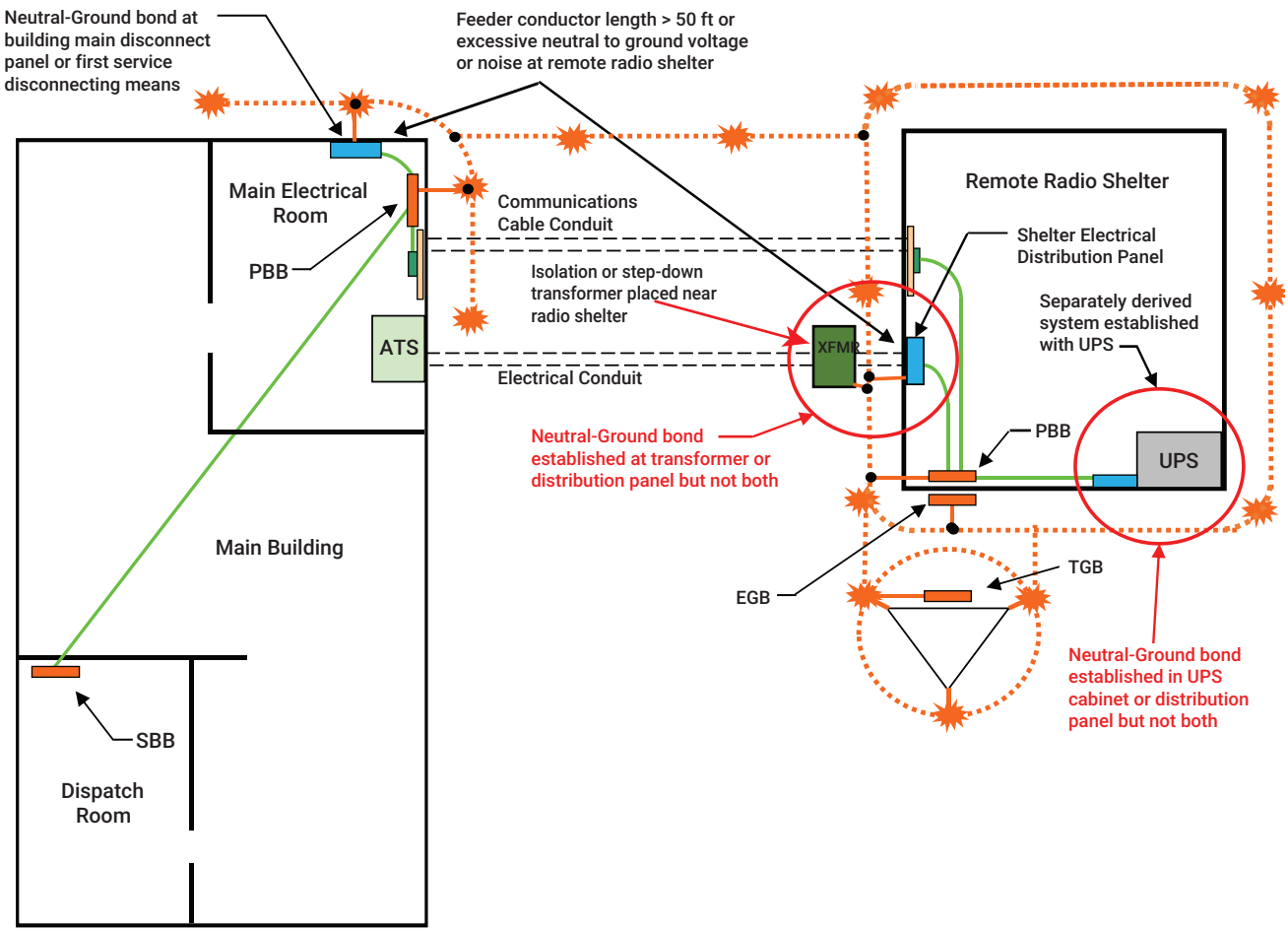


Figure 6-3. Remote Radio Shelter More Than 15.25 m (50 ft) from Main Disconnect, Isolation Transformer Installed

6.2.3.2 Larger Buildings

In larger buildings where the neutral-ground bond is located far from the equipment room, installing an isolation transformer near the equipment may be necessary to lower neutral-to-ground voltage and noise to an acceptable level. This configuration reestablishes the neutral-ground bond near the electronic equipment, helping reduce voltage and noise. See “Power Quality” on page 6-22 for more information.

6.2.4 Separately Derived Systems Using Transformers

A transformer, also known as an isolation, step-down, or step-up transformer, supplies AC power to communication sites. These transformers typically step down three-phase 277/480 VAC service to standard commercial 120/208 or 120/240 VAC service.

To improve the effectiveness of line-to-neutral (normal mode) surge suppression and to decrease neutral-to-ground voltage and noise, an isolation transformer is used to create a separately derived system where the neutral and ground conductors are bonded together either within the transformer or within the first disconnect after the transformer, and then connected to the building's common grounding electrode system (see NFPA 70-2026, Article 250.30, for additional information). Refer to “Separately Derived AC Systems” on page 5-89.

Isolation transformers are frequently used as described in “Remote Radio Shelter with Power Supplied from Other Building” on page 6-6 and “Larger Buildings” on page 6-7. They are also commonly used when the service disconnect (and thus the neutral-ground bond) is located remotely at a meter farm or H-Frame.

6.2.5 Interior Electric

The following requirements **shall** be adhered to when specifying and installing interior electrical systems:

- All interior wiring and electrical equipment installation **shall** comply with local codes such as C22.1, IEC, NFPA 70, or equivalent for the installation region.
- All panelboards and switchboards **shall** display signage and placarding according to NFPA 70-2026, Articles 110.22 and 408.4, and other applicable codes.
- Power panels, load centers, and breaker boxes **shall** be identified with distinctive placards or labels that indicate their purpose and the location of the main service disconnect. Refer to NFPA 70-2026, Articles 110.22 and 408.4, for further details.
- Access and working space **shall** be provided and maintained around all electrical equipment to ensure safe operation and maintenance (NFPA 70-2026, Article 110.26). See Figure 6-4 and refer to “Spacing Requirements for Electrical Power Equipment (AC or DC)” on page 9-6 for additional information.

NOTE: The required working space around an electrical panel **shall not** be used for storage. See NFPA 70-2026, Article 110.26(B).

  - **Depth of Working Space:** The minimum depth of the working space in front of electrical panels utilizing voltages of 1000 VAC or less **shall** be 914 mm (36 in.) according to NFPA 70-2026, Article 110.26(A)(1).
  - **Width of Working Space:** The minimum width of the working space in front of electrical panels utilizing voltages of 1000 VAC or less **shall** be the width of the equipment or 762 mm (30 in.), whichever is greater, according to NFPA 70-2026, Article 110.26(A)(2).
  - **Height of Working Space:** The working space **shall** be clear and extend from the grade, floor, or platform to a height of 2.0 m (6.5 ft) or the height of the equipment, whichever is greater, as specified by NFPA 70-2026, Article 110.26(A)(3).
  - **Additional Minimum Working Space:** Additional minimum working space may be required for voltages exceeding 1000V and/or specific equipment installation requirements. Refer to NFPA 70-2026, Article 110.26, and consult the authority having jurisdiction (AHJ) for further details.
- All branch circuit wiring **shall** be copper (APCO ANS 2.106.1-2019, section 3.13.1.8).
  - Although NFPA 70-2026 permits the use of specific aluminum or copper-clad aluminum conductor types, Motorola Solutions does not recommend aluminum for public safety, mission-critical, military, or similar applications.
  - Motorola Solutions does not approve the use of aluminum conductors in Motorola-specified or provided communications shelters or buildings.
  - See NFPA 70-2026, Article 110.5 for additional information.
- Wire, terminals, and lugs **shall** be of similar or compatible metals (NFPA 70-2026, Article 110.14).

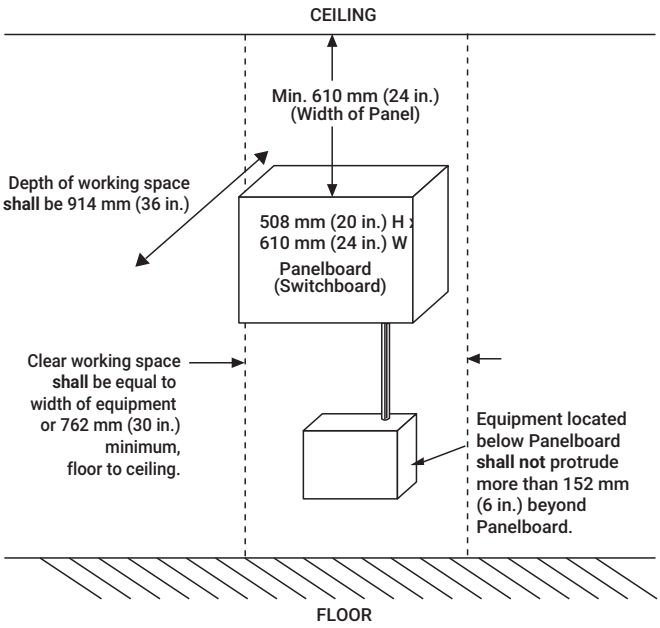


Figure 6-4. Electrical Panel Clearances

6.2.6 Power Panels

The following requirements **shall** be observed when specifying and installing interior electrical service:

- See “Interior Electric” on page 6-8 for panel working space (clearance) requirements.
- Each main distribution panel **shall** have its own main overcurrent protective device (circuit breaker or fuse). See NFPA 70-2026, Article 408.36, for further details.
- All interior panelboards and junction boxes **shall** be at least NEMA Type 1 general purpose for indoor use.
- All panelboards fed by a feeder(s) **shall** be labeled with the identification and physical location of the power source. The label **shall** be permanently attached, durable enough to resist environmental conditions, and affixed using a non-handwritten method. See NFPA 70-2026, Article 408.4(B).
- More than one distribution panel might be needed in large single-equipment rooms to accommodate the required number of branch circuits. If multiple panels are installed, they should all be supplied from the same separately derived system to avoid ground loops caused by multiple neutral ground bonds at the transformer. See IEEE 1100-2005 for additional information.
- Sub-panels **shall not** have the neutral ground bond jumper installed.
- Power panelboards **shall** be bonded to the interior single-point bonding and grounding system. Refer to Chapter 5, “Internal Bonding and Grounding (Earthing)” for requirements on bonding and grounding methods.
- Equipment Grounding Conductors (EGC) **shall not** be connected to the panelboard neutral terminal bar. See NFPA 70-2026 Article 408.40 for more details
- UPS-equipped sites require the installation of two distinct power panels as follows:
  - **Equipment Power Panel (UPS-fed Panelboard)**: this panel provides power for the communications/ electronics equipment and all associated electrically powered items.
  - **Utility Power Panel:** this panel provides power for circuits and loads other than communications and electronics. This panel powers the site's UPS and non-UPS electrical equipment, including lighting, HVAC, and wall-mounted receptacles.

6.2.6.1 Outdoor Electrical (Branch Circuits)

This section specifies the requirements for branch circuits that exit the equipment shelter for outdoor use.

- All outdoor electrical equipment **shall** be protected from the environment and sealed from the elements.
- All outdoor receptacles **shall** be Ground-Fault Circuit-Interrupter (GFCI) type or connected to GFCI breakers. See NFPA 70-2026, Article 210.8, for further details.
- Non-flexible conduit **shall** be used for all exterior circuit branches. Exceptions are feeds to vibrating equipment such as air conditioning units, which may use liquid-tight, flexible, sealed conduit.
- All exterior wall conduit penetrations **shall** be sealed.
- Exterior panelboards, receptacles, and switches **shall** be installed in NEMA Type 3 or Type 3R enclosures.

WARNING: When using equipment outdoors, GFCI receptacles are necessary to prevent electric shock or electrocution. Always test the GFCI receptacle using the manufacturer's supplied Test Button to ensure it functions correctly.

6.2.7 Circuit Protection and Labeling

NOTE: Consider the locked-rotor starting current when selecting breaker ratings for HVAC systems, louver motors, and ventilation fans. Transmitters keyed to full power can also generate unusual start-up loads, which may influence the type of breaker required for the circuit.

The following requirements **shall** be observed when specifying and installing circuit labels and protection devices:

- A method to disconnect power from a specific circuit or load without affecting other equipment **shall** be provided.
- Branch circuits for communication equipment **shall** be at least 15 A, with 20 A circuits preferred.
- A Power Distribution Unit (PDU) does not need to have a minimum of 15 A per circuit. Instead, PDU output circuits can be sized according to the specific load requirements and the PDU's specifications. See “Power Distribution Units” on page 6-12 for more information.
- Branch circuit breakers for all other equipment, such as lighting, HVAC, and wall receptacles, **shall** be rated according to manufacturer specifications and applicable local codes.
- Circuit breakers and their associated receptacles **shall** be clearly labeled and matched to the respective power panel unless otherwise specified for specific equipment. Refer to NFPA 70-2026, Article 408.4, for more details on panelboard labeling. See “AC Receptacle Requirements” on page 6-14 for information on receptacle labeling. See Figure 6-5 and Figure 6-6 for a labeling example.
- The panel schedule **shall** be filled out and kept up to date. Refer to APCO ANS 2.106.1-2019, section 3.13.1.7; NFPA 70-2026, Article 408.4; and Figure 6-6 for more details.
- Circuit breakers **shall** be sized to protect the conductor connected to them, not the load on the circuit. See APCO ANS 2.106.1-2019, section 3.13.1.6 and NFPA 70-2026, Article 240.4, for more information.



Figure 6-5. Receptacle Circuit Labeling Example



Figure 6-6. Panel Schedule Example

6.2.8 Conductors

The following requirements **shall** be followed when specifying and installing conductors:

- Copper conductors **shall** be used (APCO ANS 2.106.1-2019, section 3.13.1.8).
- Aluminum conductors **shall not** be used.
  - Although NFPA 70-2026 permits the use of specific aluminum or copper-clad aluminum conductor types, Motorola Solutions does not recommend aluminum for public safety, mission-critical, military, or similar applications.
  - Motorola Solutions does not approve the use of aluminum conductors in Motorola-specified or provided communications shelters or buildings.
  - See APCO ANS 2.106.1-2019, section 3.13.1.8 and NFPA 70-2026, Article 110.5 for additional information.
- All branch conductors **shall** have a current-carrying capacity, called “ampacity,” that is equal to or greater than the non-continuous load plus 125% of the continuous load. Refer to NFPA 70-2026, Article 210.19(A)(1), for more details.
- It is recommended to use at least 8 mm² csa (#12 AWG) conductors for equipment branch circuits.

NOTE: For three-phase branch circuits, the neutral conductor must be sized to handle overcurrent that may be induced on the neutral by a possible load imbalance.

- For three-phase branch circuits the neutral conductor **shall** be at least the same size as the load-carrying conductors. In special cases, such as highly reactive loads that may produce harmonics, the neutral size should be increased to as much as 175% of its original size. Refer to NFPA 70-2026, Article 120.61, for more information.
- All single-phase circuits **shall** be 3-wire (phase, neutral, and ground). Metallic conduits **shall not** be relied on as the equipment grounding conductor for sensitive electronic equipment (APCO ANS 2.106.1-2019, section 3.13.1.13; IEEE 1100-2005; and NFPA 70-2026, Article 647.7).

6.2.9 Conduit

The following requirements **shall** be followed when specifying and installing conduit:

- All interior surface-mounted building wiring **shall** be installed in rigid Electrical Metallic Tubing (EMT) or electrical raceways. See APCO ANS 2.106.1-2019, section 3.13.1.13; NFPA 70-2026, Article 358; and IEEE 1100-2005, paragraph 8.4.8.2, for additional information.
- Conduits **shall not** serve as the Equipment Grounding Conductor (EGC) for electronic equipment loads. An equipment grounding conductor **shall** be installed alongside the circuit conductors. Refer to IEEE 1100-2005, section 8.5.3, and APCO ANS 2.106.1-2019, section 3.13.1.13, for more information.
- The equipment grounding conductor installation **shall** ensure that disconnecting or removing a receptacle, fixture, or other device does not interrupt the equipment grounding conductor's continuity.

- Conduits **shall** be securely fastened at least every 3 meters (10 feet) and within 900 mm (3 feet) of any receptacle box, junction box, panelboard, or conduit termination. See NFPA 70-2026, Article 358.30, for further details.
- For tenant improvements, applicable local codes from the AHJ **shall** be followed.
- Cable tray support structures can be used to mount conduit runs, but cable trays themselves cannot unless they are specifically designed for that purpose. The design and installation of these cable trays and their ceiling attachments **shall** be capable of supporting an EMT distribution system, including all associated hardware, fittings, and boxes, as well as the load distributed within the tray. See NFPA 70-2026, Article 314.23, for additional information.
- Flexible Metal Conduit (FMC) can be used to route branch circuit conductors to vibrating equipment and suspended lighting fixtures. See NFPA 70-2026, Article 348, for additional information.
- Liquid-tight Flexible Metal Conduit (LFMC) **shall** be used where additional protection against liquids, vapors, or solids is needed. See NFPA 70-2026, Article 350, for more information.

6.2.10 Hardwiring of Equipment and Dedicated Receptacles

Extension cords **shall not** be used to power permanent equipment at a site (APCO ANS 2.106.1-2019, section 3.13.1.11).

For open equipment racks, hardwiring power is not always practical. A dedicated simplex receptacle or receptacle assembly mounted directly on the rack offers a convenient power solution, especially for multiple pieces of equipment. This approach also makes it easier to install Type 3 surge protective devices.

Receptacle assemblies can be pre-manufactured and then mounted on top of an equipment rack. Alternatively, a custom power pole can be fabricated and installed between racks. See “Power Distribution Units” below.

6.2.11 Power Distribution Units

A Power Distribution Unit (PDU) is a rack-mounted device that has one or more input power sources, such as circuits from a panelboard, and multiple outputs. PDU outputs are thermally protected and are designed to distribute either AC or DC power at or near the equipment rack.

PDUs vary from rack-mounted power strips to larger floor-standing units. Some PDUs offer multiple functions, such as power filtering to improve power quality, intelligent load balancing, and remote monitoring and control via LAN or SNMP. Many also feature power metering at the inlet, outlet, and PDU branch circuit level.

Requirements for PDUs are:

- PDUs **shall** be listed to IEC 62368-1:2023 or an equivalent standard (e.g., CSA or TUV).
- PDUs **shall** be installed in accordance with the manufacturer's installation instructions.
- PDU outputs **shall** be overcurrent-protected for the type of receptacle provided (e.g., AC or DC).
  - Overcurrent protection **shall not** exceed the rating of the receptacle.
  - Overcurrent protection may be rated lower than the receptacle and sized according to the actual load requirement for a given circuit.

Figure 6-7 shows an example of a PDU with multiple inputs and outputs.



Figure 6-7. Example of Power Distribution Unit with Multiple Inputs and Outputs

Figure 6-8 shows an example of a PDU with a single main input (L1, L2, neutral and ground) and multiple outputs.



Figure 6-8. Example of Power Distribution Unit with Single Main Input and Multiple Outputs

IMPORTANT: Power Distribution Units **shall** include an internal ground connection point, such as a threaded hole or post, for bonding to the AC power Equipment Grounding Conductor (EGC), in addition to any external connection designed for bonding to the internal bonding and grounding system.

6.2.12 AC Receptacle Requirements

The following requirements **shall** be observed when specifying and installing receptacles for powering communications equipment:

- All 120 VAC receptacles **shall** have three conductors: phase, neutral, and ground (IEEE 1100-2005 and NFPA 70-2026, Article 647.7).
- Receptacle ratings should be determined by conductor and circuit breaker current ratings. Consider future expansions.
- Outlet boxes or enclosures **shall** be securely mounted (NFPA 70-2026, Article 300.13 and 314.23). Cable ties **shall not** be used to secure outlet boxes or receptacles.
- Isolated ground receptacles **shall not** be used unless required by the equipment manufacturer (IEEE 1100-2005).
- Isolated ground receptacles **shall not** be used at dispatch or operator type positions (ATIS-0600321.2020, section 7.3). See “Bonding to Power at the Operator-Type Equipment Position” on page 5-142.
- Receptacles **shall** be installed near the load, such as PDU receptacles or rack-mounted receptacles, to prevent the use of extension cords.
- The use of simplex receptacles over duplex is preferred to mitigate the risk of two pieces of equipment turning on at the same time and momentarily exceeding the circuit's current capacity.
- Equipment racks may need special attention to support dedicated simplex receptacles for equipment. To meet the dedicated simplex receptacle recommendation, receptacles must be located on or very near the equipment rack. Most rack-mounted PDUs and overhead receptacle panels are good examples. A PDU **shall** be mounted on the equipment rack or enclosure and **shall** be hardwired to the breaker panel. Each simplex receptacle **shall** be served by an individual branch circuit. See “Power Distribution Units” on page 6-12.



IMPORTANT: Motorola Solutions does not advise using the multiwire branch circuit for critical equipment.



NOTE: Duplex receptacles may be fed from two separate circuits when the connecting tabs on the receptacle are removed. The neutral **shall not** be shared by two receptacles, and only one equipment grounding conductor is necessary for both circuits. When the tab is removed, NFPA 70-2026, Article 210.4(B), states: “Each multiwire branch circuit **shall** be provided with a means that will simultaneously disconnect all ungrounded conductors at the point where the branch circuit originates.” This can be achieved with a 2-pole breaker or two single-pole breakers connected with a handle tie.

- All communications equipment receptacles **shall** have the electrical box or cover plate permanently marked with the service panel and appropriate circuit identification. This label must be clearly visible without removing the plug.
- Power cord plugs **shall** be supported with strain reliefs that are sufficient to prevent accidental disconnection, where applicable. The use of twist-lock plugs does not eliminate the need for strain relief.
- Adequate service receptacles **shall** be provided for the service technician and their test equipment. These receptacles **shall** be conveniently located near the equipment being serviced, typically at least one per row. They **shall** be on separate circuits from mission-critical communications equipment.

6.2.12.1 Receptacle Testing

During system commissioning, all receptacles that power electronic equipment **shall** be tested with a commercially available receptacle tester. The tester **shall** comply with UL 1436 Edition 6 or an equivalent standard.

IMPORTANT: Perform receptacle testing procedures before power quality measurements. See “Power Quality” on page 6-22 for additional information.

NOTE: The tester used **shall** be designed for testing receptacles serving electronic equipment (see Figure 6-9 for an example). The tester **shall** test according to UL 1436 (or equivalent).



Figure 6-9. Example of Receptacle Tester

The Receptacle Tester **shall** test the following:

- Voltage
- Open ground
- Open neutral
- Open hot
- Hot/ground reversed
- Hot/neutral reversed
- Circuit voltage drop percentage (under load)
- Equipment Grounding Conductor (EGC) integrity and impedance
- Ground Fault Circuit Interrupter (GFCI) functionality (where applicable)

WARNING: Observe all safety warnings and cautions issued by the tester manufacturer.

NOTE: Follow test instructions provided by the tester manufacturer.

Table 6-1 indicates the expected results for receptacle testing.

Table 6-1. Expected Results for Receptacle Tests

Test	Expected Result	Notes
Voltage	Measured Circuit Voltage	Should be within the specific equipment tolerances. If the equipment tolerance limits are unknown, a high threshold of 126 V and a low threshold of 108 V are recommended for monitoring 120 V circuits (IEEE 1100-2005, section 6.4.2.4). See “Power Quality” on page 6-22 for more information.
Open Ground	Pass/Fail	None
Open Neutral	Pass/Fail	
Open Hot	Pass/Fail	
Hot/Ground Reversed	Pass/Fail	
Hot/Neutral Reversed	Pass/Fail	
Circuit Voltage Drop Percentage (Under Load)	Percentage of Voltage Dropped (%)	Per NFPA 70-2026, Article 210.19 Informational Note recommendations, the maximum voltage drop measured at a receptacle should not exceed 5% of the source voltage. See the tester instructions for testing details.
EGC Integrity and Impedance	Ohms (Ω) Pass/Fail	Refer to Table 6-2 for IEEE recommended maximum impedance values.
GFCI Functionality	Pass/Fail	None

IMPORTANT: Failure of any test **shall** be investigated and corrected by a qualified electrical contractor.

Table 6-2 lists the IEEE-recommended maximum Equipment Grounding Conductor (EGC) impedance, based on the circuit overcurrent device rating (see IEEE 1100-2005, Table 6-1).

Table 6-2. Impedance Guidelines for Effective Grounding of Systems and Equipment Rated 600 V or Less

Overcurrent Device Rating (A)	Circuit Voltage to Ground	
	120 V	277 V
10 A	1.6 Ω	-
15 A	1.0 Ω	1.0 Ω
20 A	0.8 Ω	0.7 Ω
25 A	0.6 Ω	0.6 Ω
30 A	0.5 Ω	0.5 Ω
40 A	0.4 Ω	0.3 Ω
60 A	0.1 Ω	0.1 Ω

Table 6-3 provides an alternative maximum EGC impedance calculation based on actual conductor gauge and length. Values indicated in the table assume use of copper conductors (see NFPA 70-2026, Table 8).

NOTE: Table 6-3 can also be used for calculating the impedance of hot or neutral conductors.

Table 6-3. Maximum EGC Impedance per 100 feet (Copper Conductors)

Conductor Size		Conductor Type	Conductor Impedance	
American Wire Gauge (AWG)	Cross Sectional Area (mm^2)		Ohms (Ω) per 100 ft	Ohms (Ω) per km
14 AWG	2.08 mm^2	Solid	0.319 Ω	10.4 Ω
		Stranded	0.326 Ω	10.7 Ω
12 AWG	3.31 mm^2	Solid	0.201 Ω	6.57 Ω
		Stranded	0.205 Ω	6.73 Ω
10 AWG	5.26 mm^2	Solid	0.126 Ω	4.148 Ω
		Stranded	0.129 Ω	4.226 Ω
8 AWG	8.37 mm^2	Solid	0.0786 Ω	2.579 Ω
		Stranded	0.0809 Ω	2.653 Ω
6 AWG	13.30 mm^2	Stranded	0.0510 Ω	1.671 Ω
4 AWG	21.15 mm^2	Stranded	0.0321 Ω	1.053 Ω
3 AWG	26.67 mm^2	Stranded	0.0245 Ω	0.833 Ω
2 AWG	33.62 mm^2	Stranded	0.0201 Ω	0.661 Ω
1 AWG	42.41 mm^2	Stranded	0.0160 Ω	0.524 Ω

6.2.13 Receptacle Strip (Relocatable Power Taps) Requirements

IMPORTANT: Receptacle strips **shall** be plugged directly into a hardwired receptacle, not into another receptacle strip or an extension cord.

Receptacle strips are designed to supply AC power to low-power equipment where several line-powered devices are located close together, such as at a dispatch operator position. The following requirements **shall** be observed when choosing and installing receptacle strips:

- Receptacle strips **shall** be listed by a Nationally Recognized Testing Laboratory (NRTL), such as UL.
- AC power receptacle strips **shall** be equipped with a 3-prong power cord.
- Receptacle strips **shall** be of metal construction (APCO ANS 2.106.1-2019, section 3.22.3.5).
- Consumer-grade receptacle strips **shall not** be used.
- Receptacle strips **shall not** have ON/OFF switches unless the switch is covered to prevent accidental switching off.
- Receptacle strips are only suitable for specific applications where they are appropriate.
- When powering multiple similar devices from a receptacle strip, ensure that a failure of the strip does not impact overall system availability. For example, avoid plugging redundant site routers into the same receptacle strip.
- Receptacle strips **shall** be easy to mount without needing disassembly.

- Receptacle strips **shall** be securely attached to the supporting structure using the designated bolt mounting method and **shall not** be secured with cable ties, double-sided tape, hook-and-loop, or other temporary fastener solutions.
- Receptacle strips **shall not** be mounted on the floor. Damage can result from foot traffic, water, water seepage, or fire sprinkler activation, any of which may pose an electrocution hazard to personnel.

6.3 Powering Equipment

The following subsections provide requirements for powering electronic equipment.

6.3.1 Equipment Powered Using Receptacle Strips

Receptacle strips (power strips) can be an effective way to manage power for equipment, but their use is subject to the following critical guidelines to ensure reliability and prevent single points of failure.

- Receptacle strips **shall** only be used if necessary.
- Receptacle strips **shall** be used only for low-power equipment, such as networking devices, dispatch operator position equipment, control stations, and other equipment designated by the system engineer.
- Multiple items that function as a single unit of equipment can be connected to a power strip, such as the equipment associated with a single dispatch operator position. See Figure 6-10.
- Items deemed individually critical, for which backup cannot be easily provided, **shall not** be powered via a power strip.
- Redundant equipment pairs **shall not** be connected to the same receptacle strip.
- No more than one receptacle strip **shall** be connected to the same branch circuit. If multiple receptacle strips are used, each strip **shall** be plugged into a dedicated branch circuit.

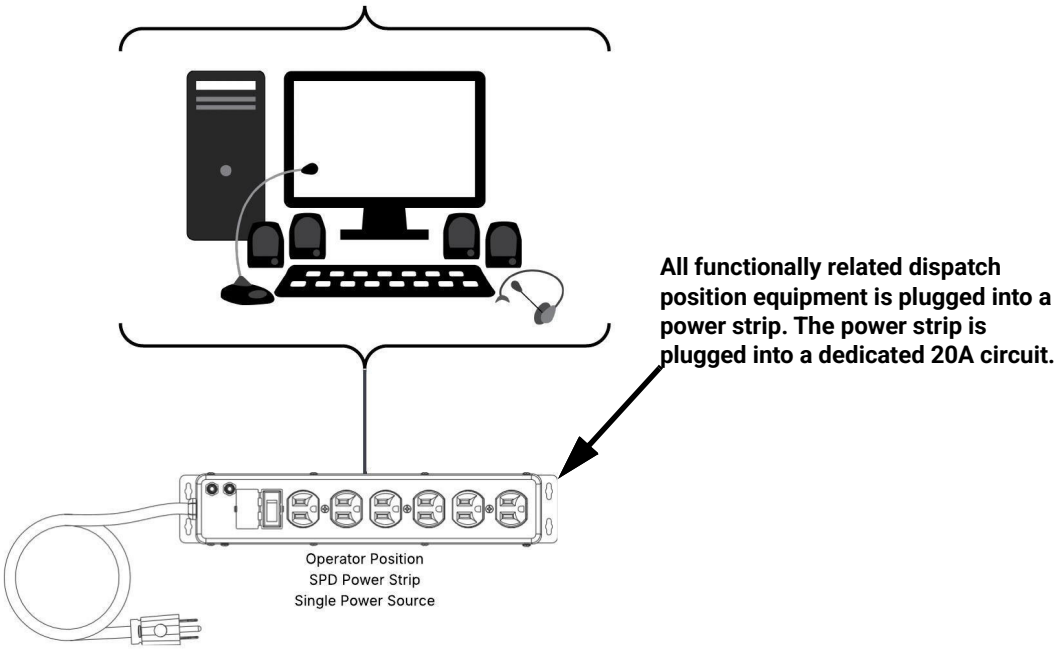


Figure 6-10. Functionally Related Equipment at a Dispatch Operator Position

6.3.2 Equipment Powering Requirements

The electrical design must prioritize system reliability and availability by following key principles for branch circuit distribution and load separation. These general requirements apply to both AC-powered and DC-powered equipment.

- Receptacles for loads other than critical equipment **shall** be fed from the main distribution panelboard, not from the equipment panel (critical loads panel) or the UPS (APCO ANS 2.106.1-2019, section 3.17.1 and IEEE 1100-2005). See “Power Quality” on page 6-22 for additional information.
- To help ensure system reliability and availability, each major piece of equipment **shall** have its own dedicated branch circuit and a dedicated receptacle (see APCO ANS 2.106.1-2019, section 3.23 and IEEE 1100-2005).
  - See Figure 6-11 on page 6-20 for an example of multiple base stations supplied by separate, dedicated circuits.
  - See Figure 6-14 on page 6-21 for an example of separate DC feeder circuits for different base station racks.
  - See Figure 6-15 on page 6-22 for an example of a DC power distribution unit for the rack equipment.
- To help ensure system reliability and availability, redundant equipment pairs, such as redundant site routers and switches, **shall** be supplied from different branch circuits. See Figure 6-12 for an example of redundant Site Router/Switch pairs supplied from different AC electrical circuits.
- To help ensure system reliability and availability, redundant power supplies for the same piece of equipment **shall** be provided from different branch circuits. See Figure 6-13 on page 6-21 for an example of redundant power supplies and networking equipment powered from different AC electrical circuits.
- To help ensure electrical system load balancing, system reliability, and availability, equipment **shall** be evenly distributed across the phases (phase A and B for single-phase systems, and phases 1, 2, and 3 for three-phase systems). For example:
  - Base stations **shall** be allocated equally across the phases, to the extent practicable, ensuring each phase has the same number of stations.
  - Trunking system control channel-capable base stations **shall** be on separate circuits and different phases, as much as practicable.
  - Dispatch center operator positions (or equivalent) **shall** be distributed equally across the different phases, to the extent practicable.
  - Redundant site routers and switches **shall** be powered from different phases.
  - Redundant site controllers **shall** be powered from different phases.
  - Other devices as identified by the system engineer and/or customer.

NOTE: Under engineering design and circuit loading review, multiple redundant power supplies from different equipment can share the same branch circuit. For example, power supply A from Router 1 and power supply A from Router 2 can share a single branch circuit; similarly, power supply B from Router 1 and power supply B from Router 2 can share another branch circuit

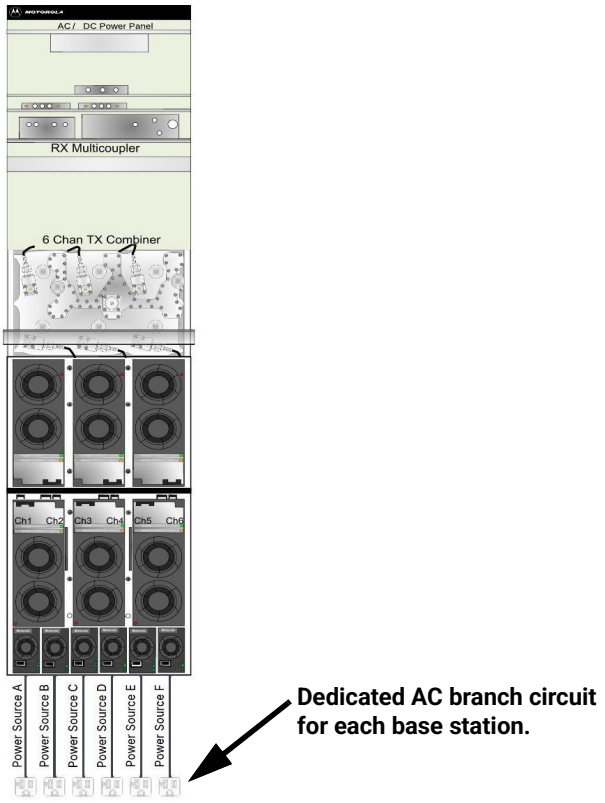


Figure 6-11. Base Stations Supplied from Separate, Dedicated AC Electrical Circuits

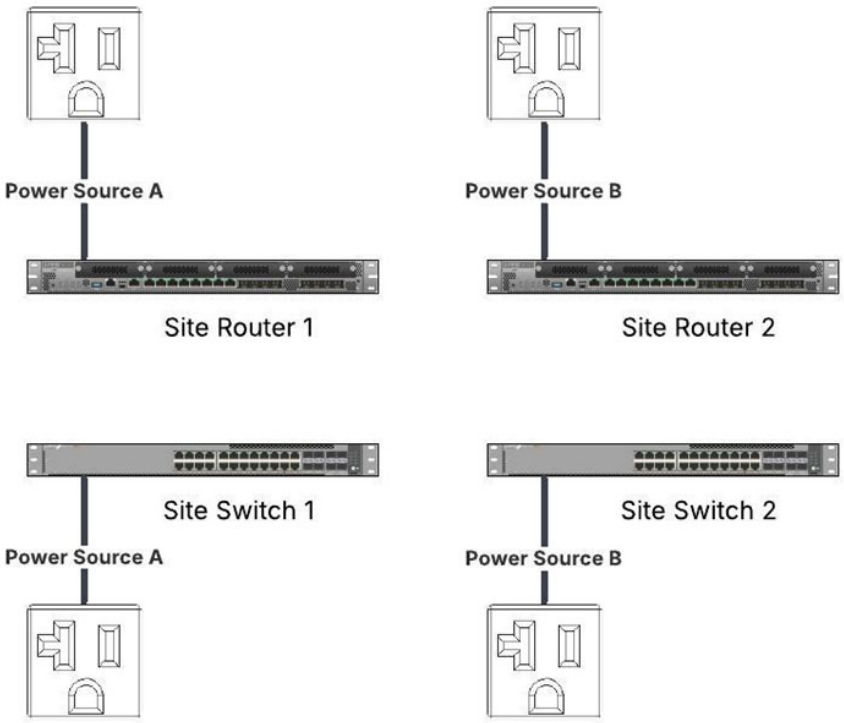
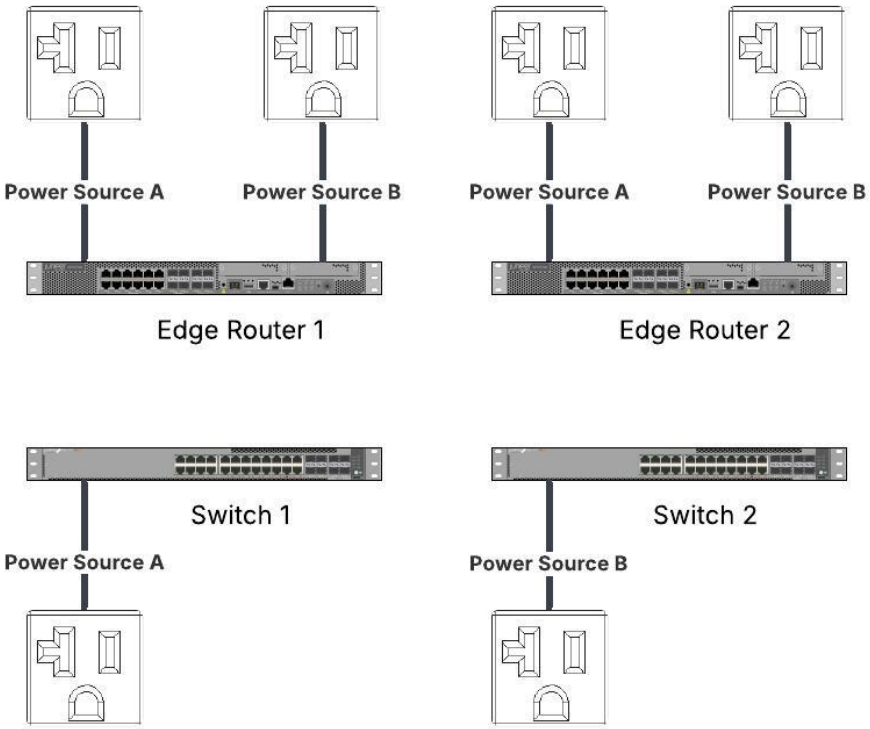


Figure 6-12. Site Router/Switch Pairs Supplied from Different AC Electrical Circuits



Redundant power supplies and networking equipment are distributed between two dedicated AC electrical circuits to ensure maximum system availability

Figure 6-13. Redundant Power Supplies Powered from Different AC Electrical Circuits

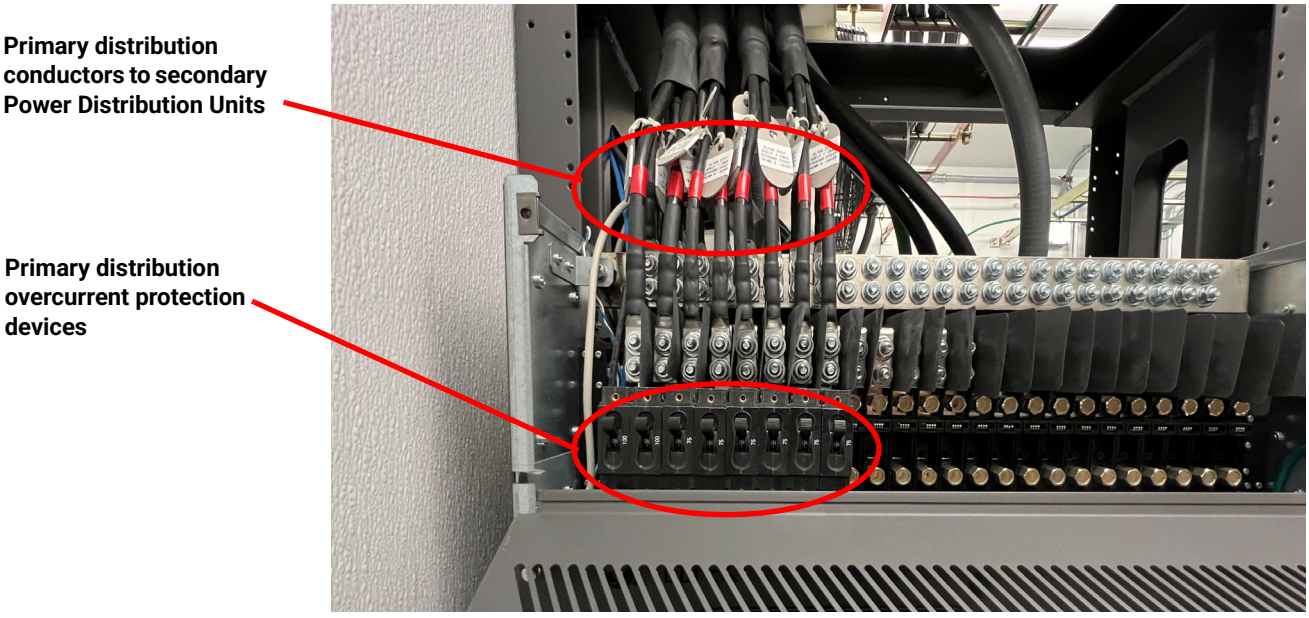


Figure 6-14. Primary DC Distribution Overcurrent Protection, Separate DC Feeder Circuits to Equipment Rack PDUs – Example

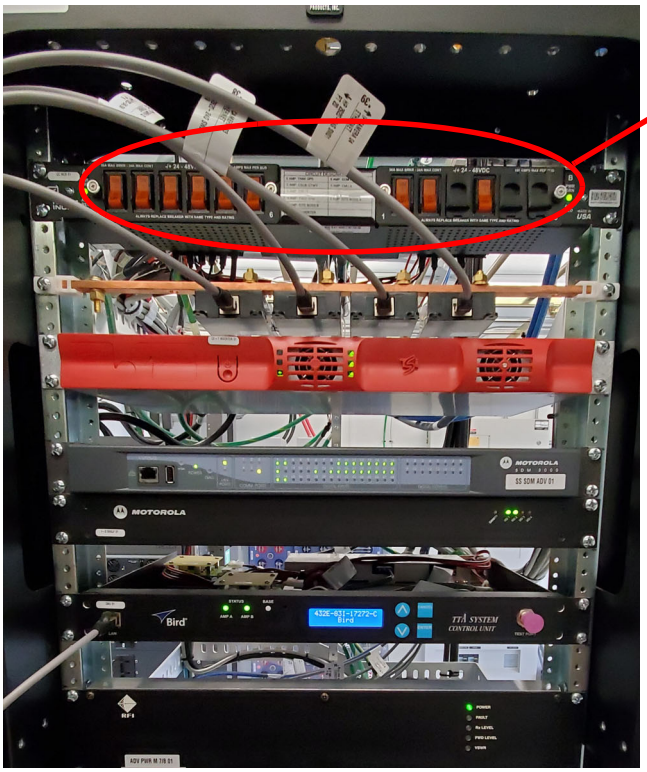


Figure 6-15. Secondary DC Power Distribution Unit and Overcurrent Protection for Rack Equipment – Example

6.4 Power Quality

Power quality is defined as “the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment” (IEEE 1100-2005 and IEEE 1159-2019). To operate reliably, electronic equipment must be supplied with quality AC power.

Motorola Solutions establishes site standards and guidelines to ensure optimal operating environments for critical electronic equipment. A crucial element for achieving system availability and reliability is delivering quality power to electronic equipment.

See Appendix H, “Glossary,” for definitions of terms relating to power quality.

IMPORTANT: Perform receptacle testing procedures before power quality measurements. See “Receptacle Testing” on page 6-15 for additional information.

6.4.1 Fundamentals of Power Quality

This paragraph introduces power quality. See IEEE 519-2022, IEEE 1100, and IEEE 1159 for further information. The requirements and recommendations here align with industry codes and standards to help ensure environments are suitable for electronic equipment. The American National Standards Institute (ANSI), British Standards Institution (BSi), Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Commission (IEC), and the Telecommunications Industry Association (TIA) have laid the groundwork for supporting electronic equipment operation.

The quality of power supplied to electronic equipment is influenced by, but not limited to, the following:

- Equipment load requirements
- Grounding (earthing) of the facility

- Sufficient delivery of power
- Interaction between connected loads
- Internal and external wiring
- Placement of the electronic equipment within the facilities

While NFPA 70-2026 and other electrical codes enforced by the authority having jurisdiction (AHJ) address power quality concerns as minimum safety requirements, these standards are often insufficient for the operational needs of electronic equipment.

6.4.2 Developing a Power Quality Plan

Before deploying electronic equipment, establish a power quality action plan. Start by reviewing the manufacturer's specified requirements for optimal performance to understand the equipment's operating standards. Next, perform a thorough assessment of the facility's current electrical environment and compare it with the equipment's requirements. This assessment should include load, grounding, bonding, isolation, and protection needs to identify any necessary corrective actions.

To ensure an optimal electrical environment, a power quality monitoring plan is crucial. This plan should require regular review of the site's operating standards, including consistent monitoring and recording of the power system, connected loads, and any failures or outages. The main aim of this program is to detect issues early and take corrective actions proactively, preventing minor problems from developing into extensive failures.

6.4.3 General Recommendations to Help Ensure Good Power Quality

The following list offers some general recommendations to improve power quality. Refer to IEEE 1100-2005 for more information.

- Use a UPS or another backup power source for critical loads.
- Use a UPS system that provides a true sinusoidal wave output to help maintain a total harmonic distortion (THD) below 5% (typically found in a UPS that uses IGBT rectifier technology).
- Isolate critical loads from noisy or inductive loads (for example, motor-driven cleaning equipment, space heaters, fans, copiers, and printers).
- Separate critical loads and other loads onto different panels (APCO ANS 2.106.1-2019, section 3.17.1 and IEEE 1100-2005).
- Install an insulated equipment grounding conductor on receptacles that feed critical loads, versus relying on the metallic conduit (IEEE 1100-2005, section 8.5.3).
- Match circuit availability to the load requirements (for example, 15-amp circuits are not suitable for powering equipment that requires a 20-amp circuit).
- Maintain minimum separation between AC power conductors and other communications cabling.
- Restrict access to power control panels and mark electrical receptacles according to their intended use (for example, HVAC controls, electrical panels and switchboards, circuits for critical loads, or other specific uses).
- Follow the recommendations/requirements of Chapter 7, “Surge Protective Devices.”
- Follow the recommendations/requirements of Chapter 6, “Power Sources.”
- Follow the recommendations/requirements of Chapter 5, “Internal Bonding and Grounding (Earthing).”
- Follow the recommendations/requirements of Chapter 4, “External Grounding (Earthing) and Bonding.”
- Follow the recommendations/requirements of Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”

6.4.4 Common Power Quality Problems

Table 6-4 summarizes some common causes of power quality problems, their symptoms, and possible corrective action to take. See IEEE 1159-2019, sections 4.4 and 5.5 for additional information. A power quality engineer may be needed to help address power quality problems.

Table 6-4. Troubleshooting Common Power Quality Problems

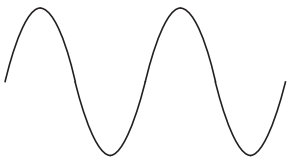
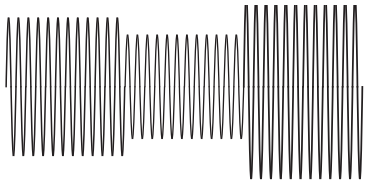
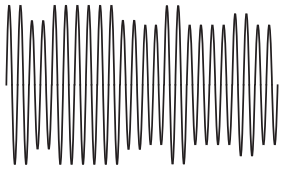
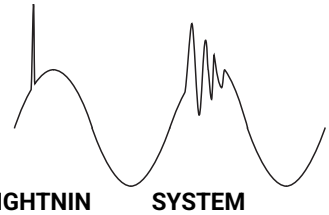
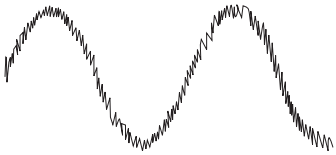
Problem	Common Causes	Symptoms	Remedies
Frequency Deviation	• Faults on bulk power transmission system • Large block of load being disconnected • Large source of generation going off-line • Generator system faults: frequency deviations are much more likely to occur where equipment is powered by an onsite generator, versus AC utility (IEEE 1159-2019, section 4.4.7).	• Writing errors in any electronic writing device • Incorrect clock timing	• If measured on AC utility, report problem to the utility. • If measured on the onsite generator, make corrective repairs to generator.
Voltage Sags, Swells, and Fluctuations  **NORMAL SINE**  **NORMAL**  **VOLTAGE**			
Voltage Sags (or dips)	• System faults • Switching of heavy loads • Starting of large motors • Large load changes • Adverse weather conditions	• Equipment shutdown • Power supply interruptions • CPU lock up • Data errors	• Corrective wiring • Relocation of critical loads • Power conditioners • UPS systems
Voltage Swells	• System faults (for example, an open neutral conductor) • Single line-to-ground fault on the system resulting in a temporary voltage rise on the non-faulted phases • Switching off a large load • Switching on a large capacitor bank	• Microprocessor failure • Equipment failure • Progressive damage to power supplies	• Relocation of critical loads • Power conditioners • UPS systems
Transients  **LIGHTNIN SYSTEM**	• Adverse weather conditions • Lightning • Load switching • Fault clearing • Capacitor discharge • Utility switching	• Damage to microprocessors • Data errors or loss • Lock ups • Catastrophic failure of electronic equipment	• Surge Protective Devices • Filters

Table 6-4. Troubleshooting Common Power Quality Problems (continued)

Problem	Common Causes	Symptoms	Remedies
Total Harmonic Distortion (> 5%) 	• Normal operation of nonlinear devices, such as switched-mode power supplies in computers • Noise-generating loads • Synthesized sine wave from a UPS or power conditioner • Overloaded building or utility transformer	• Failure of microprocessor controlled equipment • Overheating of electrical system components • Decreased life expectancy of electrical system transformers • Tripped circuit breakers	• Isolating the noise • Power conditioners • Moving loads away from noise generators • Using UPS with a true sinusoidal waveform output (typically using insulated gate bipolar transistor rectifier technology)
Noise  See IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, for additional information*.	• Power electronic devices • Control circuits • Arcing equipment • Loads with solid-state rectifiers • Switching power supplies • Improper grounding can exacerbate noise	• Equipment malfunction • Data corruption • Erratic system behavior • System lockups • Unexpected reboots • Communication errors • Display or printer errors.	For excessive neutral-to-ground noise at the receptacle (approximately 2-3 V peak): • If the neutral-to-ground bond is located remotely from the shelter, install an isolation transformer at the AC power feed into the building. This establishes a new neutral-to-ground bond, decreasing noise. • UPS with an isolation transformer • Power conditioner

6.4.5 Power Quality Testing Thresholds

Table 6-5 outlines the recommended AC power quality testing thresholds for most single-phase and three-phase configurations (IEEE 1100-2005, Table 6-2, and IEEE 1159-2019, Table 5). However, it is crucial to base the actual testing thresholds on the specific installation requirements of the connected equipment, as these may demand stricter adherence.

Table 6-5. Suggested Threshold Settings for 120 V Loads

Category	Value	Notes
Conducted Phase Voltage Thresholds		
Voltage Sags	108 V rms	–10% of nominal supply voltage
Voltage Swells	132 V rms	+10% of nominal supply voltage
Transients	200 V peak	Approximately twice the nominal phase-neutral voltage
Noise	1.5 V	Approximately 1% of the phase-neutral voltage
Total Voltage Harmonic Distortion	5%	The voltage distortion level at which loads may be affected
Frequency Deviation	± 0.1 Hz	

Table 6-5. Suggested Threshold Settings for 120 V Loads (continued)

Category	Value	Notes
Conducted Neutral-to-Ground Voltage Thresholds		
Voltage Swells	3.0 V rms	Typical level of interest for neutral and/or ground problems
Impulsive Transient	20 V peak	10% to 20% of phase-neutral voltage
High Frequency Noise	2-3 V peak	Typical equipment susceptibility level

6.4.6 Power Quality Testing Locations

To effectively monitor a site with multiple loads, start by installing the power quality monitor at the main power panel. This offers an initial overview of the voltage profile. Then, move the power quality monitor to individual load circuits, especially those with malfunctions or failures (see Figure 6-16). By comparing disturbance data, you can identify the source of issues and determine the best solutions. Refer to IEEE 1100-2005, section 6.4.2.5 for more guidance.

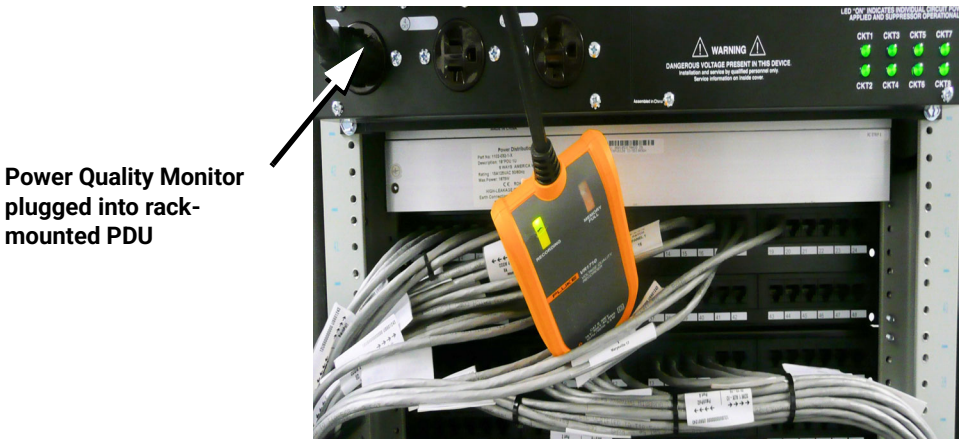


Figure 6-16. Example of Power Quality Monitor Installed at PDU

NOTE: An engineering firm might be required to assist with power quality testing and troubleshooting.

Motorola Solutions recommends the following locations for testing power quality on 120 V phase-to-neutral loads:

- To evaluate the power quality supplied to a particular piece of electronic equipment, test at the equipment's receptacle, especially if the equipment exhibits malfunctions or failures.
- To evaluate the quality of output power from a power conditioner or UPS system, test at the power conditioner or UPS power panelboard (or as close as practicable).
- To assess the power quality of secondary distribution, test at the secondary of the equipment room transformer.
- To assess the overall power quality delivered to a facility, test at the facility's main electrical panel.

WARNING: Only qualified personnel shall open an electrical panel to perform a power quality measurement. Lethal voltages may be present.

6.4.7 Power Quality Testing Duration

The duration of a monitoring period is directly tied to its objective. The aim is typically to encompass a complete power cycle, which is the interval when power usage patterns begin to repeat. For instance, an industrial plant's power usage might follow a daily or shift-based pattern. Depending on the monitoring objective, a monitoring period as brief as one shift might suffice (see IEEE 1159-2019, section 7.4.7.1).

Generally, a monitoring period of at least one full work cycle (usually seven to eight days) is recommended. However, longer periods may be necessary to capture random or seasonal disturbances. More detailed information can be found in IEEE 1100-2005, section 6.4.2.5.

6.5 Rectifier/DC Power Systems

This section provides general guidelines and requirements for selecting and installing site rectifier/DC power systems and components. Although some specific recommendations are included, the actual equipment specifications will mainly depend on the unique characteristics of each design and installation. Many of these influencing factors are emphasized throughout this section.

6.5.1 Rectifier System Requirements

6.5.1.1 Acceptable Rectifier Types

Generally, two types of rectifiers are acceptable for powering communications equipment. Details of each are described below.

- **Switch Mode Rectifier (SMR)**
  - SMRs are the industry standard for DC-powered critical systems and are the most commonly used rectifier technology at communication sites. Where practical, SMR rectifiers are the preferred choice for critical communication systems.
  - SMRs offer a high-efficiency, hot-swappable design in comparably compact packages. Compact size and efficiency enable a cost-effective n+1 redundancy design without requiring excess space.
  - SMRs have robust built-in protection against AC voltage transients and exceptional mean time between failures (MTBF). SMRs also use active, built-in current-sharing circuits to better distribute load across rectifiers.
- **Controlled Ferroresonant Rectifier**
  - Controlled Ferroresonant Rectifier (CFR) systems are less common and are an older technology. CFR systems may be in use at older, very remote communication sites.
  - Their simpler design, excellent MTBF, resistance to heavy AC transients, and high tolerance to environmental changes may make CFRs a suitable choice for extreme remote locations or areas with unstable AC power and environmental controls.
  - CFRs are larger, less efficient, and more vulnerable to AC line frequency shifts that can lead to excessive heat.

NOTE: Silicon Controlled Rectifier-based systems are not suitable for Motorola Solutions systems because their design tends to allow unacceptable levels of AC transients to propagate to the DC side, generating higher levels of Electromagnetic Interference (EMI).

6.5.1.2 Redundancy

A minimum n+1 redundancy design is recommended for rectifier systems. The n+1 approach uses one more rectifier than needed to power the site equipment. In case of a single rectifier failure, there is no loss of capacity, giving time for corrective actions. The redundant rectifier also helps recharge standby batteries after a utility power outage.

6.5.1.3 Rectifier Sizing

The rectifier power system design specifications **shall** be appropriately sized based on the equipment and site being powered. Modern SMR DC systems can be specified for applications ranging from lower to higher currents, reaching into the thousands of amps.

- Many systems enable modular expansion as needed rather than replacing entire systems.
- Consult the manufacturer's specifications when selecting rectifier size, considering surge currents, potential growth, and failure scenarios.

6.5.2 DC Distribution

The DC power distribution, or power board, serves as the connection point for site equipment. A power board may consist of two separate or combined components: the meter/alarm and control section, and the distribution/overcurrent protection section. The distribution section of the power system can be reconfigured, expanded, and modified in various ways, depending on the equipment being serviced. The alarm and control section provides metering and alarm functions for site monitoring, such as when a breaker trips. It is considered best practice to plan for system expansion and size the distribution/overcurrent section accordingly. Adding breakers or fuses to a power board for equipment expansion is more cost-effective than replacing or adding a separate DC distribution system.

6.5.3 Low Voltage Disconnect

DC systems with battery backup **shall** be equipped with a Low Voltage Load Disconnect (LVLD). A Low Voltage Battery Disconnect (LVBD) **shall not** be used instead of the LVLD. The LVLD protects the battery system from excessive drain when the system voltage drops to a specified level. Normally, sealed lead-acid (SLA) batteries are considered fully discharged when the voltage per cell (VPC) reaches 1.75 volts. For 48-volt systems (24 cells), the battery plant is fully discharged at 42 volts (1.75 x 24).

Operating battery systems beyond the “fully discharged” voltage can cause permanent damage or reduce the batteries' lifespan. Additionally, internal power supplies in equipment are designed to deliver regulated voltages (usually +12V, -12V, and/or +5V) within a certain input voltage range. If the input voltage falls below this range, the power supplies may not produce the proper voltages, leading to equipment shutdown, erratic behavior (such as power cycles), or potential damage. While LVLDs are built to protect the battery systems, they also safeguard connected equipment from low-voltage conditions.

Consult the battery manufacturer's specifications for the correct LVLD levels. Many DC rectifier/controller systems include LVLD protection, and the disconnect threshold must be set according to the battery chemistry and technology used.

6.5.4 Overcurrent Protection

Overcurrent protection devices (OCPDs), such as fuses or circuit breakers, **shall** be installed in DC power systems according to this section. Appropriately sized circuit breakers are preferable to fuses, because replacement fuses may not be readily available everywhere, possibly leading to more downtime.

IMPORTANT: All installations **shall** comply with local electrical codes and the requirements of the authority having jurisdiction (AHJ). These local codes may have more stringent or additional requirements for 48VDC systems, including battery protection, that supersede other standards.

6.5.4.1 Primary and Secondary Distribution

For telecommunications DC power systems, overcurrent protection **shall** be provided at the primary and secondary distribution levels (ATIS-0600311.2017(R2024)).

Primary overcurrent protection devices (OCPD) are installed at the DC plant's distribution point. This primary distribution typically feeds secondary distribution points, such as Power Distribution Units (PDUs) that are installed in racks throughout the equipment room. Figures 6-14 and 6-15 on page 6-22 show examples.

Figure 6-17 on page 6-29 is a schematic view of the required primary and secondary distribution overcurrent devices. The primary conductors are sized based on the expected total current load of all connected secondary PDUs. These conductors are often sized larger than necessary for simple ampacity to minimize voltage drop over the conductor length, ensuring correct voltage is maintained at the PDU inputs. The primary OCPD is then sized based on the ampacity of the large primary distribution conductors it protects. Because these primary conductors are typically large, their corresponding OCPDs are also large.

The primary circuits connect to the secondary PDUs, forming the secondary distribution. Here, the secondary conductors and their associated OCPDs (fuses or breakers contained within the PDU) are sized based on the lower current requirements of the specific equipment they power. Because these current loads are smaller, the conductors are of a smaller gauge.

Consequently, the secondary conductors and OCPDs are typically much smaller than those used in the primary distribution. This size difference helps ensure that a fault will trip only the smaller secondary OCPD, isolating the fault, while maintaining power to the unaffected primary and other secondary circuits.

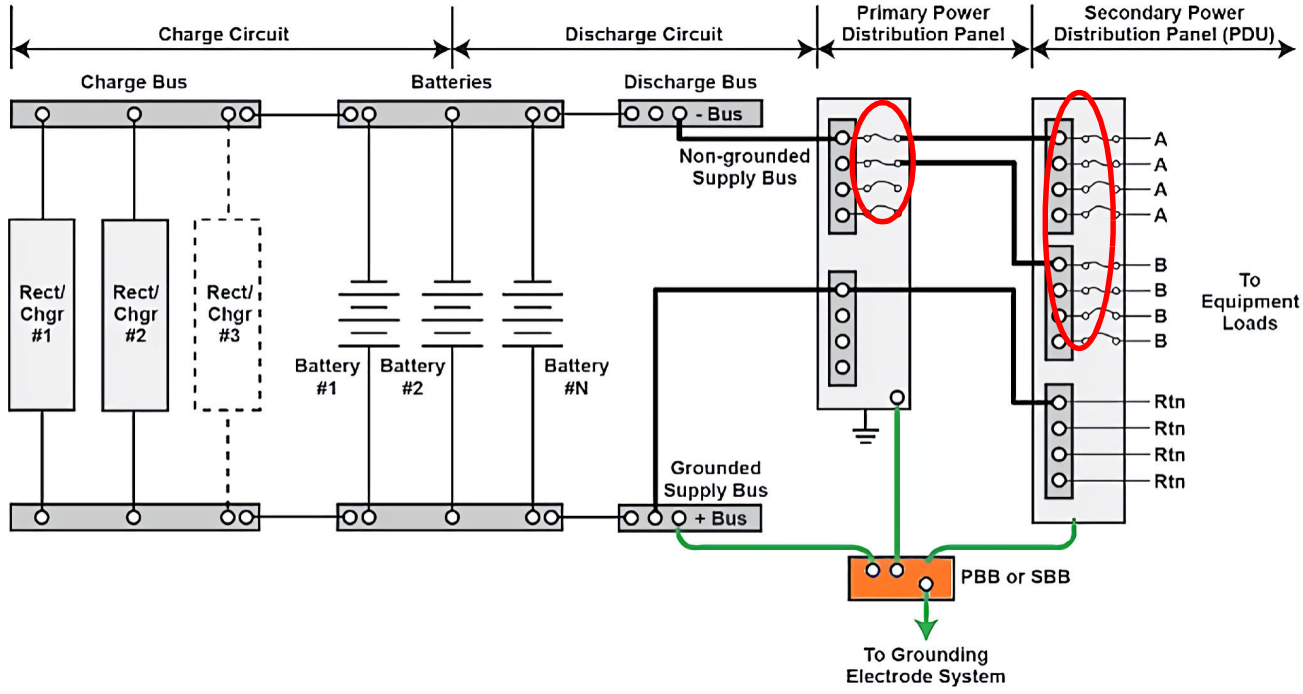


Figure 6-17. DC Power System Example Showing Overcurrent Protection

6.5.4.2 Overcurrent Protection at the Battery Plant

As a best practice and to provide a critical layer of safety, a main Overcurrent Protection Device (OCPD) **shall** be installed as close as practicable to the battery bank's main terminals (see CSA C22.1-24, section 14; IEC 60364-4-42:2023; and NFPA 70-2026, Article 240 for more information). This OCPD is essential for protecting the large-gauge battery cables from massive fault currents during a short circuit, which could otherwise cause cable failure, significant equipment damage, and a severe fire hazard. This OCPD, which may also serve as the disconnect for the load during battery servicing, must meet several key requirements:

- The OCPD **shall** be a non-sparking circuit breaker installed in the ungrounded leg of the circuit (see Figure 6-18 and Figure 6-19 on page 6-30).
- The OCPD's rating **shall not** exceed the circuit conductors' current-carrying capacity (ampacity).
- The battery conductors **shall** be sized according to “DC Power Conductor Capacity” on page 6-30.

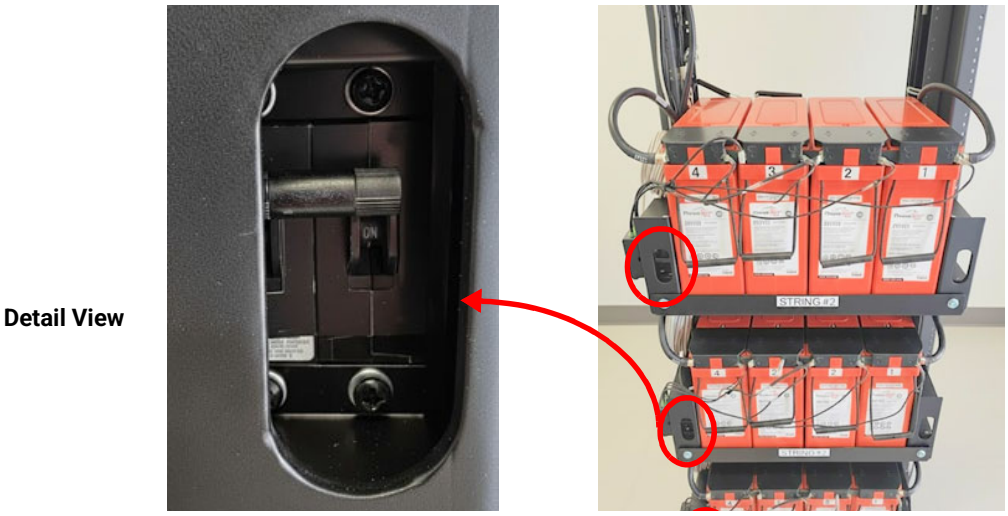


Figure 6-18. Overcurrent Protection Devices Installed at Batteries: Example 1

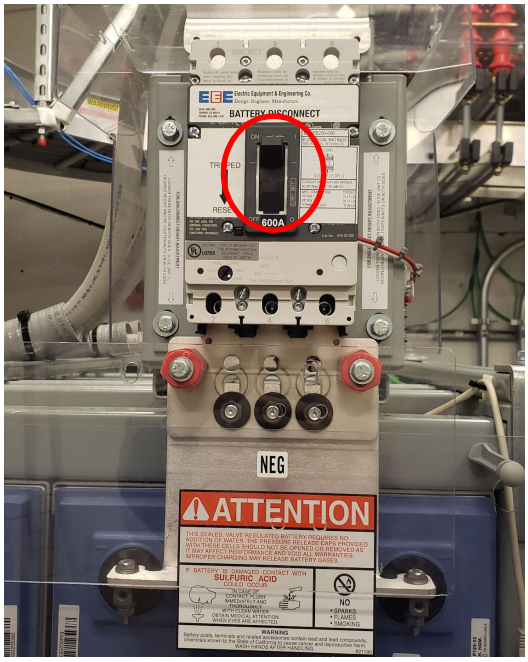


Figure 6-19. Overcurrent Protection Devices Installed at Batteries: Example 2

6.5.5 DC Power Conductor Capacity

The power conductors supplying DC power to site equipment **shall** be sized according to expected load requirements and current-carrying capacity, known as “ampacity.” Ampacity refers to the maximum short-term current the conductor can handle without generating enough heat to damage the insulation. Conductors **shall** have an ampacity that is equal to or greater than the non-continuous load plus 125% of the continuous load. Refer to NFPA 70-2026, Article 210.19(A)(1), for more details.

Ampacity is determined by the following factors:

- Ambient temperature
- Insulation type
- Heat-dissipating characteristics of the cable transport
- Number of cables in a bundle or enclosed raceway

A conductor's ampacity varies with ambient temperature. NFPA 70-2026, Article 310.16, offers guidance. Also, a conductor in free air has higher ampacity than when inside a conduit or raceway. These enclosed wire management systems trap heat, decreasing safe current capacity. When sizing DC cable, refer to the tables in NFPA 70-2026, Article 310.15.

The maximum allowable voltage drop must also be considered when sizing power cables for DC systems. Minimizing voltage drop in DC systems may require larger DC power cables than those used in AC systems.

Table 6-6 on page 6-31 shows the minimum copper conductor size required for the given maximum current and corresponding one-way power conductor length from the DC source to the distribution point, such as a power distribution unit (PDU), to ensure a voltage drop of 3% or less at the PDU. The maximum voltage drop of 3% is based on a 48 V system with 90°C-rated copper conductors using methods outlined in NFPA 70-2026, Article 310.16. The one-way distance accounts for both the positive and negative conductors. An online calculator is available at http://www.calculator.net/voltage-drop-calculator.html.

IMPORTANT: Calculations for voltage drops other than 3%, DC systems other than 48 V, conductors other than THHN (or equivalent), conductors with less than a 75°C (167°F) rating, or current and length values outside this table may require consulting an engineer.

NOTE: Motorola Solutions recommends consulting with an engineer to identify the appropriate conductor size.

Table 6-6. Minimum Copper Conductor Size (AWG) for Given Current and Length

One-Way Distance (ft)	25A	50A	75A	100A	125A	150A
10	10 AWG*	6 AWG*	2 AWG*	1 AWG*	1/0 AWG*	2/0 AWG*
20	10 AWG	6 AWG	2 AWG*	1 AWG*	1/0 AWG*	2/0 AWG*
30	8 AWG	4 AWG	2 AWG*	1 AWG*	1/0 AWG*	2/0 AWG*
40	6 AWG	4 AWG	2 AWG	1 AWG	1/0 AWG	2/0 AWG
50	6 AWG	3 AWG	2 AWG	1/0 AWG	2/0 AWG	3/0 AWG
60	4 AWG	2 AWG	1 AWG	1/0 AWG	3/0 AWG	3/0 AWG
70	4 AWG	2 AWG	1/0 AWG	2/0 AWG	3/0 AWG	4/0 AWG
80	4 AWG	1 AWG	1/0 AWG	3/0 AWG	4/0 AWG	250 kcmil
90	4 AWG	1 AWG	2/0 AWG	3/0 AWG	4/0 AWG	250 kcmil
100	3 AWG	1/0 AWG	3/0 AWG	4/0 AWG	250 kcmil	300 kcmil
125	2 AWG	2/0 AWG	4/0 AWG	250 kcmil	300 kcmil	350 kcmil
150	2 AWG	3/0 AWG	4/0 AWG	300 kcmil	350 kcmil	500 kcmil

*Conductors in these cells were increased in size to match the overcurrent protection device.

GENERAL NOTES:

- Table based on a 48 V system and copper conductors (THHN or equivalent) rated at 90°C (194°F) and a maximum ambient temperature of 30°C (86°F).
- For loads of 100 A or less, conductor ampacity is determined using the 60°C (140°F) column in NFPA 70-2026, Article 310.16, according to Articles 110.14(C) and 240.4(D).
- For loads over 100 A, conductor ampacity is determined using the 75°C (167°F) column in NFPA 70-2026, Article 310.16, according to Articles 110.14(C) and 240.4(D).
- See CEC Rule 4-006 in Canada.
- The maximum allowed current of a given conductor may require derating based on other factors, such as ambient temperature, circuit breaker terminal rating, and equipment terminal temperature rating.

6.5.6 Floor and Ceiling Runs, Plenum and Riser Grade Cabling

WARNING: Plenum-rated power cabling SHALL be used for all power cabling runs within a plenum (air handling) space. Standard power cabling SHALL NOT be installed within a plenum space. Refer to NFPA 70-2026, Article 300.25, and the authority having jurisdiction.

IMPORTANT: Wiring within plenum spaces and risers **shall** conform with all applicable NFPA and AHJ codes.

NOTE: See “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30 for information regarding the installation of communications cabling within plenums and other spaces used for environmental air. The same general requirements **shall** be applied to DC power system wiring.

The following requirements specify installation practices that minimize smoke and combustion products from electrical wiring in areas handling environmental air, in the event of a fire. Per NFPA 70-2026, Article 100, a plenum is defined as “a compartment or chamber to which one or more air ducts are connected and that forms part of the air distribution system.”

- Wiring systems of any type **shall not** be installed in ducts used to transport dust, loose stock, or flammable vapors (NFPA 70-2026, Article 300.25(A)).
- Wiring systems of any type **shall not** be installed in any duct or shaft containing only such ducts, used for vapor removal (NFPA 70-2026, Article 300.25(A)).
- Wiring installed in other spaces used for environmental air, such as the area above a suspended ceiling or as otherwise defined in NFPA 70-2026, Article 300.25(C), **shall** be installed in accordance with NFPA 70-2026, Article 300.25(C).

WARNING: Electrical installations placed in hollow spaces, vertical shafts, ventilation, or air-handling ducts SHALL be installed so as not to significantly increase the spread of fire or combustion products. Openings around penetrations through fire-resistance-rated walls, partitions, floors, or ceilings SHALL be firestopped with approved methods to preserve the fire-resistance rating. Firestopping these penetrations can be done using specially manufactured fire seals or fire-barrier caulking. Refer to NFPA 70-2026, Article 300.23, TIA-569-E, and IFC-2024, section 703 for more information.

NOTE: According to NFPA 70-2026, Article 300.25(D), electrical wiring in air-handling areas beneath raised floors for information technology equipment is allowed in accordance with NFPA 70-2026, Article 645.5(E).

6.5.7 DC Power Budget

A DC power budget **shall** be established to correctly size DC power cables and reduce voltage drop in the distribution network. Figure 6-20 shows an example of a power budget. For most batteries, the typical DC operating range is 2.33 – 1.75 VPC, or 56 – 42 V for a 48 V system, and 28 – 21 V for a 24 V system. The endpoint equipment, repeaters, network hardware, and others will have a DC operating voltage range listed in the manufacturer's specifications.

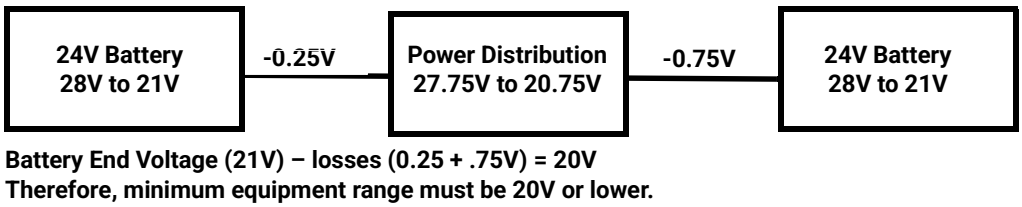


Figure 6-20. DC Power Budget

To establish a DC power budget, identify the lowest voltage within the equipment's operating range (end voltage). When multiple devices are connected to a branch, use the specification with the highest minimum voltage. The difference between the equipment's end voltage and the battery's end voltage represents the total voltage drop budget.

The total system voltage drop is calculated from the batteries to the main distribution, from the main distribution to the remote distribution, and from the remote distribution to the end load. Factors such as wire size, distance between components, and equipment load also contribute to the overall voltage drop.

After determining the equipment end voltage of the system, if it is equal to or higher than the battery's end voltage, then a battery with a higher end voltage may need to be selected. Batteries with higher end voltages are usually physically larger, so space considerations must be taken into account.

6.6 Uninterruptible Power Supplies

This section offers guidelines and requirements for choosing and installing a site Uninterruptible Power Supply (UPS). Although some specific recommendations are included here, the actual UPS specifications depend on many factors, including some that may be unique to the installation.

The UPS system is designed to supply short-term power to specific critical loads during utility power irregularities, brief outages, or long-term outages when used with a standby generator system. Most UPS configurations typically offer between 5 and 10 minutes of backup power at full rated load. The UPS usually provides an alert when the battery is nearing depletion or if a failure occurs. See APCO ANS 2.106.1-2019, section 3.17 for more details.

NOTE: At sites where a standby generator is used alongside a UPS, the UPS **shall** be programmed or configured to enable the generator to provide power during a utility outage. Some UPS units, by default, may not recognize generator power as “clean” and will not switch to the secondary power source. Any AC “line quality sampling” feature on the UPS should be disabled to prevent the UPS from rejecting the generator as a power source.

NOTE: A standby generator system is designed to supply long-term power during utility outages. The UPS usually only provides temporary power, bridging the gap between utility power loss and the generator, stabilizing and transferring the load.

6.6.1 Determining UPS Output and Installation Requirements

The following requirements and considerations **shall** be observed when specifying and installing UPS systems:

- UPS **shall** provide a true sinusoidal output. Step-synthesized output **shall not** be acceptable. See APCO ANS 2.106.1-2019, section 3.17.2 for more information.
- UPS **shall**, at a minimum, be sized to sufficiently support the load demands of all critical site equipment, including a margin for growth. Site or floor-mounted UPS installations may include a separate subpanel powered by the UPS circuit for critical site equipment.
- UPS **shall** be capable of delivering full-rated output power for a duration exceeding the switchover period between utility power loss and stabilized generator power.
- Floor loading **shall** be considered for the intended installation location.
- The main service panelboard **shall** have enough capacity and breaker space to accommodate the UPS.
- The intended location of UPS **shall** have adequate capability to exhaust the heat generated by the UPS.
- The ambient temperature range near the UPS **shall** be in accordance with the manufacturer's specifications.
- Adequate space for safe servicing of the UPS and batteries **shall** be considered when planning the location of the UPS. For most floor-mounted UPS units, a minimum clearance of 1 m (39 in.) in front of the battery servicing doors is necessary. Refer to the manufacturer's installation manual for additional clearance requirements.
- UPS units **shall not** be used as work surfaces or storage locations.
- All UPS units **shall** be bonded in accordance with “Transformers, Inverters and UPS Systems (Containing Isolation Transformer)” on page 5-91.
- Preventive maintenance for the UPS unit and batteries, including replacement intervals, **shall** follow the manufacturer's specifications.

6.7 Alternative Power Sources

For sites without access to commercial AC power utilities, a customer may opt to use solar and/or wind-powered systems. Solar panels and wind generators charge batteries that are part of the Energy Storage System (ESS), which then supplies power to site equipment. Liquefied Petroleum Gas (LNG or propane), Natural Gas (NG), or other fuel sources may be used as backup or to supplement solar and/or wind systems.

Solar and wind-driven systems may provide limited power at times; however, both technologies have advanced significantly in their ability to generate electricity efficiently. When planning the overall power system, it is essential to estimate the total predicted power usage for the site. The duty cycle for all transmitters, network support equipment, and environmental controls **shall** be calculated and used to size the system appropriately. Solar and/or wind power may be most suitable for smaller sites with low power demands, where the physical size and cost of a standalone generator system are impractical. See Figure 6-21 for examples.

NOTE: Sites dependent on HVAC place high demands on a power system, which may make them less suitable for solar or wind power sources. Fueled generator systems could be a better option for sites that need both an alternative power source and more robust HVAC systems because of the climate.

For some sites, it might be practical to use wind generators to back up a solar panel system. During sunless days if energy demand exceeds the charging rate, as long as there is wind, battery charging can continue. These systems take advantage of more sunny days in the summer and windier days in the winter. Wind generators should be mounted higher than buildings or other nearby obstructions to maximize wind flow.



Figure 6-21. Typical Solar Panel and Wind Generator Installations

6.7.1 System Planning for Alternative Power Sources

When developing a stand-alone power system, it is recommended to hire a contractor specializing in alternative power sources due to the potentially complex design and constantly evolving technologies. To ensure the power source meets the site's power demands, consider the following guidelines to help estimate the approximate average battery system load.

- Total typical ampere-hours (Ah) used by all site equipment over a 24-hour period. (1 ampere used continuously for 1 hour equals 1 Ah.)
- The voltage that the power system must be capable of providing. Communications sites typically use 12-volt, 24-volt, or 48-volt battery systems.
- The average number of consecutive sunless days expected at the location (for solar installations).
- The typical number of consecutive windless days expected at the location (for wind installations).

The daily Ah rating is determined as shown in the following example using typical characteristics for a single-repeater site:

- **Single repeater requires 7A for Tx (A_{Tx}) and 1A for Rx (A_{Rx})**
- **Radio link requires 1.6A for Tx and 1A for Rx**
- **Duty Cycle of 20% (Tx 20%, Rx 80%)**
- Using the following formula: **[(A_{Tx} × %Tx) + (ARx × %Rx)] x 24 hrs = average Ah required**
- For the example characteristics given, the repeater requirement is: **[(7 x 0.2) + (1 x 0.8)] x 24 = 52.8 AH/day**
- Radio Link requirement is: **[(1.6 × 0.2) + (1 × 0.8)] x 24 = 26.9 Ah/day**
- The total requirement is: **79.7 Ah/day, plus any additional items such as environmental controls, lights, etc.**

6.7.2 Requirements for Alternative Power Sources

Solar photovoltaic (PV) and wind power systems installed in the USA **shall** comply with the requirements of NFPA 70-2026 Articles 690 (PV) and 694 (wind), as applicable. Consult the local AHJ for any additional requirements and for installation requirements outside the USA. The following requirements and considerations **shall** be followed for all PV and wind system installations:

- PV panels **shall** be located away from objects that could block sunlight from reaching the panels. Panels **shall** be pole- or roof-mounted, as required.
- Observe the total time a particular location has direct sunlight throughout the day. Note in any calculation or specification that the site batteries are charged only when the solar panel is exposed to sunlight at a level sufficient for the PV cells to generate energy.
- The angle of the sunlight with respect to the PV panel throughout the year **shall** be considered. Shadows cast by nearby objects may be different as the sun's angle changes with the seasons.
- For fixed PV panel mounting, a good starting point angle for year-round use is the location's latitude. However, better results will be achieved by adjusting the angle by +15° in winter and -15° in summer in northern latitudes.
- Because the optimal angle changes throughout the year, trackers are available that automatically reposition PV panels to follow the sun. However, these are rarely used at communications sites due to higher maintenance needs and the risk of failure.
- PV panels **shall** be oversized by at least 10% to ensure they meet the site's power requirements.
- Battery storage **shall** be adequate to supply power to the site for 5 to 10 days without wind or sun.
- Batteries rated for deep-cycle use **shall** be used in systems that routinely discharge and recharge up to 80% of the battery system capacity.
- PV panels and wind generation systems **shall** be mounted in secure locations and/or high enough to discourage vandalism. For extreme protection, bullet-resistant solar panels are available.
- PV panels **shall** be mounted high enough to clear deep winter snowfalls, where applicable.
- PV panels and support structures **shall** be sufficient to support the weight of snow and/or ice accumulation, where applicable.
- PV panels **shall** be mounted and supported such that damage by high winds is avoided.
- Outside cabling **shall** be well secured and protected with conduit or run inside the mounting pole.
- Plan the battery location in accordance with “Battery Systems” on page 6-37. In earthquake-prone areas (Seismic Design Category D or higher), batteries **shall** be mounted in seismic-rated battery racks secured to the floor.

6.7.3 Installation of Alternative Power Sources

Install the PV panels and wind generator following the manufacturer's instructions and the design details provided by the alternative power sources contractor, where applicable.

- If PV panels are roof-mounted, the metallic portions of the framework **shall** be bonded to the site grounding electrode system in accordance with “Grounding Roof-Mounted Antenna Masts and Metal Support Structures” on page 4-124.
- If PV panels are pole-mounted, the pole ground **shall** be bonded to the site grounding electrode system in accordance with “Solar Photovoltaic Systems” on page 4-123.
- Wind turbine generator metallic portions, tower, and other exposed metal hardware **shall** be bonded to the site grounding electrode system in accordance with Chapter 4, “External Grounding (Earthing) and Bonding” and NFPA 70-2026, Article 694.

- Cabling from outdoor portions of the system should be installed in conduit and securely fastened. Cables from pole-mounted solar panels or wind generators may be routed inside the mounting pole. Necessary precautions **shall** be taken to prevent moisture ingress into the cable. See NFPA 70-2026, Articles 690 and 694 for details.
- Batteries **shall** be installed in accordance with “Battery Installation” on page 6-44 and secured against earthquakes in seismically active areas (Seismic Design Category D or higher) using a seismic-rated battery rack rated for the site's seismic zone or category. Secure the rack to the floor per the manufacturer's instructions.

6.7.4 Maintenance of Alternate Power Sources

NFPA 70B-2026, chapter 9, outlines recommendations for maintenance intervals for PV panels and wind power electric systems. Chapters 30 (PV) and 31 (wind) provide recommended maintenance tasks and procedures. If required by the local AHJ, these recommendations **shall** be followed. Otherwise, observe the following tasks:

- PV panels **shall** be cleaned and inspected annually or as needed to prevent the buildup of bird droppings, dust, or pollen that could decrease efficiency by blocking sunlight.
- Cracked or damaged PV panels **shall** be replaced.
- Wind electric systems **shall** be visually inspected for blade damage and excessive wear.
- Cracked or damaged turbine blades **shall** be replaced.
- Manufacturer's instructions for maintaining PV panels, wind turbines, and battery systems **shall** be observed.

6.8 Battery Systems

Battery systems typically fall into two categories: Energy Storage Systems (ESS) and Stationary Batteries. An ESS is a complete battery system that may include inverters or converters to adjust voltage levels or to switch between AC and DC systems (NFPA 70-2026 Article 100). Stationary Batteries are those that provide temporary backup power to critical systems during a power failure, such as emergency lighting, fire protection systems, UPS units, and equipment at DC-powered communication sites. An ESS generally includes Stationary Batteries as part of its setup. This section specifically addresses Stationary Battery systems under NFPA-2026 Article 480 and other relevant sections as indicated. Additional guidelines for ESS are outlined separately in NFPA 70-2026, Article 706, and for large ESS installations in IFC-2024, section 1207, as well as NFPA 855-2026. The final classification of any installation is determined by the local authority having jurisdiction (AHJ).

Batteries for equipment standby or backup can use various chemistries and styles, such as Lead-Acid, Ni-Cad, Lithium-ion, and others. Lead-acid batteries are the most common in communication sites and are generally classified into two types: Vented lead acid (VLA, flooded cell or wet cell) and Valve Regulated Lead Acid (VRLA or sealed) batteries. VLA batteries present higher personal and environmental risks because they emit hydrogen gas during normal operation and can spill harmful liquid electrolytes if tipped or damaged. VRLA (sealed) batteries typically do not vent hydrogen and are less prone to leaks when tipped. VRLA batteries may use a gel-style electrolyte or other stable chemistry to reduce hazardous conditions.

Due to the nature of VLA batteries, where applicable and appropriate, it is recommended to contract certified Hazardous Materials handlers for tasks involving handling battery systems containing hazardous materials.

6.8.1 Battery Safety

WARNING: Motorola Solutions employees and contractors SHALL NOT handle hazardous materials unless they are properly trained and wearing the appropriate personal protective equipment (PPE) according to manufacturer guidelines and Safety Data Sheets (SDS). This includes warehouse storage, transportation and installation of batteries and battery systems.

WARNING: Vented lead-acid (flooded or wet cell) battery failures involving large-scale electrolyte leaks may constitute a Hazardous Material (HAZMAT) condition. Regular site personnel SHALL NOT handle or clean up HAZMAT. Special training, HAZMAT certification, spill mitigation, reporting, cleanup techniques, and monitoring are required under the US Federal Clean Water Act and NFPA regulations. The authority having jurisdiction SHALL be notified of any HAZMAT situation.

WARNING: Exercise extreme caution when handling and working near batteries. Battery systems pose many personal and environmental risks, such as:

- **Explosion Hazard: Lead-acid batteries produce hydrogen sulfide gas, increasing the risk of explosion.**
- **Chemical Burns or Blindness: Sulfuric acid in lead-acid batteries can cause severe tissue burns or blindness if it contacts the eyes.**
- **High Current Capabilities: Can result in arc flashes that can lead to burns and fires.**

Refer to NFPA 70E Handbook for Electrical Safety in the Workplace, which provides guidance for safe practices related to batteries.

NOTE: The Safety Data Sheets (SDS) **shall** be kept at each communications site, describing any HAZMAT materials present at the site. SDS outlines HAZMAT reactivity, flammability, and emergency spill/release mitigation procedures.

All applicable NFPA, OSHA, and AHJ codes **shall** be followed for the installation and maintenance of battery systems. All warning statements from the battery manufacturer, as well as instructions regarding the type and extent of Personal Protective Equipment (PPE) necessary to minimize hazards for the specific batteries being installed, **shall** be adhered to.

This section provides safety rules and guidelines for working with VLA (flooded, wet cell) and VRLA (sealed) batteries. VLA batteries demand more careful handling and safety precautions than VRLA batteries. The items listed below serve as guidelines for both types unless noted otherwise. Always read and understand the manufacturer's documentation before installing or maintaining battery systems. Refer to “Typical Battery Safety Kit” on page 3-31 for the required onsite safety equipment when working with batteries.

Adhere to the following general installation and maintenance guidelines for all battery types:

- Observe and follow all precautions listed on the placards attached directly to the batteries.
- Use insulated tools for voltage and environmental safety when working on batteries or battery systems. Refer to NFPA 70E-2024, Article 320.3(C). Tools that have been field modified, such as those wrapped in electrical tape, **shall not** be used.
- PPE and/or other safety equipment, such as personal emergency eyewash kits, specified by the manufacturer, **shall** be provided within the battery containment area.
- Personnel **shall** wear necessary PPE when installing or maintaining batteries.
- Personnel **shall not** wear electrically conductive items, like jewelry, when installing or servicing batteries.
- Under certain conditions, HAZMAT-certified transporters and/or material handlers may be required. Consult the manufacturer's documentation and the local AHJ as required.
- Proper lifting techniques and/or equipment **shall** be used to avoid injury. Some installations may require a two-person lift.

- Batteries **shall** have insulated covers and/or insulated terminal protectors installed.
- Batteries **shall not** be used as a work surface.
- Batteries **shall** be covered while work is being performed overhead.
- Warning signs, such as “NO SMOKING” and “Authorized personnel only,” **shall** be prominently posted in appropriate locations. Locations include the battery room and the exterior of the battery room entry door. See NFPA 70E-2024, Article 320.3(A)(6) for further information.
- All sources of an open flame or spark (smoking, lighters, or torches) **shall** be strictly prohibited in the battery area.
- When batteries are located in an area accessible to persons other than qualified system maintenance personnel, additional safeguards, such as a protective shield or barrier, **shall** be installed. This safeguard prevents accidental contact with or access to battery cells and battery circuit conductors.
- Spills of any type of battery acid (wet, gel, or otherwise) **shall** be mitigated, cleaned, and disposed of according to manufacturer guidelines and those of the AHJ. Electrolyte or neutralized electrolyte **shall not** be disposed of by flushing down a drain or spilling onto soil. Certain spill types and quantities may create a HAZMAT condition.
- A container of non-oxidizing material for coating electrical connections **shall** be left onsite.

For VLA installations or others as required by NFPA, OSHA, and/or the AHJ, the following installation and maintenance guidelines **shall** be followed.

- A lightweight, acid-resistant apron in good working condition **shall** be permanently stored onsite near the battery plant. The fabric **shall** be acid-, caustic-, puncture-, and flame-resistant.
- An acid-resistant, full-face shield in good working condition **shall** be permanently stored onsite near the battery plant. The shield **shall** meet all requirements of ANSI Z87.1. Protective eyewear that does not provide full face protection **shall not** be used.
- At least one pair of acid-resistant gloves in good working condition **shall** be permanently stored onsite near the battery plant. Gloves **shall** be of sufficient length to cover the hand, wrist, and forearm to protect from chemical splash.
- One 0.5 kg (1 lb) box of sodium bicarbonate (baking soda) or equivalent acid-neutralizing compound **shall** be permanently stored onsite near the battery plant. A source of water is required to mix with the baking soda for electrolyte neutralization.
- An emergency eyewash station that is highly visible **shall** be permanently mounted near the battery plant. The eyewash station **shall** consist of a minimum of a sealed rinse agent, such as bottles of eyewash rinse solution, capable of neutralizing acids and/or caustics for the duration necessary to mitigate injury. For installations where personnel measure battery specific gravity or handle electrolyte, a plumbed or self-contained emergency eyewash and shower fixture capable of flushing for 15 minutes is preferred where practicable. See NFPA 70E-2024 Article 320.3(B)(1), and OSHA 1910.268.2.2 for further details. Consult the AHJ for any additional requirements that may apply. ANSI Z358.1 provides guidelines for plumbed and self-contained eyewash and shower fixtures.



IMPORTANT: Eyewash solution has an expiration date. Discard and replace eyewash solution, bottles, and solutions in self-contained systems according to the expiration date on the bottle or container, which is typically every 36 months. Only appropriate eyewash solutions **shall** be used on non-plumbed systems.

- VLA batteries emit small amounts of hazardous gas during normal operation, and provisions **shall** be made to prevent excessive buildup. Ventilation options such as fans, roof ridge vents, louvered fans, or a tubing system to vent batteries externally should be considered where applicable. Some installations may not need additional air movement beyond natural airflow in an occupied space or HVAC circulation. See NFPA 70-2026 Article 480.10 for more details. When required by manufacturer's specifications, OSHA, NFPA 855-2026, or the AHJ, follow any additional ventilation requirements.

NOTE: In most cases, VRLA (sealed) batteries do not need extra venting. VRLA batteries have a valve that opens to release small amounts of internal gases as needed. Check local codes and the AHJ for applicability. Check the battery labels to find the correct protection for the specific type of battery.

- Where present, the manufacturer-specified flame-arresting safety cap **shall** be installed, secured, clean, and in good condition. The safety cap helps provide maximum protection against potential explosions.
- Batteries **shall** be kept clean to prevent short circuit hazards, rack corrosion, and the risk of electrical shock. Use a solution of water and sodium bicarbonate to clean batteries if needed. Avoid using abrasive cleaners, detergents, or petroleum-based cleaning products on battery containers.
- Battery banks with multiple cells and circuit protection exceeding 20 amperes should have a protective shield made of 12.7 mm (0.5 in.) or thicker polycarbonate or hard rubber. This shield should be installed on a support frame and securely mounted in front of the battery rack to protect personnel in case of a violent structural failure of any cell(s). The shield should extend at least 76 mm (3 in.) above and below the height of the protected cells. Follow the battery manufacturer's recommendations.

6.8.2 Battery Containment Area

The following requirements and considerations **shall** be observed when specifying and designing a battery containment area:

- Certain areas may require UL-listed Intrinsically Safe vent fans, electrical, and electronic equipment. See NFPA 70-2026, Article 500 through 505, when Intrinsically Safe equipment is necessary.
- Battery containment areas **shall** have sufficient lighting to ensure safe work. Refer to NFPA 70E-2024 Article 320.3, NFPA 70-2026, Article 480.10(F), and “Lighting” on page 3-19.
- Signs indicating “Electrical Hazard,” the use and wear of appropriate PPE, and prohibiting access to unauthorized personnel **shall** be posted in suitable locations, such as within the battery room and on entry doors to the room. See NFPA 70E-2024, Article 320.3, and IFC-2024, Article 1207.4.8.
- Where required by battery chemistry and/or the AHJ, NFPA 704 compliant signs warning of any chemical hazards, the electrochemical technology in use, and reactivity with water **shall** be posted. See NFPA 70E-2024, Article 320.3, IFC-2024, Article 1207.4.8, and “Minimum Required Signage” on page 3-32.
- When VLA (vented, flooded cell) batteries are specified, a separate battery room that is sealed from adjacent spaces and adequately vented (see NFPA 70-2026 Article 480.10 or NFPA 855-2026 if applicable) to the building exterior is recommended. Verify with the local AHJ for any additional relevant codes.
- For large battery installations that exceed the capacities listed in Table 6-7, follow the guidelines in IFC 1207-2024. Typically, IFC 1207-2024 references NFPA 855-2026. Consult with the AHJ for any additional applicable codes.

Table 6-7. Energy Storage System Threshold Quantities

Battery Technology	Energy Capacity
Lead-acid, all types	70 kWh
Ni-Cad, Ni-MH, and No-Zn	70 kWh
Lithium-ion, all types	20 kWh

- Installations using stationary vented lead-acid (VLA, flooded) batteries that exceed 70 kWh (about 50 gallons of electrolyte) **shall** have an approved spill containment and neutralization system to prevent the flow of liquids into nearby areas. Valve Regulated Lead Acid (VRLA) batteries are generally exempt from this requirement. (See guidelines in IFC 2024, section 1207.6).

WARNING: Appropriate fire extinguisher(s) shall be present in the battery room, according to NFPA and local AHJ guidelines. See “Fire Protection and Safety” on page 3-21 and relevant subsections.

If battery configurations utilize bolt-on terminal connections, the following items **shall** be provided:

- Connector bolt wrench (nonconductive)
- Lifting sling and spreader block, if applicable
- Container of non-oxidizing material for coating electrical connections
- At sites with VLA (flooded lead-acid) batteries, the following additional items **shall** be provided:
  - Hydrometer with markings every 10 points
  - Acid-resistant container for storing the hydrometer
  - Thermometer, battery

6.8.3 Battery Backup Duration

Many communications shelter designs include a two-hour standby battery backup as a standard feature. A two-hour duration is generally enough for urban areas, giving technicians time to address and resolve onsite power issues. However, for remote or hard-to-reach locations, a backup duration of four or more hours might be better to account for longer response times.

Standby battery backup requirements can range from just a few minutes, allowing time for a standby generator to start, stabilize, and transfer power, up to several hours. The duration of the standby battery backup depends on system needs, the availability of an alternative power source, and customer requirements.

NOTE: Standby battery backup systems usually do not supply power to the HVAC system. Temperature-related shutdowns, caused by thermal protection systems in most communications equipment, **shall** be considered when determining the maximum operational time under standby battery backup conditions. In some cases, thermal shutdown may occur well before the standby battery is depleted.

6.8.3.1 High Rate of Discharge

Some installations may include multiple RF repeaters, microwave equipment, network support equipment, or other devices that draw significant current. If the standby battery system will operate in a high-rate application or if an existing system is converted to one, the manufacturer's specifications should be checked to ensure the batteries are suitable for high-rate use. High-rate systems demand that the hardware-such as cables and connectors-used to connect the batteries be adequately sized and rated to handle the heat generated by high discharge rates. Refer to NFPA 70-2026, Article 480.12.

6.8.3.2 Long Duration Backup

During extended primary power outages caused by utility power loss or standby generator failures, the site HVAC system will be offline. Without environmental controls, site temperatures may rise or fall (depending on the season) outside the equipment's designed operating range. Most communications equipment and supporting devices, such as switches, routers, and GPS receivers, automatically shut down during over- or under-temperature conditions.

Depending on the site design and the equipment powered by the standby batteries, significant temperature increases or decreases can occur quickly. If the utility outage lasts long enough, the loss of HVAC might become the true limiting factor in standby battery backup systems. Given the heat generated by the equipment and possible variations in outside ambient conditions, consulting an HVAC contractor is advisable. HVAC professionals can assess how long it may take for the site to reach the high or low operating temperature limits of the powered equipment. In worst-case scenarios, standby battery backup durations longer than the estimated time may not be recommended. Careful consideration of costs, environmental factors, and the equipment's thermal load is essential to determine a balanced and realistic standby battery backup duration.

6.8.4 Battery Sizing

Battery sizing depends on the equipment's characteristics and electrical load. The process for determining standby battery size can be simple or quite complex, depending on the system. Stationary standby batteries, used for fixed locations, are typically rated in Amp-Hours (Ah).

Many standby battery manufacturers provide an Ah rating based on a standard 8-, 10-, or 20-hour discharge duration, depending on the intended use. These standard durations are often referred to as a battery's current (C) rating. A rating of C/8 (8-hour) indicates a battery is better suited for quick discharge, such as in UPS applications, whereas a C/20 (20-hour) rating is better suited for longer discharge periods. Generally, an 800 Ah battery can deliver 100 Amperes per hour over 8 hours, or 8 Amperes per hour over 100 hours. However, this scaling is not always linear, as the discharge rate over time depends on the battery's design specifications. Always consult the battery manufacturer's specification sheets to determine rated capacities at different hour ratings when selecting a standby battery.

When choosing standby batteries, consider environmental factors and aging characteristics. Temperature affects the current capacity of typical VLA or VRLA batteries. At lower temperatures, a battery's Ah capacity is less than its rated Ah. At higher temperatures, the capacity may increase. Table 6-8 provides correction factors to adjust the expected load based on different temperatures. Refer to the manufacturer's specifications for various adjustments. Note that new batteries might not provide 100% of their capacity immediately. It can take several charge-and-discharge cycles for a battery bank to reach full capacity.

Table 6-8. Battery Rating Temperature Correction Factors

10°C/50°F	15°C/60°F	20°C/68°F	25°C/77°F	30°C/86°F	35°C/95°F
1.190	1.110	1.056	1.0	0.956	0.930

As a battery ages, its capacity gradually decreases. When a standby battery's capacity falls to 80% of its original rating, it should be considered at the end of its life. These factors should be considered when selecting batteries and planning for regular replacements. A common guideline is to multiply the calculated load by 1.25 to account for aging.

The DC load in most modern systems is considered steady-state because it changes little, even during busy periods. To find the Ah required for a standby battery system, multiply the load in amperes by the backup time. Add a temperature correction factor and an aging margin to determine the total size of the standby battery system.

For example, to find the required amp-hour rating for a load of 32 amperes with a backup time of 4 hours at an average low temperature of 15°C/60°F, multiply the load (32 A) by the duration in hours (4 h), the temperature correction factor (1.110), and the aging margin of 1.25. In this case, the standby battery system should be rated for at least 178 Ah.

To determine standby battery backup ratings, it is essential to know the power requirements and duration of each charge. Several online calculators are available to help in calculating the appropriate rating. Consult the project engineer for power and load calculations whenever possible. Equipment specification sheets typically show maximum current draw and voltage. IEEE 485-2020 offers additional guidelines for sizing lead-acid type batteries.

6.8.5 Battery Rating

Batteries **shall** be sized to ensure the standby system maintains correct voltage for the required duration. Use worst-case scenarios considering age and deterioration, lowest temperatures, expected load, and the availability of backup power sources.

6.8.6 Multiple Battery Strings

Best practices specify that battery types, ratings, and service life **shall not** be mixed within a rack. When expanding a site, new batteries of the same type **shall** be installed. Old batteries **shall** be removed and recycled where possible. Mixing batteries can lead to uneven current distribution and charging issues. Furthermore, using different types of batteries can greatly raise the risk of persistent battery system issues.

Floor loading, growth, and system load must be considered to determine the required number of battery strings. All standby battery backup systems need regular maintenance (see NFPA 70B-2026, chapter 36 for guidelines). Some maintenance procedures require batteries to be offline. It is strongly recommended to consider at least two standby battery strings to ensure backup power in the event of an interruption during battery maintenance.

Careful consideration should be given to avoid installing too many standby battery strings. When a fault occurs in a single cell of a battery string, diagnosing and locating it can become more challenging as the number of battery strings increases.

To prevent catastrophic failure of a single string of batteries in the standby battery plant, overcurrent protection **shall** be installed for each individual string. This protection **shall** be rated for the system voltage and cable size. A general guideline for sizing the protection is provided below. Refer to NFPA 70-2026 or an equivalent standard to ensure the overcurrent protection is properly sized.

System ampacity/Number of battery strings – 1 = Recommended protection

Manufacturer recommendations for the maximum number of standby battery strings can vary significantly. Motorola Solutions recommends the power system be initially designed for at least two standby battery strings and up to six when fully implemented. This provides a margin for future growth if additional equipment exceeds the expected load of a fully operational system

6.8.7 Battery Charging

Many standby batteries that have been discharged below full charge must be fully recharged within 24 hours. During this process, significant charging current may flow, and VLA (flooded-cell) batteries will emit more gas than during normal float-charge operation. Ensure ventilation is in place to protect personnel from hazardous fumes. A float charge must be maintained to keep standby batteries fully charged. Overcharging or undercharging batteries can increase maintenance needs and significantly reduce service life. It is essential that the charging system is correctly adjusted according to the manufacturer's specifications. Overcharging and undercharging alarms **shall** be installed to quickly detect battery charging problems.

6.8.8 Battery Temperature Requirements

Battery performance and lifespan are heavily affected by operating temperature. To achieve optimal performance and extend service life, the battery should be kept around 24°C (75°F). When the temperature drops, the battery runtime decreases; when it rises, it may increase. However, exposure to high temperatures can greatly reduce the battery's lifespan.

The reference temperature is often overlooked in battery ratings. Battery manufacturers typically use 22.2°C (72°F) as the standard reference temperature. A battery operating at 0° C (32°F) provides 30% of its capacity but may last 130% or more of its expected service life. Conversely, a battery at 38°C (100°F) may deliver 130% of its capacity but might last less than a year. Consult the battery manufacturer's documentation for the recommended operating temperature range.

NOTE: If building codes do not permit batteries inside the same compartment as the climate-controlled radio equipment enclosure, outdoor battery pedestals may need protection from direct sunlight or be elevated to prevent burial in snow during winter (where applicable).

6.8.9 Battery Installation

Follow manufacturer warnings, and, as indicated, provide personal protective equipment in the area where batteries are installed. If practical, have a plumbed eyewash station and emergency shower available in VLA installations.

WARNING: Battery acid can cause severe burns and blindness if it contacts skin or eyes. Wash affected skin or eyes immediately with running water. Seek medical attention right away. To prevent spills, DO NOT tip batteries. Jewelry SHALL NOT be worn while working on batteries. Installation personnel shall wear necessary safety equipment when installing batteries. Use proper lifting techniques and equipment to avoid injury. Batteries may require a two-person lift. Insulated tools SHALL be used when installing or maintaining battery systems.

Battery installation **shall** comply with the manufacturer's specifications, NFPA 70-2026, NFPA 855-2026, and all applicable national, state, and local codes for the authority having jurisdiction (AHJ). Observe the following cautions when installing batteries:

- Do not slide, drag, tip, or drop batteries.
- Batteries are typically installed on shelves or racks due to their size, weight, and service requirements.

IMPORTANT: In areas prone to earthquakes (Seismic Design Category D or higher), seismic-rated racks **shall** be used. Seismic racks **shall** be secured to either the floor or the wall, but **shall not** be secured to both. The installation of seismic racks **shall** strictly follow the manufacturer's specifications.

- Racks and shelves **shall** be designed to hold the total weight of the batteries and other required supporting equipment. They should be assembled and installed following the manufacturer's specifications.
- Battery racks **shall** be secured to either the floor or to a wall.
- The batteries **shall** be prevented from falling due to accidental movement by installing a rim to prevent tipping, interconnecting the batteries to prevent movement, or using another manufacturer-approved method.
- Metal racks **shall** be grounded in accordance with specifications provided in Chapter 5, “Internal Bonding and Grounding (Earthing)”.
- Ensure the floor area can support the installation by calculating the total weight of the rack and batteries. Consult the building or structure diagrams or a civil engineer for floor loading specifications if needed.
- All terminal connections **shall** be tightened to the manufacturer's specifications.
- A non-sparking circuit breaker **shall** be installed in the ungrounded leg of the circuit as close as practical to the battery terminal to provide overcurrent protection. The ampere rating of the circuit breaker **shall** be of a suitable size to handle the maximum load and charging currents and **shall not** exceed the ampere rating of the circuit conductor. This device may also serve as the disconnect for the load during battery servicing.
- Circuit conductors, including jumpers between cells, **shall** be jacketed copper with an AWG size at least rated for the maximum DC load. Some installations may require a conductor size larger than the minimum specified to reduce voltage drop between batteries, battery banks, and the equipment.

IMPORTANT: Conductor jackets for DC circuits **shall** be correctly identified. The floating or ungrounded conductor **shall** be red in color, or marked at intervals not to exceed 610 mm (24 in.) with durable red tape. The grounded conductor **shall** be black in color, or marked at intervals not to exceed 610 mm (24 in.) with durable black tape. Some manufacturers' specifications may allow deviations from this guideline. For installations outside the USA, consult the AHJ and adhere to the applicable codes.

- Battery charge/source conductors **shall** be enclosed in PVC, metallic conduit, or raceway for protection against physical damage. Conductors **shall not** be exposed except at near-terminations. Listed type TC conductors, when appropriate, do not need additional protection if the guidelines in NFPA 70-2026, Articles 336 and 392, are followed.
- Any additional disconnect devices, such as switches, **shall** have an ampacity rating equal to or greater than the circuit protection device.
- Battery terminals **shall** be coated with a protective compound or spray according to the manufacturer's specifications.
- Exposed battery terminals, fuse terminals, and/or breaker terminals **shall** be protected from accidental contact with tools, racks, equipment, or other metal objects.
- Installations utilizing stationary vented lead-acid (VLA, flooded) batteries that exceed 70 kWh (approximately 50 gallons of electrolyte) **shall** be equipped with an approved spill containment and neutralization system to prevent the flow of liquids into adjoining areas. Valve Regulated Lead Acid (VRLA) batteries are generally exempt from this requirement. (See guidelines in IFC 2024, section 1207.6). See Figure 6-22.
- The local AHJ **shall** be consulted for any additional regulations relevant to battery installations.



Figure 6-22. Example of Battery Spill Containment System

6.8.10 Battery Maintenance Disconnect

Battery systems require regular off-line maintenance. Each battery string must have an individual disconnect to isolate it from the rest of the DC system. The disconnect device **shall** be designed to adequately cover live conductors and prevent arcing during circuit make or break.

Before disconnecting batteries, ensure that the rectifier system can supply clean DC without depending on the batteries' inherent filtering. Unstable or noisy DC output could cause equipment failure.

6.9 Standby Generator Systems

This section describes the requirements for optional backup or standby generators, which are essential for providing reliable and stable power to critical loads when commercial power fails. Generators **shall** be sized to handle the necessary loads and to maintain steady frequency and voltage during a potential outage.

Generally, there are two types of generator systems:

- **Emergency generators** are intended to provide backup power for life-saving systems, such as safe egress from an occupied structure, fire protection systems, and lighting. Generators classified as Emergency Generators **shall** comply with NFPA 70-2026, Article 700, NFPA 110-2025, and other applicable regulations per the authority having jurisdiction (AHJ). Emergency generators may also be used to provide backup power for other deemed-critical functions, such as public safety communications equipment.

- **Optional standby/backup generators** do not support occupied structures such as office buildings, fire departments, or other occupied facilities. Generators installed to support a communications shelter may be classified as optional standby/backup generators.

Standards in this section apply to optional backup or standby generators. Therefore, it is highly recommended to clearly understand the differences between backup/standby and emergency generator systems before purchasing generator equipment or starting installation work. Additionally, some generator systems may be part of a Critical Operations Power System (COPS), and therefore, the additional requirements outlined in NFPA 70-2026, Article 708, **shall** be followed. Check with the applicable AHJ and/or the end-user (customer) to determine the intended installation type.

NOTE: Some customer s may choose not to install a standby generator at all locations, due to factors such as cost, fuel availability, or other considerations. These installations might include a properly-sized manual transfer switch and an externally mounted UL-listed weatherproof generator inlet designed for the site load. During a primary power outage, this setup allows connecting a temporary portable generator as needed.

NOTE: In locations where commercial power is unavailable and a generator must serve as the primary power source, these installations **shall** be rated for continuous duty and installed in accordance with the standards covered in this section. Additionally, installations in the USA **shall** meet NFPA 70-2026, NFPA 110-2025, and the AHJ's applicable codes and regulations for continuous-duty generators as a primary power source.

A generator system consists of the generator itself, a cooling system, a fuel supply system, a transfer switch, and a control panel equipped with essential alarms. For liquid-fueled generators, the fuel tank can be integrated into a single housing, such as a base-mounted tank, or placed separately above or below ground. Likewise, the transfer switch and control panel may be combined in a single cabinet or installed separately, indoors or outdoors, in a weatherproof enclosure.

Generators can be installed outdoors as standalone units or indoors within a building or structure. The best placement depends on several factors, including the generator's size, fuel supply method, noise regulations, and available space. Local building codes may also specify which fuel types are allowed for indoor installations

6.9.1 Generator Output and Derating Considerations

When planning a backup generator, consider the following factors to calculate generator power output requirements and ensure the backup generator can safely and effectively handle all required equipment at the site.

- The voltage, phase, and load requirements for all equipment intended to be supported by the generator **shall** be obtained. Creating a power plan that includes electrical load requirements, such as UPS and switched power supplies, ensures that all equipment is accounted for in calculations and the generator selection process. Typically, these values are specified by the customer, an electrical engineer, or a systems engineer.
- Consider worst-case scenarios for generator load. Plan generator size based on a power-loading plan that includes the electrical requirements of all equipment installed at a site. Spec sheets will help in planning for worst-case scenarios, such as all transmitters keyed simultaneously at a site.
- Consider site expansion. As new or additional equipment is installed or existing equipment is upgraded, planning for 30% power growth is reasonable.
- Consider whether the generator load will be three-phase or single-phase. Many generators are rated for three-phase operation and must be derated when used in a single-phase application. Consult the manufacturer's recommendations when using a generator for a single-phase application to ensure the maximum load requirements are met. Three-phase operations require load balancing across the phases. Balance transmitters, electric heaters, HVAC units, and other high-current items across all three phases when planning circuit connections supported by the generator.
- Consider the site's physical and environmental factors. Generators may require derating depending on altitude, temperature, and fuel type. Follow the manufacturer's recommendations for deration.

- The generator **shall not** be used under conditions that exceed the manufacturer's specifications for the particular generator.

6.9.2 Generator Placement

All generators **shall** have an adequate supply of fresh air to operate properly according to the manufacturer's guidelines. Sufficient airflow is crucial for safe and efficient combustion, as well as for cooling the engine and generator. The generator's size often determines the type of cooling required. Typically, generators under 7.5 kW are air-cooled, while those above 7.5 kW are water-cooled. Both types need sufficient airflow to cool effectively. The manufacturer's instructions will specify the required airflow rate.

NOTE: The type of fuel used for a generator can influence the height of the fuel source relative to the generator. A gravity-fed liquid fuel source, such as some diesel configurations, may require the tank to be positioned higher than the fuel inlet. For certain LPG or LNG fuel sources, the generator might need to be mounted higher than the fuel source outlet. Refer to the manufacturer's installation instructions for specific requirements when installing the fuel tank.

6.9.2.1 Generators Located Indoors

For generators located indoors, such as within a separate structure or inside the site building, the following requirements **shall** be met:

- Personnel safety **shall** be prioritized to prevent injuries and minimize hazards. Some installations may expose engine parts or exhaust system components due to a lack of protective housing, posing a potential danger. Guards or shields **shall** be installed over exposed moving engine parts that pose safety risks to personnel.
- The generator **shall** be placed in a location accessible only to authorized personnel.
- Provide adequate space—generally 914 mm (3 ft) on three sides— for generator service. NFPA 70-2026, state, and local codes may have additional guidelines and **shall** be consulted.
- To mitigate vibration and noise transfer to the structure and surrounding area, the concrete foundation for the generator should be separate from the structure, or other vibration-isolation mechanisms should be used.
- All manufacturers' installation recommendations **shall** be followed to ensure adequate ventilation, fuel supply, and engine exhaust.
- Size the fresh air intake, radiator exhaust, and fuel exhaust ports according to manufacturer guidelines, and ensure they are properly maintained.
- An automatic louver or shutter system should be installed on the exterior of the radiator exhaust duct. The louver or shutter system should open and close automatically based on the generator's operating state.
- An automatic louver or shutter system should be installed on the fresh-air intake to close the duct when not in use. The louver or shutter system should open and close automatically based on the generator's operating state.
- Adequate fresh air supply **shall** be evaluated. Insufficient fresh air can cause harmful exhaust fumes or gases to enter the room or building through doors, windows, and/or vent pipes. Follow the manufacturer's guidelines and check local codes for recommendations and additional guidance.
- Providing a sufficient supply of fresh air is crucial. Without it, air may be pulled in through doors or existing vent pipes, causing downdrafts. This can bring unwanted or dangerous fumes and gases back into the building, which is especially risky in occupied areas. Always consult local codes for guidance and recommendations.
- Fuel supply lines **shall** be routed and installed in accordance with the manufacturer's recommendations to prevent potential damage.
- The engine exhaust system pipe and muffler **shall** comply with all manufacturer's recommendations.
- The engine exhaust **shall** be equipped with a rain cap.

- Warning signs and hearing protection **shall** be provided in areas where noise levels exceed 85 dBA (A-weighted measurement).
- In areas where the noise levels exceed 85 dBA, warning signs and hearing protection **shall** be provided.

IMPORTANT: Due to the potential of excessive generator heat, the flammability of materials used in the construction of the indoor generator room **shall** be considered.

6.9.2.2 Generators Located Outdoors

For outdoor generators, the following requirements **shall** be met:

- The generator **shall** be housed in a sufficiently rugged enclosure to protect the unit, especially the radiator and fuel tank (if part of the generator), from weather, animal or insect entry, and tampering.
- The generator **shall** be placed inside a fenced area, with enough space between the fence and the equipment for servicing.
- A muffler **shall** be used to reduce noise. If the generator is installed near occupied buildings, a muffler appropriate for residential areas **shall** be used.
- The engine exhaust **shall** be equipped with a rain cap.
- Position the generator to shield housing, intakes, and cooling systems from excess dust and moisture. Also, place the generator to prevent exhaust gases from entering the site structure or nearby buildings.
- Position the generator to ensure adequate ventilation, as recommended by the manufacturer.
- In colder climates, other considerations may apply, such as installing an engine block heater, using fuel stabilizers, or meeting other installation requirements.
- Appropriate consideration **shall** be given to the grade concerning the fuel source and inlet.

6.9.3 Fuel Supply for Generators

Generators can operate on various fuels, including diesel, liquid propane, gaseous propane, natural gas, or gasoline. NFPA 30, NFPA 37, NFPA 54, and NFPA 58 should be followed as applicable to the fuel supply type and storage system used. Other state, provincial, and local fueling requirement codes must be followed and may vary by state or locality. In locations outside the USA, all relevant codes from the AHJ **shall** be observed.

Choose a generator based on the most common and practical fuel source available in the area. When available, utility-provided natural gas offers the most reliable fuel source and removes concerns about installing and maintaining fuel storage tanks.

IMPORTANT: CFR 47 112, NFPA 30, and OSHA 1910.106 may impose additional requirements for specific facility types, bulk fuel storage tanks, and installations in or near protected areas.

In general, the following fueling considerations **shall** be observed:

- **Liquefied Petroleum Gas (LPG)**: LPG, commonly known as propane, is readily available and easily transported to remote sites. It is considered an excellent all-around backup generator fuel. An LPG-configured generator should be considered.
- **Diesel and gaseous propane:** These fuels are not ideal for colder climates. Diesel needs regular anti-bacterial treatment, water drainage, and must be periodically replaced with fresh fuel. Because of contamination concerns, diesel generators are banned for new systems on US Federal lands.
- **Natural gas:** Some installations may require a reservoir tank in addition to the supply line. The power output of natural gas generators may be reduced by 20% compared to gasoline-fueled generators. Follow the manufacturer's specifications when output derating is needed with natural gas as the fuel source.
- **Gasoline:** Gasoline is usually not a good fuel for remote generators. It is highly flammable and has limited storage life. Stale gasoline can cause difficult or failed starts of generator engines.

- In case of a fuel spill, EPA (or equivalent) rules **shall** be followed. All spills **shall** be mitigated and cleaned up according to applicable rules and regulations.
- Fuel storage tanks are required for all fuels except utility-provided natural gas. Some natural gas utilities may offer a storage tank as a backup during a utility outage. In all cases, manufacturer specifications for generators and tanks regarding fuel supply lines **shall** be followed.
- All bulk fuel storage tanks **shall** be listed for the specific fuel type for which they are intended.
- All above-ground bulk fuel storage tanks **shall** be secured to concrete pads using captive hardware.
- Above-ground bulk fuel storage tanks in flood-prone areas should be secured with a safety cable around the tank, attached to a stable anchoring device in the soil, to prevent the tank from detaching and floating away during flood conditions.
- Bulk liquid fuel storage tanks **shall** be equipped with secondary containment capable of retaining 110% of the volume of the largest single container within the containment structure and with interstitial monitoring devices capable of detecting a leak in the primary or secondary containment system unless tertiary containment is provided.
- When external secondary containment, such as dikes, curbs, and runoffs, is used, it **shall** be designed to handle storm water and debris.
- Where required by federal regulations or local codes, fuel lines or other system components that extend beyond the storage tank secondary containment area **shall** be designed with secondary containment.
- All fuel lines **shall** be protected within the fuel storage area and along the route to the generator. Location and installation of the fuel tank and fuel lines **shall** meet all applicable environmental, building, and fire safety codes.
- Externally located bulk fuel storage tanks **shall** be enclosed within a fenced or protected area to prevent damage and unauthorized access.
- For bulk liquid fuel storage tanks, the minimum recommended distance between the storage tank and a fence or important building is 1.5 m (5ft), depending on the storage tank size. See NFPA 30-2024 for additional details.
- For LPG bulk fuel storage tanks, the minimum recommended distance from the tank to a fence is 1.2 m (4 ft). The minimum recommended distance between the bulk fuel storage tank and the site building is 3 m (10 ft). See NFPA 58-2024 for additional details.
- LPG fuel tanks **shall** be equipped with a fuel vent pressure relief valve. The relief valve vent **shall** be directed away from the tank, sources of ignition, and flammable material.

6.9.4 Transfer Switch

A transfer switch **shall** be installed to switch between commercial power and standby power. This switch is generally co-located with the site electrical service panel. The following considerations **shall** be observed:

- The switch **shall** have an ampere rating equal to or greater than the circuits to be transferred.
- The transfer switch is generally located inside a building; however, if enclosed in an approved watertight housing, it may be located outside.
- Where required by applicable codes, a disconnect switch **shall** be provided in the feeder cabling between the generator and the transfer switch. This switch facilitates generator servicing and provides an additional safety device to prevent AC power backfeed into the commercial service.
- The neutral-ground bond **shall not** be made in the transfer switch.
- Transfer switch installation **shall** comply with the manufacturer's recommended installation guidelines.
- Installations **shall** meet all applicable national and local codes, such as the CEC, IEC, NFPA 70-2026, and NFPA 110-2025.
- Surge suppression **shall** be installed. See Chapter 7, “Surge Protective Devices.”

6.9.5 Electrical Wiring Considerations

When designing the interconnection wiring between the generator, transfer switch and site AC mains, the following considerations **shall** be observed:

- **Interconnection Wiring:** Two sets of circuit conductors **shall** be run between the transfer switch and the generator. One set is for low-voltage control and alarm circuits, while the second set is for the electrical service. Each set **shall** be installed in its own dedicated conduit or raceway.

IMPORTANT: Control and alarm circuits **shall not** be installed within the same conduit or raceway as the electrical service. Refer to NFPA 70-2026, Article 725, for additional information.

- **Conduit and Raceway Sizing/Routing:** Conduits and raceways **shall** be sized and routed in accordance with NFPA 70-2026 and other relevant national, state, or local codes.
- **Dedicated Generator Circuit:** A dedicated, protected electrical circuit **shall** be provided at the generator for engine/battery heaters and service equipment. If located outdoors, this circuit **shall** be equipped with ground-fault protection. Refer to “Outdoor Electrical (Branch Circuits)” on page 6-10 for further details.

6.9.6 Installation Plan

Standby generator systems require careful planning and precise installation to ensure long-lasting, reliable operation. A qualified engineer or inspector **shall** review all aspects of the installation, including generator placement, sizing and positioning of vents for airflow, fuel storage or supply, exhaust system placement, and electrical connections, to verify compliance with applicable NFPA 70-2026, NFPA 110-2025, and relevant national, state, and local codes.

Consider the following general guidelines:

- **Exhaust Gas Dispersion:** The exhaust system **shall** be designed so gases disperse into the open atmosphere, preventing them from being drawn or blown into building interiors. Precautions **shall** be taken when generators are installed within or near occupied structures.
- **Foundation Sizing:** The foundation size **shall** be determined by the geographic area of installation.
- **Access for Maintenance:** Existing door sizes in the finished structure **shall** allow for the removal or replacement of the generator's largest subassembly.
- **Vent Hood Design:** Rain hoods over intake and exhaust vents **shall** be designed to withstand local extreme conditions. When high snowfall or drifting may occur, vent hoods should be installed at an appropriate height and directed away from the elements.

NOTE: For radiator-cooled generators, the cooling air inlet **shall** be at least 1.5 times the area of the radiator duct receptacle. The flow of cooling air and heated air **shall** be controlled by automatically operated louvers.

- Seismic Considerations: Installations in earthquake-prone areas (Seismic Design Category D or higher) may require specialized design and installation features. This is especially important for fuel lines, fuel storage, exhaust systems, and muffler supports. Appropriate geological information should be consulted regarding seismic considerations.
- Indoor Installations: Indoor installations **shall not** exceed maximum floor loading capacities. Shock mounts are recommended and may be required on some installations to minimize vibration transfer.
- Battery Placement: Batteries that are not essential to generator operation **shall not** be located within the generator room unless the room is adequately ventilated.
- Ventilation Requirements: Follow the manufacturer's guidelines and specifications to ensure adequate air exchange in the generator room.

6.9.7 Alarms, Meters and Gauges

NOTE: To ensure continuous alarm reporting, remote alarm systems **shall** operate independently of the power sources they monitor. Alarms **shall** transmit even if a phone line is interrupted, the primary power source fails, or the common battery bank is depleted.

- All generators **shall** be equipped with an engine high-temperature alarm/shutdown and a low-oil-pressure alarm/shutdown.
- All generators **shall** be equipped with an oil pressure gauge.
- Frequency, voltage, and ammeters are recommended and, if installed, **shall** be located at either the generator control panel or the automatic transfer switch (ATS).
- Additional meters, gauges, remote alarms, and engine and battery heater options **shall** be evaluated. When implemented, these alarms provide early detection of potential issues, helping significantly reduce costs and downtime.

IMPORTANT: Alarm circuits for external generators **shall** be surge protected as described in Chapter 7, “Surge Protective Devices”

6.9.8 Generator Installation Grounding

All generators, fuel storage tanks above or at grade level and fences discussed within this chapter **shall** be grounded as described in the following subsections.

6.9.8.1 Indoor Generator Grounding

Generator systems located indoors **shall** be bonded to the internal bonding and grounding system as follows:

- The generator **shall** be bonded using the manufacturer's specified chassis grounding connection to the internal Primary Bonding Busbar (PBB), a Secondary Bonding Busbar (SBB), the Internal Perimeter Bonding Bus (IPBB), or the Halo Ground Ring as detailed in Chapter 5, “Internal Bonding and Grounding (Earthing).”
- If not integrated into the generator unit, the generator transfer switch **shall** be bonded to the interior PBB, an SBB, the IPBB, or Halo Ground Ring as detailed in Chapter 5, “Internal Bonding and Grounding (Earthing).”

6.9.8.2 Outdoor Generator Grounding

Generator systems located outdoors **shall** be bonded to the external grounding electrode system according to methods specified in “Grounding (Earthing) Generators External to the Building” on page 4-99. In addition, the following **shall** be observed:

- The generator **shall** be bonded to the external grounding electrode system using the manufacturer's specified chassis grounding connection, as detailed in Chapter 4, “External Grounding (Earthing) and Bonding.”
- Separate metallic fuel tanks **shall** be bonded to the external grounding electrode system as detailed in “Fuel Tank Bonding” on page 4-121.
- Metallic fencing surrounding the generator installation **shall** be bonded to the external grounding electrode system as detailed in “Fence And Gate Grounding and Bonding” on page 4-109.
- If not integrated into the generator unit, the generator transfer switch, typically installed in the site building or shelter, **shall** be bonded to the interior Primary Bonding Busbar (PBB), a Secondary Bonding Busbar (SBB), the Internal Perimeter Bonding Bus (IPBB), or Halo Ground Ring as detailed in Chapter 5, “Internal Bonding and Grounding (Earthing).”

6.9.9 Generator Installation

The generator system **shall** be installed in accordance with the manufacturer's recommended guidelines and applicable AHJ regulatory codes. Additionally, consider the following:

- Follow the manufacturer's installation recommendations and guidelines.
- Foundations for outdoor installations **shall** be sized to support the weight (check local codes for special considerations).
- All related components, including the generator, fuel tank(s), and transfer switch/control panel, **shall** be securely attached to their designated foundations or support structures.
- Fuel lines **shall** be adequately secured, protected, and free of leaks.
- All system components must be installed to enable safe and easy servicing while the equipment is running.
- For installations in earthquake-prone areas (Seismic Design Category D or higher), additional supports may be required for components such as fuel lines, exhaust systems, and mufflers. Installation **shall** adhere to any additional manufacturer recommendations and local codes in these regions.
- For installations in earthquake-prone areas (Seismic Design Category D or higher), standby generators should be mounted on vibration isolators. Additionally, flexible cables should be used for electrical and grounding connections, and flexible tubing should be provided for fuel systems.

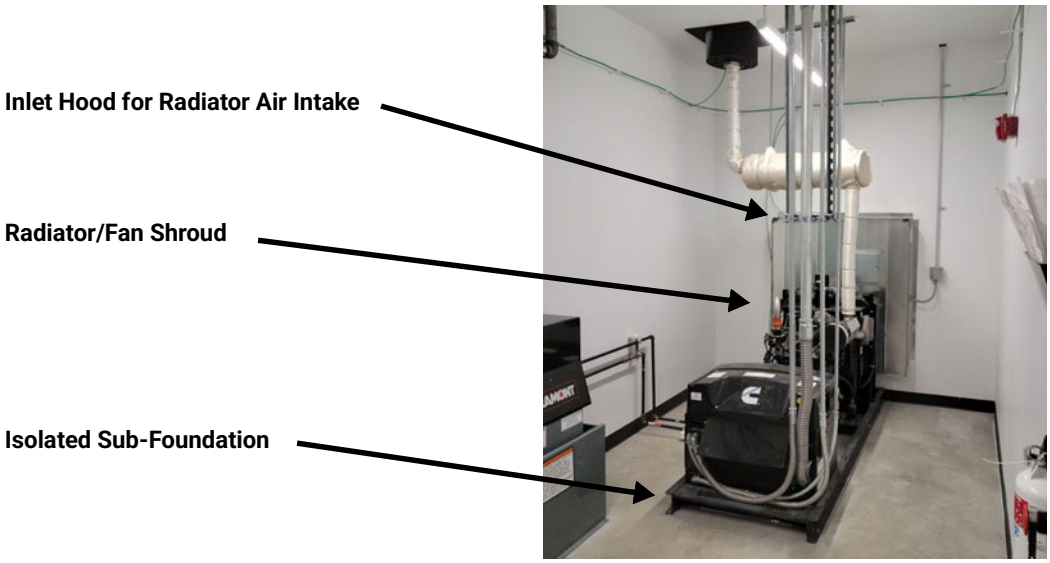


Figure 6-23. Completed Installation of Typical Generator System

6.9.10 Generator Startup

Generators are usually shipped without fluids (oil and coolant) and with fuel lines disconnected. Therefore, an authorized manufacturer's service representative must review the installation, make necessary preparations, and perform the initial startup.

Observe the following considerations:

- The manufacturer's startup recommendations **shall** be followed.
- All fluid levels **shall** be checked to ensure adequate supply before starting the generator.
- The generator **shall** be checked for correct voltage and frequency while operating with and without a load. Values **shall** be within the manufacturer's specifications and **shall not** vary more than 3% for rated voltage or 5% for rated frequency.
- All controls on the transfer switch/control panel **shall** be verified to ensure load pickup, transfer, re-transfer, and shutdown.

- The battery charger's charge rate should be checked.
- Set the exercise clock to local time after confirming the exercise operation. The clock should be programmed to run the generator for at least 30 minutes every 7 days. It is recommended to operate the generator under load.
- All alarm connections **shall** be verified and tested for functionality.
- The fuel and exhaust systems **shall** be checked for leaks.
- Check to ensure all safety shields and covers are in place before starting the generator.
- If a UPS system is used, tests **shall** be performed to verify that the UPS functions correctly when powered by the generator. If issues arise, the frequency and voltage tolerances may need to be reviewed.

6.9.11 Generator Safety

In general, the following safety precautions **shall** be observed:

- All manufacturers' safety guidelines **shall** be followed during installation and operation.
- All moving parts **shall** be enclosed or protected.
- Safety shields and covers **shall** be in place except as necessary for service.
- Hot surfaces, such as engine exhaust pipes and mufflers, **shall** be protected to prevent accidental contact by foreign material or persons.
- “No Smoking,” “Caution: Hearing Protection Required,” and “Automatic equipment, may self-start” signs **shall** be posted within a generator room or adjacent to a generator when located in a room with other equipment.
- Points where exhaust system components pass through walls **shall** have approved feedthrough thimbles installed.
- Fuel lines **shall** be protected from damage.
- Electrical circuits **shall not** be exposed.
- Ensure exhaust gases disperse and do not draw back into the building interior.
- Generators installed in earthquake-prone regions **shall** comply with all relevant safety regulations for such locations.

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CHAPTER 7

Surge Protective Devices

This chapter includes the following topics:

- “Introduction to Surge Protection” on page 7-1
- “Conformance with UL 1449 5th Edition - AC Surge Protective Devices” on page 7-5
- “Technologies Available” on page 7-5
- “AC Power Surge Protection Requirements” on page 7-5
- “AC Power SPD Installation Requirements” on page 7-31
- “Communication Circuit Protection” on page 7-33
- “Video, Security, and Access Control” on page 7-48
- “Broadband Point-to-Point and Multi-point Wireless Links” on page 7-50
- “Satellite and Television Broadband Services” on page 7-53
- “RF Surge Protection” on page 7-53
- “Surge Protection for Dispatch Centers and Operator Positions” on page 7-66
- “DC Systems Surge Protection” on page 7-68
- “AC Power Line SPD Test Certification Requirements and Test Methods” on page 7-73
- “Electromagnetic Pulse (EMP) Considerations” on page 7-75

NOTE: The term Transient Voltage Surge Suppressor (TVSS) has been replaced with Surge Protective Device (SPD).

7.1 Introduction to Surge Protection

Surges and transient power anomalies are potentially destructive electrical disturbances; the most damaging are overvoltage occurrences and short-duration overvoltage events. Sometimes referred to as “spikes,” high-energy transient power anomalies can arise from inductive load switching, other events within the power system, or capacitive and inductive coupling from environmental events such as nearby lightning activity. Environmental and inductive power anomalies are wide-band occurrences with a frequency range from near DC to well into the high frequency (RF) spectrum.

Surge Protective Devices (SPDs) are required for all communication sites, enclosures and facilities housing critical electronics, networking, and RF equipment (see APCO ANS 2.106.1-2019, ATIS-0600321.2020, ATIS-0600334.2019(R2024), FAA-STD-019G, IEEE 1692-2023, NFPA 780-2026, NFPA 1221-2019, and NFPA 1225-2022). Installing SPDs in-line with critical network equipment helps mitigate spurious over-voltages on conductors entering the communications enclosure. Surge protection reduces risk of injury to personnel, equipment damage, and equipment and/or system downtime. Although lightning may cause the most visible damage, it is not the predominant cause of transient voltages.

IMPORTANT: All electrically conductive points of entry (for example, AC power, telephone, LAN, signal/control, RF, and video security) into a site **shall** be protected from surges using an SPD.

Transient voltage sources include, but are not limited to, the following (see IEEE C62.41.2-2002 and MIL STD 188-125-1 for more information):

- Power company switching
- Generator transfer
- Shared commercial feeders with poor line regulation
- Load switching
- Fault currents
- HVAC units
- Heating elements
- Power tools
- Electric motors
- Fluorescent lighting
- Elevators
- Switching of inductive loads
- Lightning activity
- Electromagnetic Pulse (EMP)

The four major site surge entry points listed below and shown in Figure 7-1 require surge protection to effectively protect a site and reduce the probability of damage.

1. AC Power
   - External branch circuits or feeders
   - Generator
   - Main utility service
2. Data/Security/Telephone
   - Access control
   - Broadband
   - Control
   - Data circuits
   - LAN
   - Video security
3. RF Cabling
   - Antenna transmit and receive lines
   - Cable TV service
   - GPS
4. Tower Lighting Systems
   - AC power
   - Control and signal

IMPORTANT: SPDs alone cannot adequately protect a communications site. Proper grounding and bonding **shall** be incorporated at a communications site to provide an adequate level of protection. See Chapter 4, "External Grounding (Earthing) and Bonding", and Chapter 5, "Internal Bonding and Grounding (Earthing)", for bonding and grounding details and requirements.

NOTE: In this manual, high lightning areas are areas with lightning flash density greater than two flashes/km^2/year. See "Lightning Activity and Exposure" on page 4-4.

The requirements presented in this chapter provide suitable protection for communications equipment and sites in most areas. Areas subject to high lightning activity require additional SPD design considerations as described in this chapter.

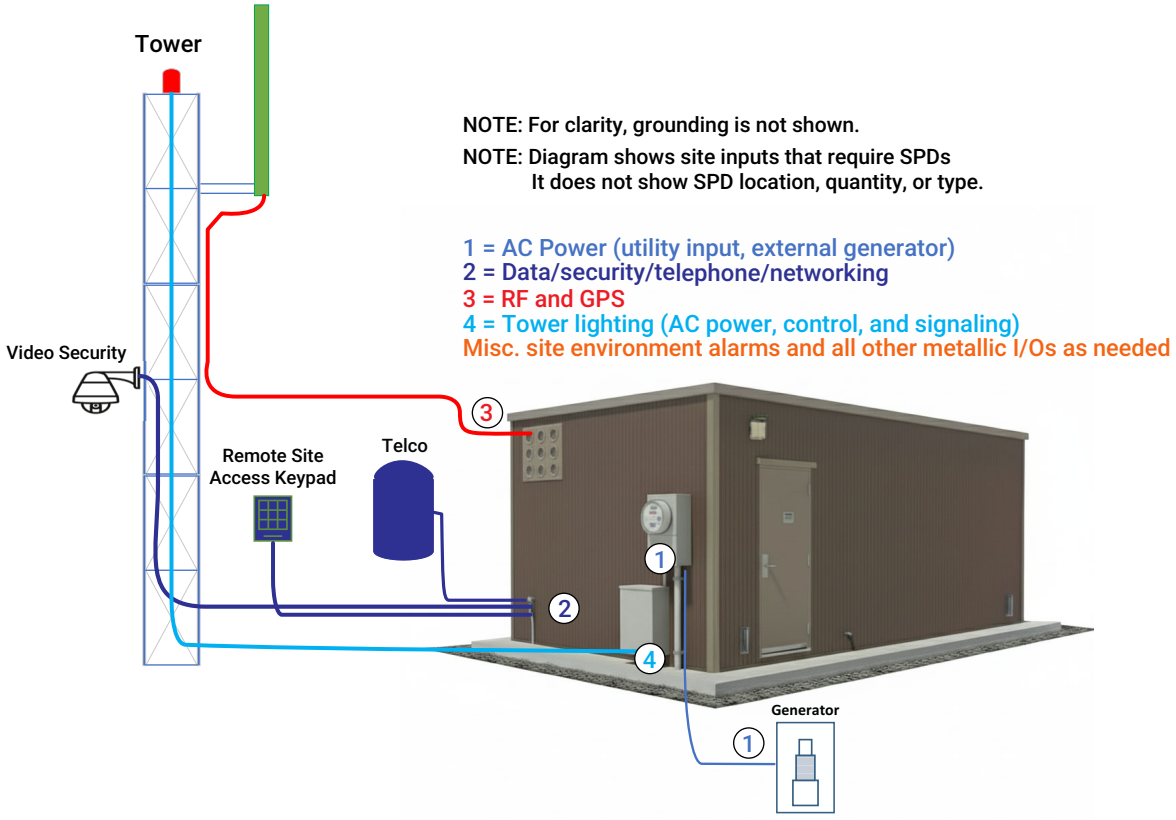


Figure 7-1. Overview of Site Inputs Requiring Surge Protective Devices

The goal of surge suppression in low voltage circuits (less than 1000 volts) is to maintain system availability. Failure of a single SPD at a communications site leaves the site vulnerable to further damage. To maintain adequate protection for mission-critical applications, it is necessary to install multiple layers of protection in some cases (AC power, for example) as presented in this chapter.

The minimum SPD installation requirement for AC at a typical communications facility is shown in Figure 7-2 and Figure 7-3.

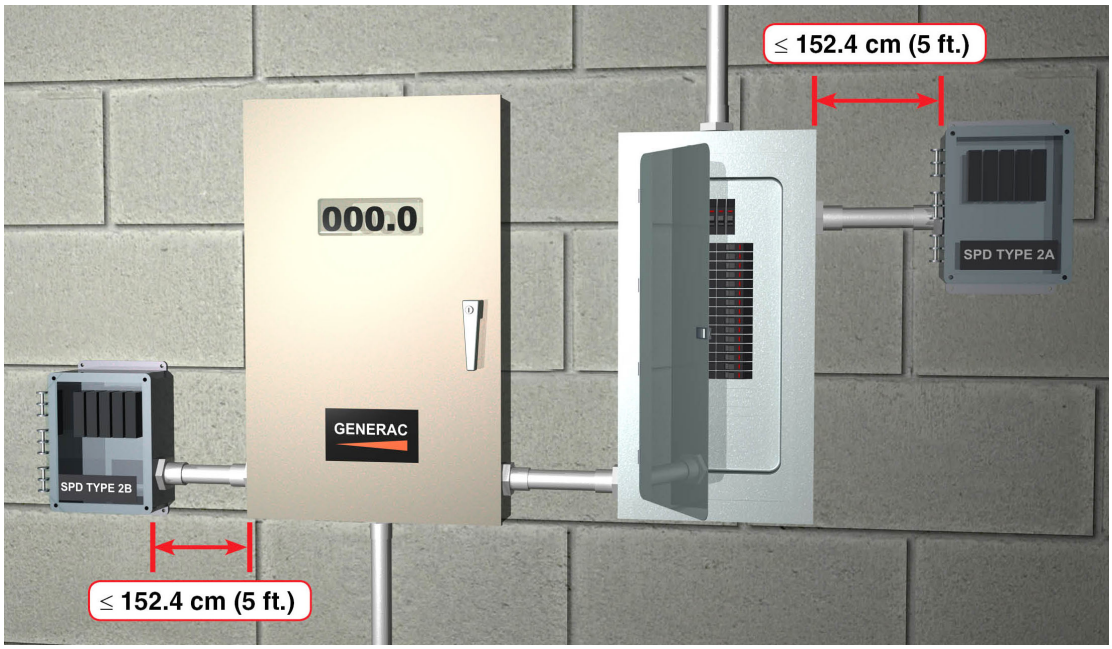


Figure 7-2. Minimum AC Surge Protection Installation Complement for a Typical Communications Site

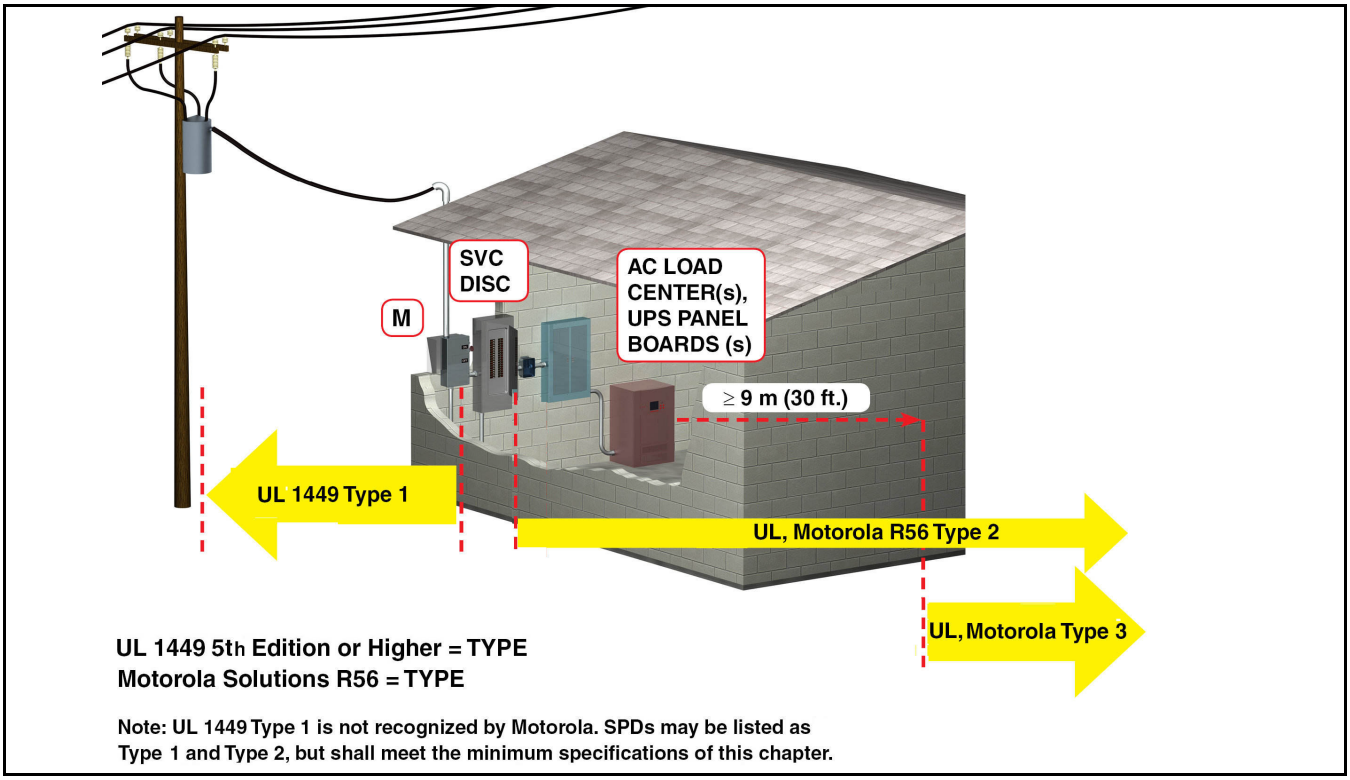


Figure 7-3. AC Surge Protection Category, Location and Type Definitions

NOTE: UL Type 1 SPDs **shall not** be substituted in place of Type 2A or Type 2B SPDs approved by Motorola Solutions.

7.2 Conformance with UL 1449 5th Edition - AC Surge Protective Devices

Underwriters Laboratories standard 1449 (UL 1449) is the primary recognized safety standard for SPDs. It describes materials and installation requirements for SPDs used for the protection of AC electrical circuits. The standard, updated in 2021, is published as UL 1449 5th Edition, and is applicable to AC SPDs conforming to this manual.

NOTE: SPDs approved for international markets outside the applicability of UL 1449 5th Edition **shall** be certified to IEC 61643-1 or IEC 62368-1 (latest versions).

NOTE: The SPD type terminology used in this manual aligns with UL 1449 terminology.

7.3 Technologies Available

Several major SPD types are available. The most common and most reliable are the Metal Oxide Varistor (MOV) and the Silicon Avalanche Diode (SAD) types. These are ideal for protection of power and telephony or data circuits because of their fast response time and high energy-handling capability.

Although somewhat effective in specific applications, other components such as gas discharge tubes, spark gaps, surge relays, capacitors, and inductors, are not acceptable as power SPDs at communications facilities, because their typical response time is too slow.

It may be necessary to use more than one type of component in a protective device to obtain the best possible combination of SPD characteristics. The most common combination forming a “hybrid circuit” incorporates a high current but slower-acting component with a faster-acting but lower power-rated component. For AC power, this is typically a coordinated MOV and SAD combination.

CAUTION: Gap or Crowbar Type SPDs shall not be used as AC power line surge suppression, except where Common Mode (L-G, N-G) may be necessary.
Silicon Carbide, GAP, and Carbon Block surge components shall not be used for Normal Mode (L-L, L-N) AC line surge protection. These components will disconnect power from the load, resulting in reboots or requiring human interaction.

7.4 AC Power Surge Protection Requirements

Requirements for Motorola Solutions approved AC surge protection are detailed in Table 7-1 through Table 7-5, and “AC Power Line SPD Test Certification Requirements and Test Methods” on page 7-73. AC SPDs are low-impedance circuits when activated. By design, they help prevent overvoltage anomalies from reaching sensitive loads and shunt overcurrent through the neutral conductor to earth.

SPDs are required on all power conductors (service, feeders, and branch circuits) to and from communications facilities (see APCO ANS 2.106.1-2019, section 3.21; IEEE 1692-2023, section 11; NFPA 780-2026, section 4.19; NWSM 30-4106:2017, section 2.1; and TIA-607-E). All SPDs **shall** be installed per the manufacturer’s instructions.

The facility grounding and bonding systems **shall** be designed and implemented to help ensure that the electrical service, all SPDs, and the communications system components within the equipment area are at the same potential (see Chapter 4, “External Grounding (Earthing) and Bonding”, and Chapter 5, “Internal Bonding and Grounding (Earthing)”). This is critically important to help ensure maximum safety of personnel and maximum effectiveness of the SPDs.

The AC power SPDs **shall not** cause interruptions to the site power when they operate. To reduce this possibility, all AC power SPDs **shall** be designed for and installed as parallel devices. A suitable disconnecting means **shall** be provided to permit servicing. Alarms or remote monitoring to report a device failure are recommended.

IMPORTANT: All AC power SPDs used within the United States **shall** be UL 1449, 5th Edition (or later) listed (see NFPA 70-2026, Article 242.2).

7.4.1 AC SPD Requirements Based on Facility Description

Table 7-1 through 7-5 specifies the minimum AC power SPD requirements for various communications facilities. The voltage and phase requirements are site-specific and depend on the electrical service characteristics of the specific location.

IMPORTANT: If the configurations differ from those shown in Table 7-1 through 7-5, consultation with Motorola Solutions or another engineering firm is recommended.

IMPORTANT: All critical load panels, even when powered by a UPS, require the surge protective devices shown in the diagrams in this section.

Table 7-1. Required Surge Protective Devices For Standalone Building or Shelter

Service Configuration	Remote Disconnect	ATS (Utility Input)	Shelter Main Panel	Subpanel(s)	SPD at Equipment
Standalone Building or Shelter Without a Generator					
The main service disconnect and all panels are located within the same shelter. See Figure 7-4 on page 7-9.	-	-	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.
Standalone Building or Shelter with a Generator					
The main service disconnect and all panels are located within the same shelter. See Figure 7-5 on page 7-9; Figure 7-18 on page 7-18.	-	Type 2B or 2A	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.

Table 7-1. Required Surge Protective Devices For Standalone Building or Shelter (continued)

Service Configuration	Remote Disconnect	ATS (Utility Input)	Shelter Main Panel	Subpanel(s)	SPD at Equipment
Standalone Building or Shelter, Generator-Powered Only (no Utility)					
The site is powered by an onsite generator. There is no utility service to the site. See Figure 7-6 on page 7-10.	-	-	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.
Standalone Building or Shelter Without Local Generator Main Service Disconnect Located Remotely from Equipment Building					
Utility H Frame or Pole at fence or property line, or onsite power distribution building. The main disconnect and neutral-ground bond are at this location. See Figure 7-7 on page 7-10.	Type 2A or 2B is recommended if the distance between the remote location (H-Frame) and the building is greater than 15.25 m (50 ft) (Figure 7-7A)[1]. Per note 1, an SPD is not necessary at this location if an isolation transformer is installed (Figure 7-7B).	-	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.
Power supplied from a main building (for example, dispatch center, admin building, police station, etc.). In this configuration, the main building provides the generator backup. See Figure 7-8 on page 7-11	See Note 1 at end of table. A Type 2A or 2B SPD **shall** be installed on the panel supplying power to the remote radio building to prevent surges from backfeeding into the main building.	-	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.

Table 7-1. Required Surge Protective Devices For Standalone Building or Shelter (continued)

Service Configuration	Remote Disconnect	ATS (Utility Input)	Shelter Main Panel	Subpanel(s)	SPD at Equipment
Standalone Building or Shelter With Local Generator Main Service Disconnect Located Remotely from Equipment Building					
Utility H Frame or Pole at fence or property line, or onsite power distribution building. The main disconnect and neutral-ground bond are at this location. See Figure 7-9 on page 7-11 and Figure 7-10 on page 7-12.	Type 2B or 2A is recommended if the distance between the remote location (H-Frame) and the building is greater than 15.25 m (50 ft). An SPD is not necessary at this location if an isolation transformer is installed according to Note 1.	Type 2B or 2A if not already installed at the disconnect location (with or without an isolation transformer)	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.
Power supplied from a main building (for example, dispatch center, admin building, police station, etc.). In this configuration, the local generator provides the backup. See Figure 7-11 on page 7-12 and Figure 7-12 on page 7-13.	See Note 1 at end of table. A Type 2A or 2B SPD **shall** be installed on the panel supplying power to the remote radio building to prevent surges from backfeeding into the main building.	Type 2B or 2A	Type 2A	Not Required. A Type 2A or 2C device may be installed at subpanels for additional protection, especially in areas with high lightning activity.	Type 3 according to Table 7-4.
Standalone Temporary or Movable Sites (Site on Wheels – SOW)					
	Follow requirements for "Main Service Disconnect Located Remotely from Equipment Building" if the main service disconnect is located remotely.	-	Type 2A	-	Type 3 according to Table 7-4.
Standalone Cabinets					
	Follow requirements for "Main Service Disconnect Located Remotely from Equipment Building" if the main service disconnect is located remotely.	-	Type 2A	-	-

1. Motorola Solutions recommends installing an isolation transformer at the radio building where the neutral-ground bond is located remotely (greater than 15.25 m or 50 ft), such as with an H-frame, remote power building, main building, or similar installation. The isolation transformer recreates the neutral-ground bond locally at the building or shelter, thereby increasing the effectiveness of the building or shelter-mounted SPD.

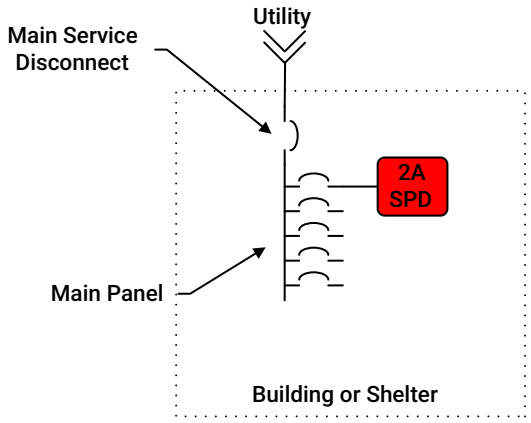


Figure 7-4. SPDs Required for a Standalone Building or Shelter Without a Generator

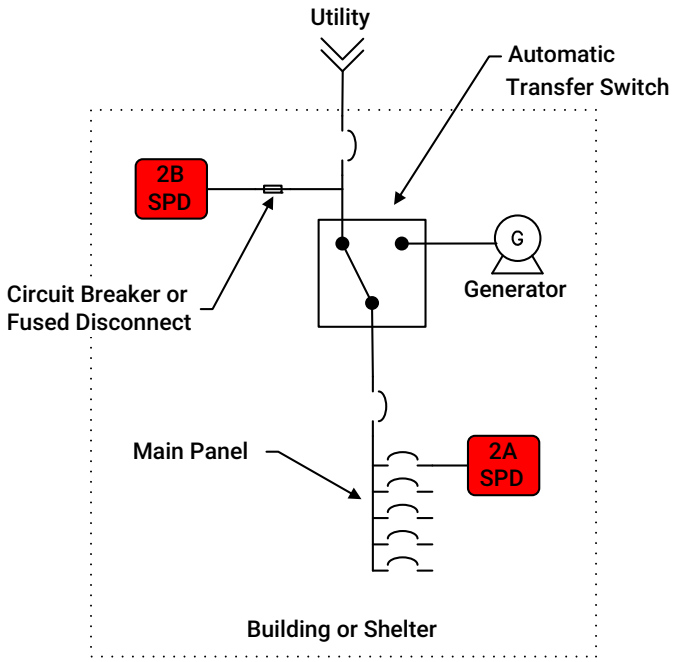


Figure 7-5. SPDs Required for a Standalone Building or Shelter With a Generator

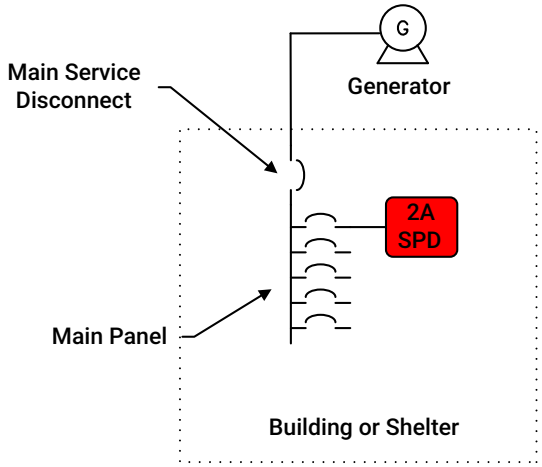


Figure 7-6. SPD Required for a Standalone Building or Shelter With Generator Power Only

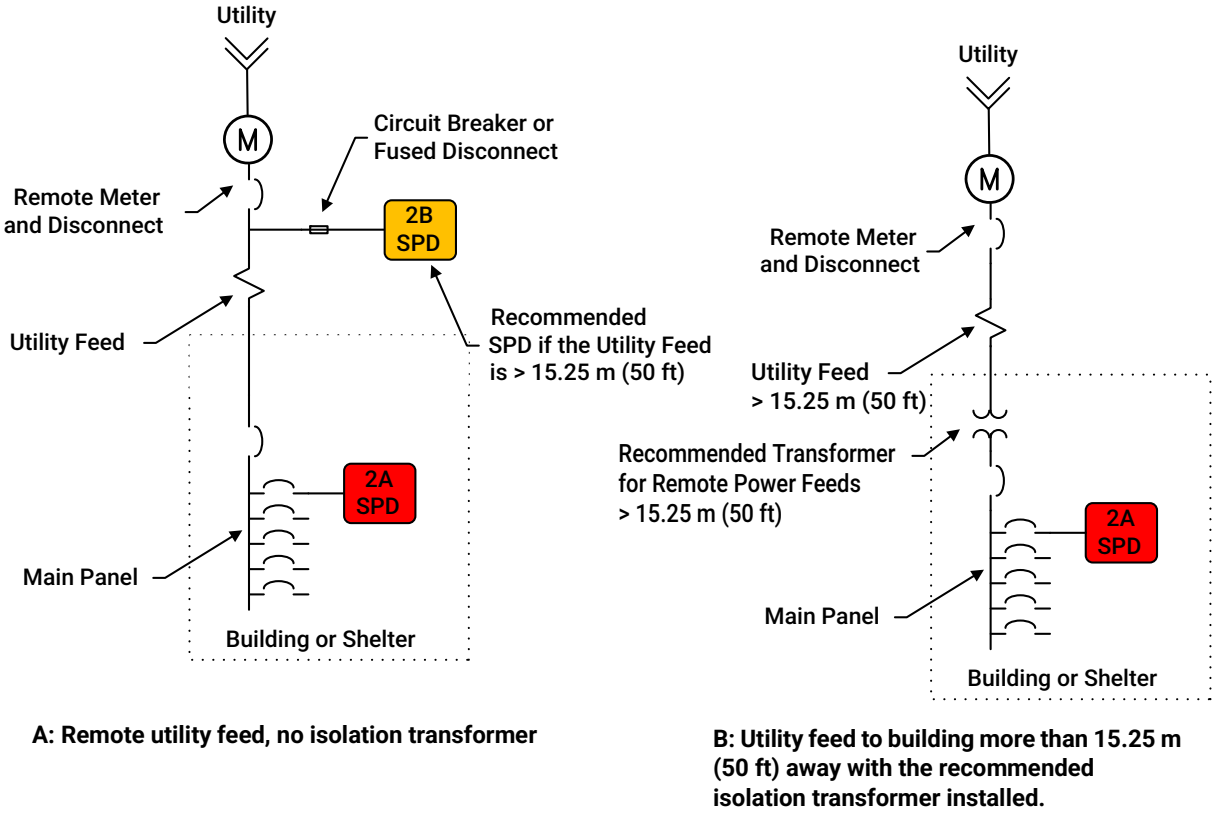


Figure 7-7. SPD Required for Standalone Building Without Local Generator, Main Service Disconnect Remote from Building

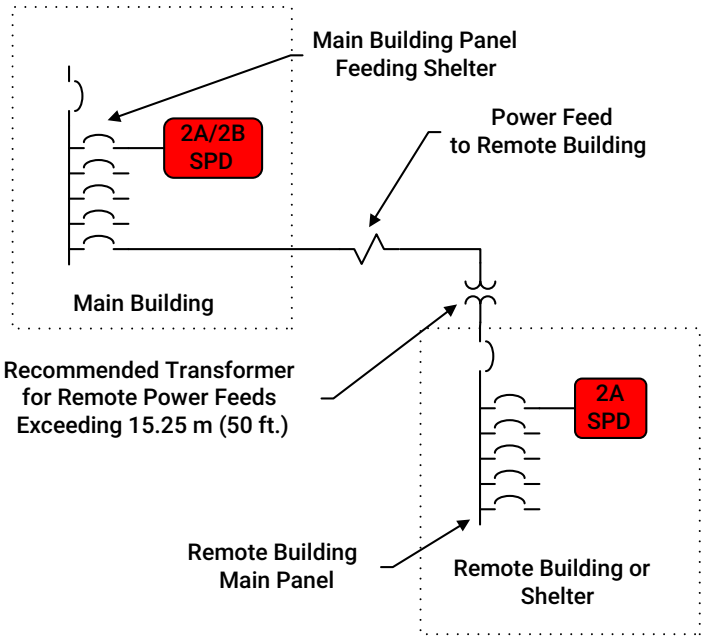


Figure 7-8. SPDs Required for Standalone Building Without Local Generator, Power Supplied from Main Building Onsite

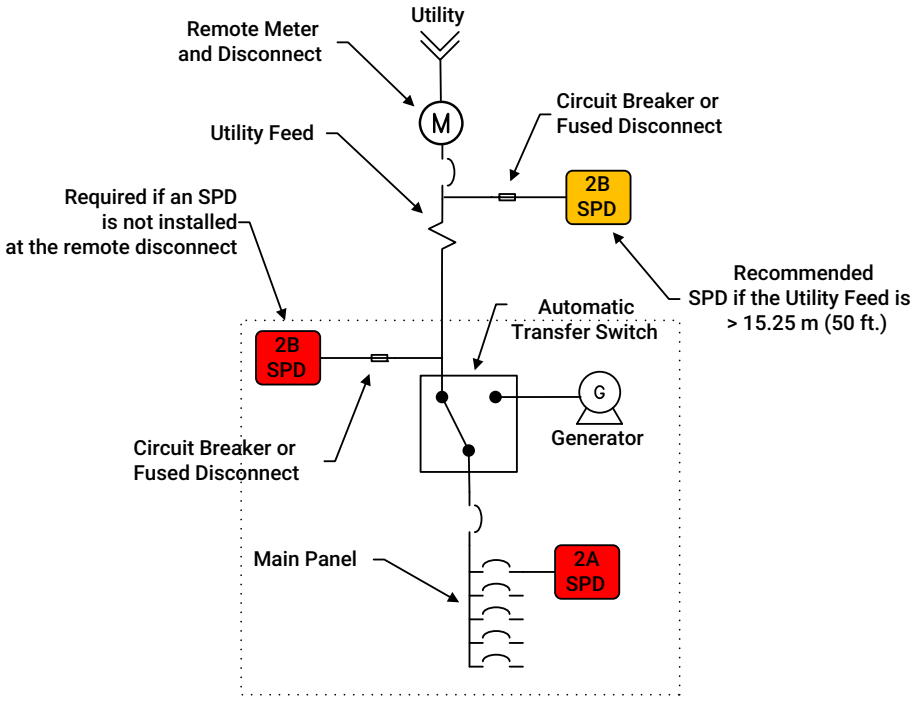


Figure 7-9. SPDs Required for Standalone Building With Local Generator; Main Service Disconnect Remote from Equipment Building

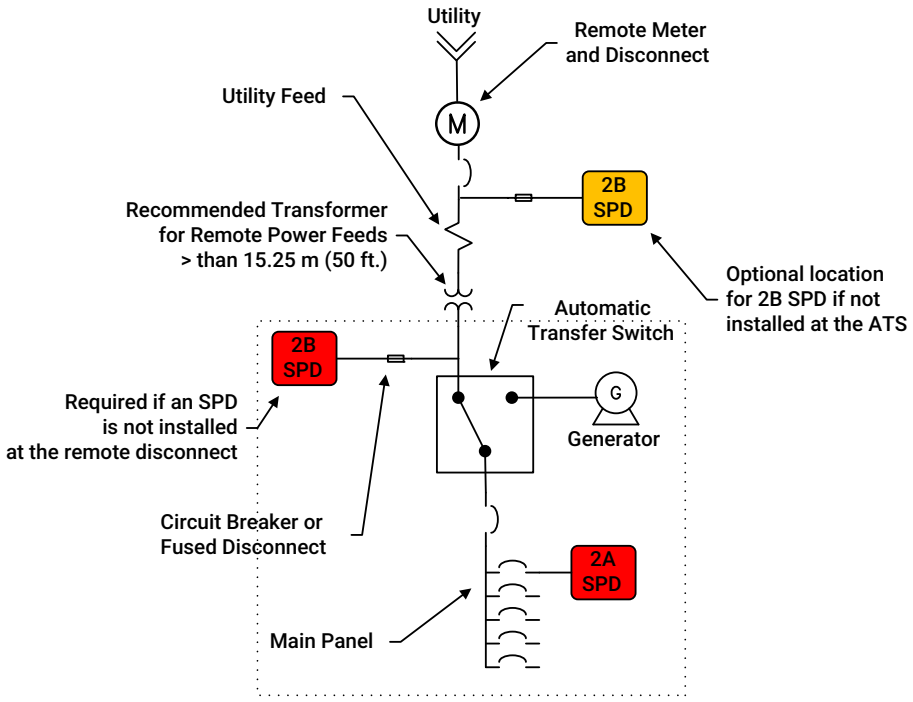


Figure 7-10. SPDs Required for Standalone Building With Local Generator; Main Service Disconnect Remote from Equipment Building

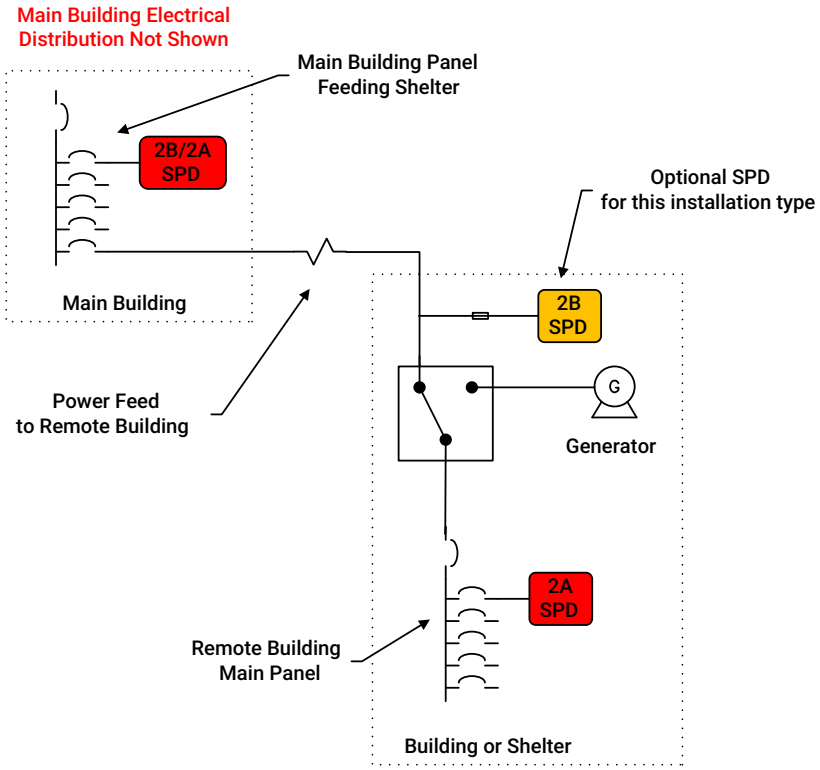


Figure 7-11. SPDs Required for Standalone Building With Local Backup Generator; Power Supplied by Main Building Onsite

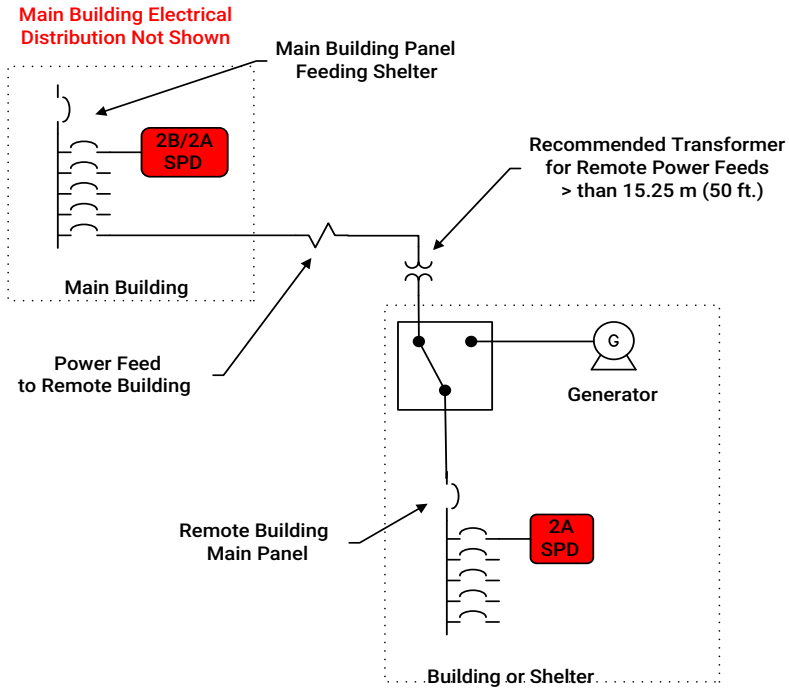


Figure 7-12. SPDs Required for Standalone Building With Local Backup Generator; Power Supplied by Main Building Onsite; Remote Power Feed has Isolation Transformer

Table 7-2. Required Surge Protective Devices For Commercial Buildings and Similar Larger Structures

Service Configuration	Electrical Entrance	ATS	Main Equipment Room Critical Loads Panel	Equipment Room Critical Loads Subpanels	SPD at Equipment
Equipment Area Located within a Larger Structure Generator Backup Power Provided at the Building Level					
The main service disconnect is located in another part of the same structure. Generator backup power is provided at the building level. See Figure 7-13 for the typical SPD installation.	As required by applicable code (see NOTES 2 and 3 below). A Type 2B or 2A is recommended in common installations.	As required by applicable code (see NOTES 2 and 3). A Type 2B or 2A is recommended in common installations.	Type 2A or 2C. A Type 2A is required if a 2A or 2B is not installed at the electrical entrance, or cannot be verified; otherwise, a Type 2C is permitted.	As required by code (see NOTES 2 and 3). A Type 2C or 2A is required if the distance to the Equipment Room Critical Loads Main Panel exceeds 15.25 m (50 ft) (see NOTE 4).	Type 3 according to Table 7-4 on page 7-18.
Equipment Area Located within a Larger Structure Generator Backup Power Provided at the Equipment Room Level					
The main service disconnect is located in another part of the same structure. See Figure 7-14 for the typical SPD installation.	As required by applicable code (see NOTES 2 and 3). A Type 2A or 2B is recommended in common installations.	Not Required.	Type 2A or 2C. A Type 2A is required if a 2A or 2B is not installed at the electrical entrance, or cannot be verified; otherwise, a Type 2C is permitted.	As required by code (see NOTES 2 and 3). A Type 2C or 2A is required if the distance to the Equipment Room Critical Loads Main Panel exceeds 15.25 m (50 ft) (see NOTE 4).	Type 3 according to Table 7-4 on page 7-18.
NOTE 2: See NFPA 70-2026, Article 708.8 and NFPA 1221-2019, section 4.7.6.2. **NOTE 3**: Consultation with Motorola Solutions Engineering or another engineering firm may be required. **NOTE 4:** The system engineer, customer, and/or AHJ should determine critical equipment.					

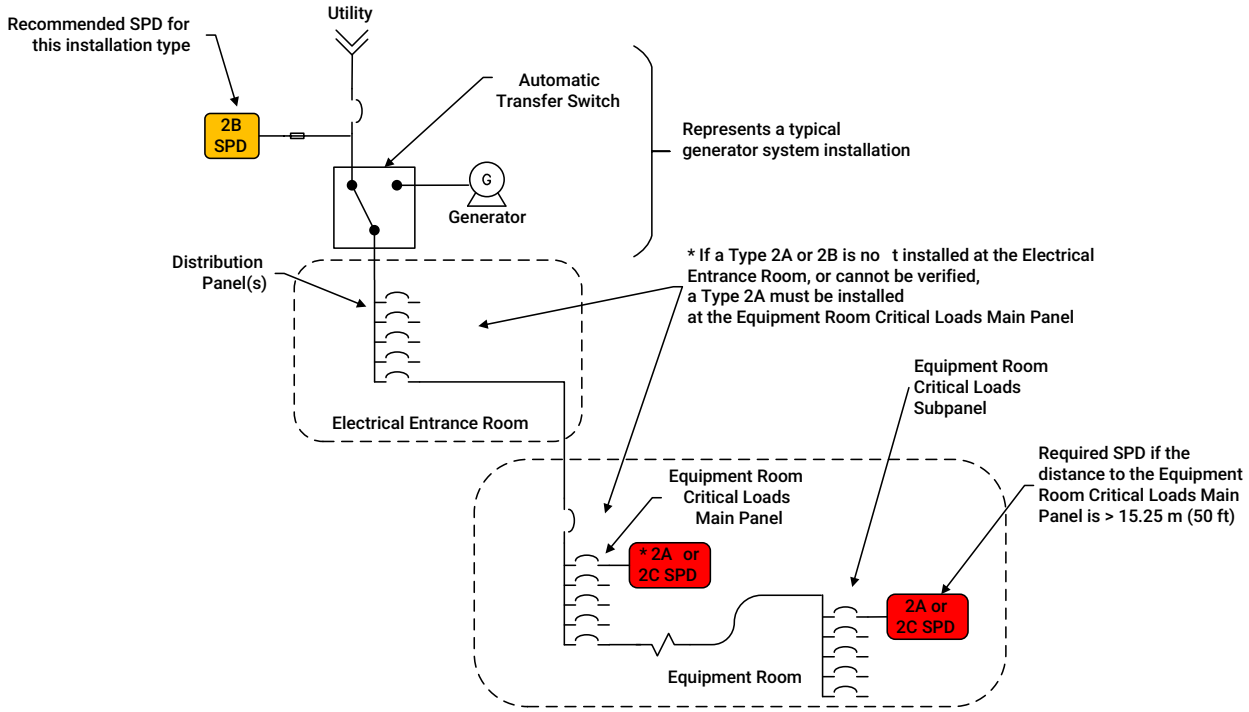


Figure 7-13. SPDs Required for Equipment Area Located within a Larger Structure; Generator Backup Provided at Building Level

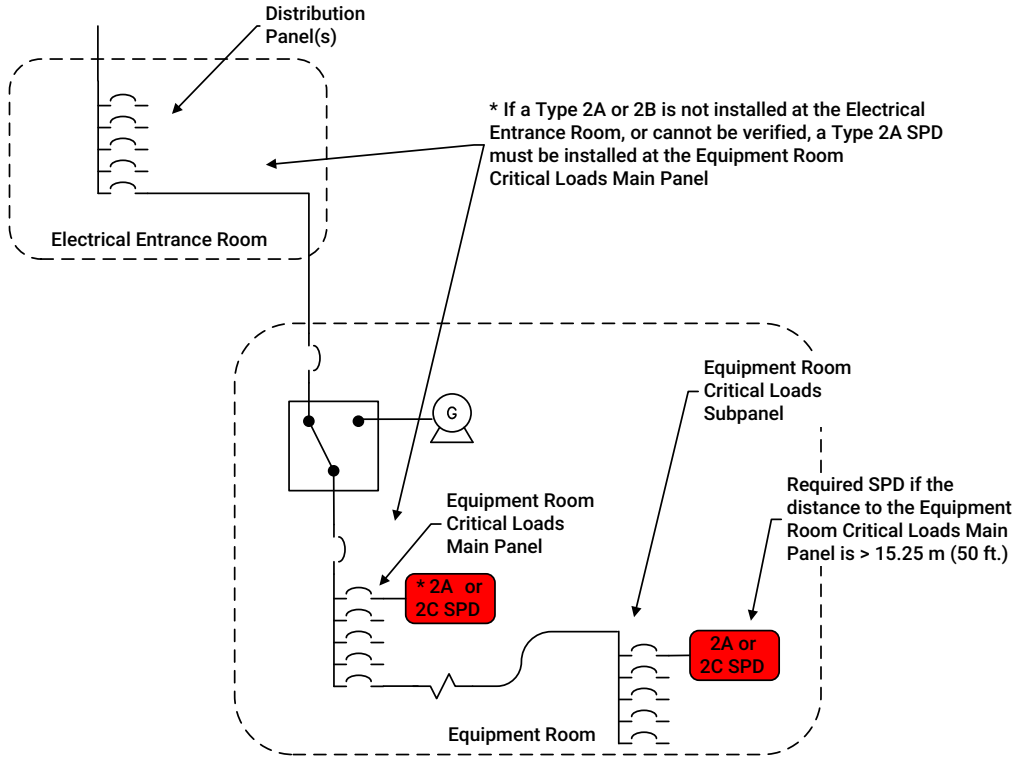


Figure 7-14. SPDs Required for Equipment Area Located within a Larger Structure, Generator Backup Power Provided at the Equipment Room Level

Table 7-3. Required Surge Protective Devices For Dispatch Centers

Service Configuration	ATS (Utility Input)	Main Distribution Panel(s)	Critical Loads Subpanel(s)	SPD at Equipment
Dispatch Center				
The main distribution panel does not directly feed critical equipment. The system engineer, customer, and/or AHJ should determine critical equipment. See Figure 7-15.	As required by applicable code (see NOTE 5). A Type 2A or 2B is recommended to protect the entire facility and ATS.	Type 2A or 2B	Type 2C or 2A at equipment subpanels and dispatch area subpanels. A Type 2A is required if a 2A or 2B is not installed at the electrical entrance, or cannot be verified; otherwise, a Type 2C is permitted.	Type 3 SPD with a grounding point for critical equipment installed at operator positions. See Figure 7-17 on page 7-17 and Figure 7-26 on page 7-27. Type 3 according to Table 7-4.
The main distribution panel directly feeds critical equipment. See Figure 7-16 on page 7-17.	Type 2B	Type 2A	Type 2C or 2A at equipment subpanels and dispatch area subpanels.	Type 3 SPD with a grounding point for electronic equipment installed at operator positions. See Figure 7-17 on page 7-17. Type 3 according to Table 7-4.
NOTE 5: See NFPA 70-2026, Article 708.8 and NFPA 1221-2019, section 4.7.6.2.				

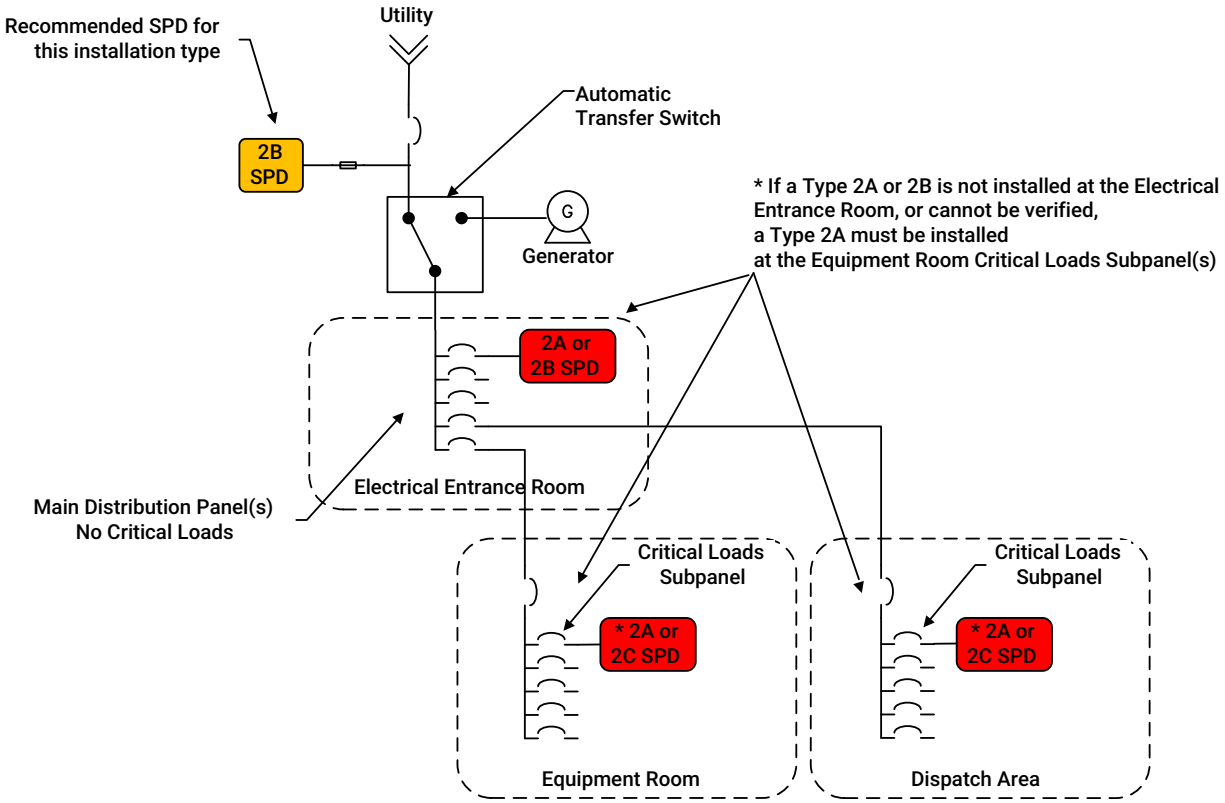


Figure 7-15. SPDs Required for Dispatch Center; Main Distribution Panel Does Not Directly Feed Critical Equipment

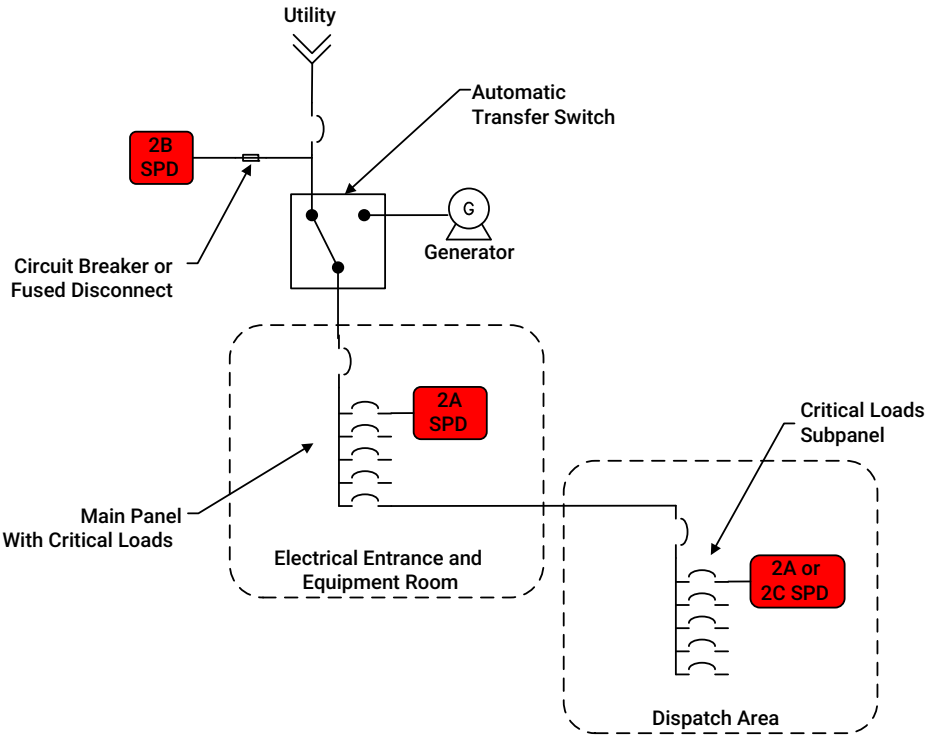


Figure 7-16. SPDs Required for Dispatch Center; Main Distribution Panel Directly Feeds Critical Equipment

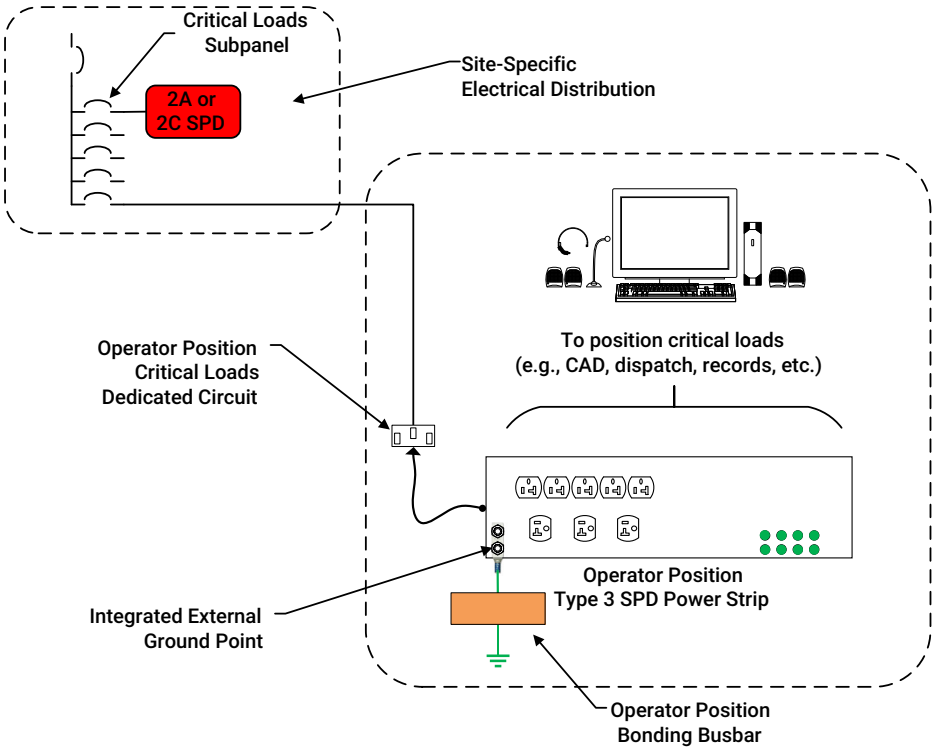


Figure 7-17. SPDs Required for Dispatch Center Operator Positions

Table 7-4. Type 3 SPD Installation Requirements and Recommendations

Type 3 SPD Installations	Load Type	Lightning Activity	Required/Recommended
Conductor length (one way) to the loads exceeds 9.144 m (30 ft) from the nearest upstream Type 2A or 2C protected panel.	Critical equipment	-	Recommended
Conductor length (one way) to the loads exceeds 9.144 m (30 feet) from the nearest upstream Type 2A or 2C protected panel.	Critical equipment	High	Required
Conductor length (one way) to the loads exceeds 15.2 m (50 ft) from the nearest upstream Type 2A or 2C protected panel.	Critical equipment	-	Required
Dispatch Operator Position Equipment	Critical equipment	-	Required. The Dispatch Operator Position (or equivalent) Type 3 SPD requires an external grounding point for bonding to the Operator Position Bonding Busbar. See Figure 7-26 on page 7-27.

Table 7-5. Type 2D SPD Installation Requirements

Type 2D SPD Installations	Required/Recommended	Notes
Circuits run outside the building to power external devices, such as tower lighting controllers, remote light poles, and generator heaters, among others.	Required	This SPD helps prevent lightning energy and other surges from feeding back into the communications building. Install the SPD outside the building near the circuit exit point, and ground it directly to the grounding electrode system as practicable. See Figure 7-22.



Figure 7-18. Example of AC SPD Installation at Typical Communications Site

7.4.2 Motorola Solutions Definition of SPD Types

Surge Protective Devices (SPD) used for AC power protection referenced in this section are defined as:

- Type 2A (SAD/MOV)
- Type 2B (MOV)
- Type 2C (SAD subpanel)
- Type 2D (External Branch Circuit)
- Type 3 (Point of Use)

These SPD types are described below. SPDs **shall** be selected based on the operating voltage and the number of phases of the circuits to be protected. See Table 7-7 on page 7-30 for required specifications for various SPDs. Tables 7-1 through 7-5 specify the type of SPD required by site type.

7.4.2.1 Type 2A (SAD/MOV) Surge Protective Device

The Type 2A SPD combines Silicon Avalanche Diodes (SAD) and Metal Oxide Varistors (MOV) to deliver robust surge protection for AC systems. As detailed in Table 7-1 through Table 7-3, beginning on page 7-6, the Type 2A SPD is versatile and suitable for a wide range of applications. It employs two distinct technologies:

Silicon Avalanche Diode (SAD): This fast-acting device provides moderate energy handling capabilities, ensuring quick response to surges.

Metal Oxide Varistor (MOV): While slower to respond than the SAD, the MOV can dissipate significantly higher energy levels, offering enhanced protection against more severe surges.

Together, these technologies help ensure comprehensive protection against voltage surges in electrical systems. The Type 2A requirements are listed in the following subsections.

7.4.2.1.1 Type 2A AC SPD Design Requirements

- The device **shall** meet the requirements of Table 7-7 on page 7-30.
- The SPD **shall** be listed to UL 1449, 5th Edition or later.
  - The test results obtained **shall** be made available to Motorola Solutions for approval.
  - In addition to the UL 1449 tests, the I_{max} test results **shall** be made available to Motorola Solutions for approval. This may require an additional Nationally Recognized Testing Laboratory (NRTL) in addition to the UL testing laboratory.
- The device **shall** consist of primary modules using Silicon Avalanche Diode (SAD) technology and secondary modules using Metal Oxide Varistor (MOV) technology.
- The suppression components **shall** be voltage-limiting type.
- The SPD **shall** be designed for permanent connection in a parallel configuration.
- The SPD **shall** be designed as an external device to the electrical switchboard or panelboard. See IEEE 1100-2005, section 8.4.2.5 for more information.
- The SPD **shall** be designed to accommodate 16 mm^2 csa (#6 AWG) or larger conductors.
- Each module or subassembly **shall** be modular in design to allow for easy field replacement.
- The enclosure rating of the SPD **shall** be NEMA 4 or higher (NWSM 30-4106:2017, section 2.5.2.2).
- Each SPD **shall** have indicator lamps on or visible from the front of the device showing that power is applied and that the protection integrity has not been compromised.
- The SPD **shall** include the capability for remote monitoring, such as form “C” dry contacts or SNMP traps.
  - The device **shall** indicate when there is an input power failure, or the integrity of any module has been compromised. A device using SNMP traps indicates power failure by a loss of communication with the SNMP managing device.

- Form C contacts **shall** be isolated from the AC power circuitry to safeguard the alarm circuit or reporting device against a catastrophic event.
- Connection to the remote monitoring contacts of the SPD **shall** utilize 0.34 mm^2 (#22 AWG) or larger conductors.

7.4.2.1.2 Type 2A AC SPD Environmental Design Requirements

See Table 7-8 on page 7-31 for Type 2A SPD environmental specifications.

7.4.2.1.3 Type 2A AC SPD Installation Requirements

- Type 2A SPDs **shall** be installed in the required locations as described in Table 7-1 through Table 7-3, beginning on page 7-6.
- The SPD **shall** be installed according to the manufacturer's requirements.
- Electrical connection to the SPD **shall** be made using 16 mm^2 csa (#6 AWG) or larger conductors.
- The conductors used to connect the SPD **shall not** be longer than necessary and **shall** avoid unnecessary bends (see NFPA 70-2026, Article 242.24).
- Electrical connection to the SPD **shall** be made using a 60 A or larger breaker according to the manufacturer's instructions. The conductor size **shall** match the breaker size (see NFPA 70-2026, Article 110).
- Except in Protected Multiple Earth (PME) systems, suppression modules **shall not** be connected between any phase conductor or neutral conductor and the equipment grounding conductor or ground (L-G, Common Mode Neutral to Ground).



Figure 7-19. Example of Type 2A SPD Installed at Distribution Panel

7.4.2.2 Type 2B (MOV) Surge Protective Device

The Type 2B SPD employs Metal Oxide Varistor (MOV) technology to deliver strong surge protection for AC systems. Typically installed at the AC utility entry point, the Type 2B serves as the first line of defense against voltage surges, operating in tandem with Type 2A or Type 2C devices placed at other strategic locations (see Table 7-1 through Table 7-3). Used together, the different SPD types provide comprehensive surge protection, ensuring enhanced safety and reliability for mission-critical systems. The requirements are as follows:

7.4.2.2.1 Type 2B AC SPD Design Requirements

- The SPD **shall** meet the requirements of Table 7-7 on page 7-30.
- The SPD **shall** be listed to UL 1449, 5th Edition or later.
  - The test results obtained **shall** be made available to Motorola Solutions for approval.
  - In addition to the UL 1449 tests, the I_{max} test results **shall** be made available to Motorola Solutions for approval. This may require an additional Nationally Recognized Testing Laboratory (NRTL) in addition to the UL testing laboratory.
- The SPD **shall** consist of modules using Metal Oxide Varistor (MOV) technology.
- The suppression components **shall** be voltage-limiting type.
- The SPD **shall** be designed for permanent connection in a parallel configuration.
- The SPD **shall** be designed as an external device to the electrical switchboard or panelboard. See IEEE 1100-2005, section 8.4.2.5 for more information.
- The SPD **shall** be designed to accommodate 16 mm^2 csa (#6 AWG) or larger conductors.
- Each SPD module or subassembly **shall** be modular in design to allow for easy field replacement.
- The enclosure rating of the SPD **shall** be NEMA 4 or higher (NWSM 30-4106:2017, section 2.5.2.2).
- Each SPD **shall** have indicator lamps on or visible from the front of the device showing that power is applied and that the protection integrity has not been compromised.
- The SPD **shall** include the capability for remote monitoring, such as form “C” dry contacts or SNMP traps.
  - The device **shall** indicate when there is an input power failure or the integrity of any module has been compromised. A device using SNMP traps will indicate power failure by a loss of communications in the SNMP managing device.
  - Form C contacts **shall** be isolated from the AC power circuitry to safeguard the alarm circuit or reporting device from a catastrophic event.
  - Connection to the remote monitoring contacts of the SPD **shall** utilize 0.34 mm^2 (#22 AWG) or larger conductors.

7.4.2.2.2 Type 2B AC SPD Environmental Design Requirements

See Table 7-8 on page 7-31 for the Type 2B environmental specifications.

7.4.2.2.3 Type 2B AC SPD Installation Requirements

- Type 2B SPDs **shall** be installed in the required locations as described in Table 7-1 through Table 7-3, beginning on page 7-6.
- The SPD **shall** be installed according to the manufacturer's requirements.
- The SPD **shall** be installed on the load side of the service disconnect (could be the utility input of the ATS).
- Electrical connection to the SPD **shall** be made using 16 mm^2 csa (#6 AWG) or larger conductors.
- The conductors used to connect the SPD **shall not** be longer than necessary and **shall** avoid unnecessary bends (see NFPA 70-2026, Article 242.24).
- Electrical connection to the SPD **shall** be made using a 60 A or larger breaker or fuses according to the manufacturer's instructions. Per NFPA 70-2026, Article 110, the conductor size **shall** match the breaker or fuse size.
- Except in Protected Multiple Earth (PME) systems, suppression modules **shall not** be connected between any phase conductor or neutral conductor and the equipment grounding conductor or ground (L-G, Common Mode Neutral to Ground).

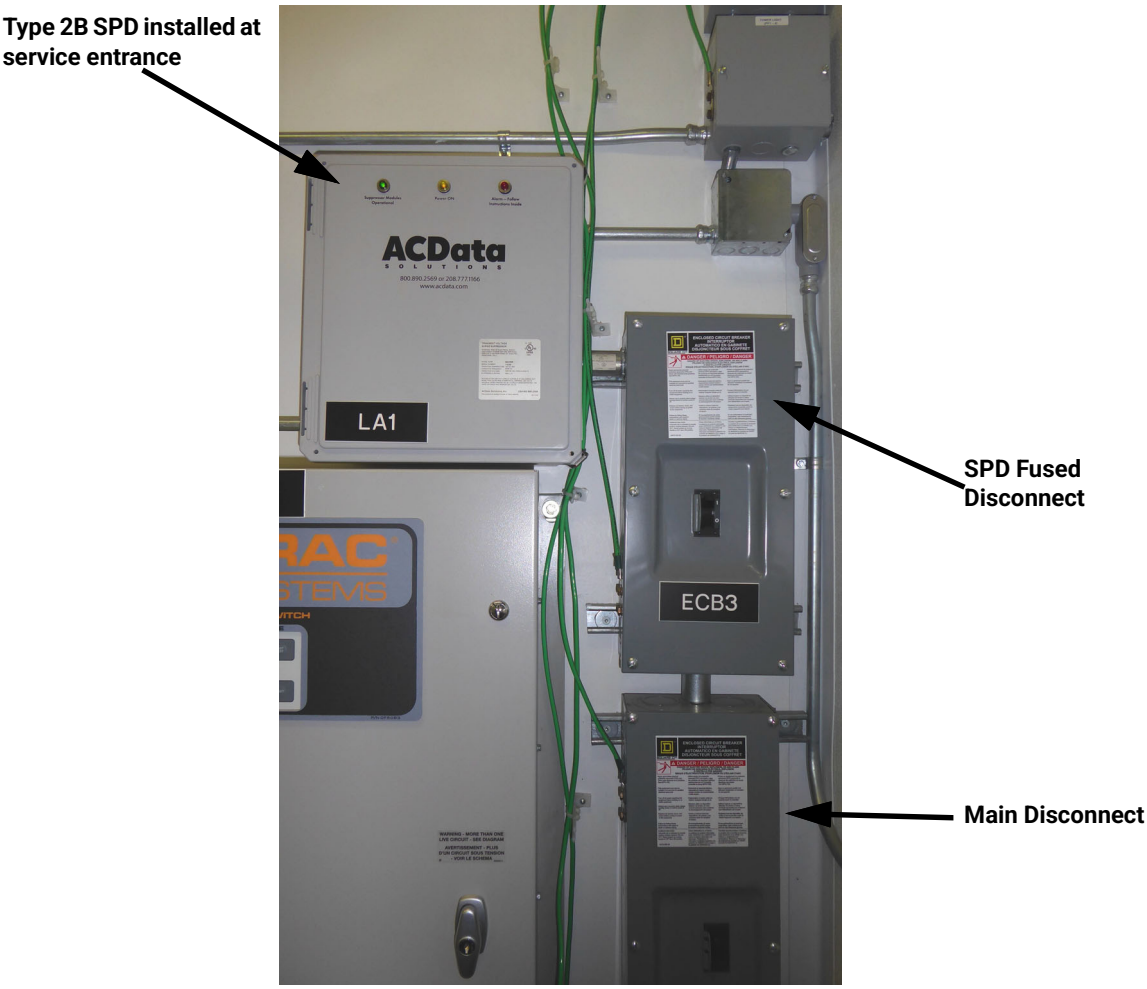


Figure 7-20. Example of Type 2B SPD Installed at Building Entry

7.4.2.3 Type 2C (SAD) Subpanel SPD

The Type 2C SPD employs Silicon Avalanche Diode (SAD) technology to protect subpanels in equipment rooms, dispatch areas, separate floors, and other critical locations. When used in conjunction with Type 2A and Type 2B SPDs, the Type 2C SPD provides an essential layer of protection, thereby enhancing the facility's overall surge protection strategy. The Type 2C SPD **shall** only be installed where the subpanel is downstream from a panel protected by either a Type 2A or Type 2B SPD; otherwise, a Type 2A SPD is required. Type 2C SPDs are commonly utilized in commercial building installations, such as dispatch centers, Emergency Operations Centers, and IT facilities (see Table 7-1 through Table 7-3, beginning on page 7-6). See NENA-STA-027.3-2018, section 6.3.1; NFPA 70-2026, Article 708.8; and NWSM 30-4106:2017, section 2.5.3 for more information. Type 2C SPD requirements are listed below. See Figure 7-21 on page 7-24 for a Type 2C SPD example.

IMPORTANT: The Type 2C SPD **shall not** be used in place of a Type 2A or 2B SPD. Type 2C SPDs are only permitted on subpanels that are downstream from a Type 2A or 2B SPD.

NOTE: A Type 2A SPD may be used where a Type 2C device is required.

7.4.2.3.1 Type 2C Approved Locations

IMPORTANT: Use of a Type 2C SPD does not negate the need for a Type 2A or 2B device as defined in Table 7-1 through Table 7-3, beginning on page 7-6.

Type 2C SPDs are approved for use on subpanels that are downstream from a Type 2A or 2B protected panel. Some example locations include the following:

- Dispatch center equipment room subpanel.
- Dispatch area subpanel.
- Core or Prime Site equipment area subpanel.
- Other remote equipment room subpanels.

7.4.2.3.2 Type 2C AC SPD Design Requirements

- The SPD **shall** meet the requirements in Table 7-7 on page 7-30.
- The SPD **shall** consist of modules using Silicon Avalanche Diode (SAD) technology.
- The SPD **shall** be tested to UL 1449, 5th Edition. The test results obtained **shall** be made available to Motorola Solutions for approval.
- The suppression components **shall** be voltage-limiting type.
- The SPD **shall** be designed for permanent connection in a parallel configuration.
- The SPD **shall** be designed as an external device to the electrical switchboard or panelboard. See IEEE 1100-2005, section 8.4.2.5 for more information.
- The SPD **shall** be designed to accommodate 16 mm^2 csa (#6 AWG) or larger conductors.
- The SPD **shall** be modular in design to allow for easy field replacement.
- The enclosure rating of the SPD **shall** be NEMA 4 or higher (NWSM 30-4106:2017, section 2.5.2.2).
- Each SPD **shall** have indicator lamps on or visible from the front of the device showing that power is applied and that the protection integrity has not been compromised.
- The SPD **shall** include the capability for remote monitoring, such as form “C” dry contacts or SNMP traps.
  - The device **shall** indicate when there is an input power failure, or the integrity of any module has been compromised. A device using SNMP traps will indicate power failure by a loss of communications in the SNMP managing device.
  - Form C contacts **shall** be isolated from the AC power circuitry to safeguard the alarm circuit or reporting device should there be a catastrophic event.
  - Connection to the remote monitoring contacts of the SPD **shall** utilize 0.34 mm^2 (#22 AWG) or larger conductors.

7.4.2.3.3 Type 2C AC SPD Environmental Design Requirements

See Table 7-8 on page 7-31 for the Type 2C environmental specifications.

7.4.2.3.4 Type 2C AC SPD Installation Requirements

- Type 2C SPDs **shall** be installed in the required locations as described in Table 7-1 through Table 7-3, beginning on page 7-6.
- The SPD **shall** be installed according to the manufacturer's requirements.
- Electrical connection to the SPD **shall** be made using 16 mm^2 csa (#6 AWG) or larger conductors.
- The conductors used to connect the SPD **shall not** be longer than necessary and **shall** avoid unnecessary bends (see NFPA 70-2026, Article 242.24).

- Electrical connection to the SPD **shall** be made using a 60 A or larger circuit breaker according to the manufacturer's instructions. Per NFPA 70-2026, Article 110, the conductor size **shall** match the breaker size.



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Figure 7-21. Example of Type 2C SPD

7.4.2.4 Type 2D External Branch Circuit Surge Protective Device

The Type 2D branch circuit SPD safeguards the site's electrical system against surges originating from external branch circuits that power devices such as the tower's aircraft warning lights, generator heater, electric gates, and more. By effectively managing these surges, the Type 2D device prevents them from feeding back into the building's electrical system, ensuring protection at the site. Branch circuits supplying external equipment **shall** have Type 2D surge protection (see Table 7-5 on page 7-18). See Figure 7-22 for an example Type 2D SPD.

NOTE: Type 2D SPDs are not required on the code-required convenience receptacles installed on the exterior of the shelter or building.



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Figure 7-22. Example of Type 2D SPD

7.4.2.4.1 Type 2D AC SPD Design Requirements

- The Type 2D SPD **shall** meet the requirements of Table 7-7 on page 7-30.
- The SPD **shall** use Metal Oxide Varistor (MOV) technology. SAD may also be used in addition to MOV.
- The SPD **shall** be tested to UL 1449, 5th Edition. The test results obtained **shall** be made available to Motorola Solutions for approval.
- Common Mode (L-G, N-G) circuit protection is preferred over Normal Mode (L-N).

7.4.2.4.2 Type 2D AC SPD Environmental Design Requirements

See Table 7-6 for the Type 2D environmental specifications.

Table 7-6. Type 2D SPD Environmental Specifications

Specification	Range
Operating temperature range	-40°C to +75°C (-40°F to +167°F)
Storage temperature range	-40°C to +75°C (-40°F to +167°F)
Environmental Protection Rating	NEMA-4
Humidity	0 to 95%, non-condensing

7.4.2.4.3 Type 2D AC SPD Installation Requirements

- The SPD **shall** be installed according to the manufacturer's requirements.
- The SPD **shall** be installed outside the building or shelter if practicable and bonded directly to the grounding electrode system. This helps prevent any surges from entering the building or shelter. See Figure 7-23.

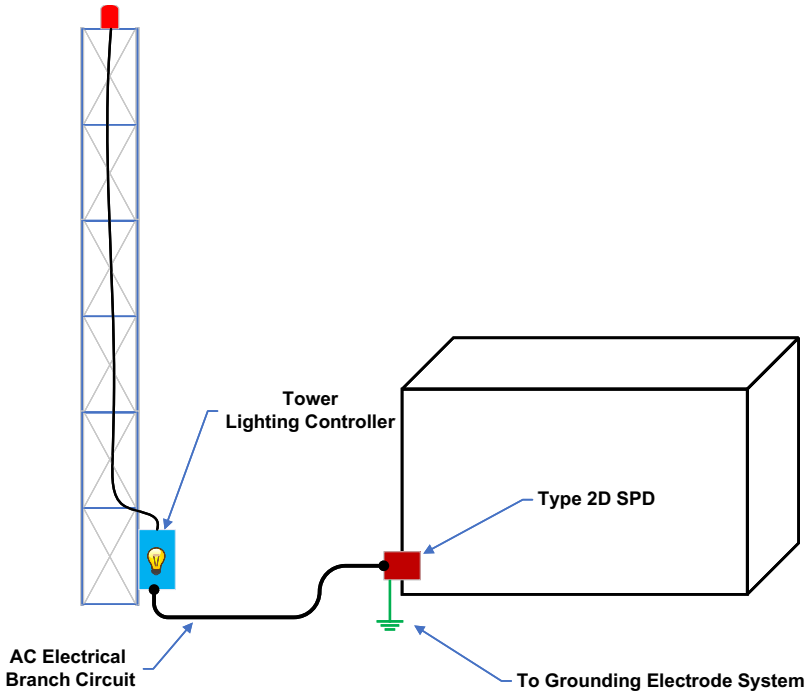


Figure 7-23. Type 2D SPD Installation Example

- For installations preventing outdoor placement of the SPD, route the circuit as close as practicable to the Primary Bonding Busbar (PBB). This ensures the SPD can be effectively grounded, either to the PBB or directly to the grounding electrode system, depending on which offers the shortest and most direct path to earth. See Figure 7-24.

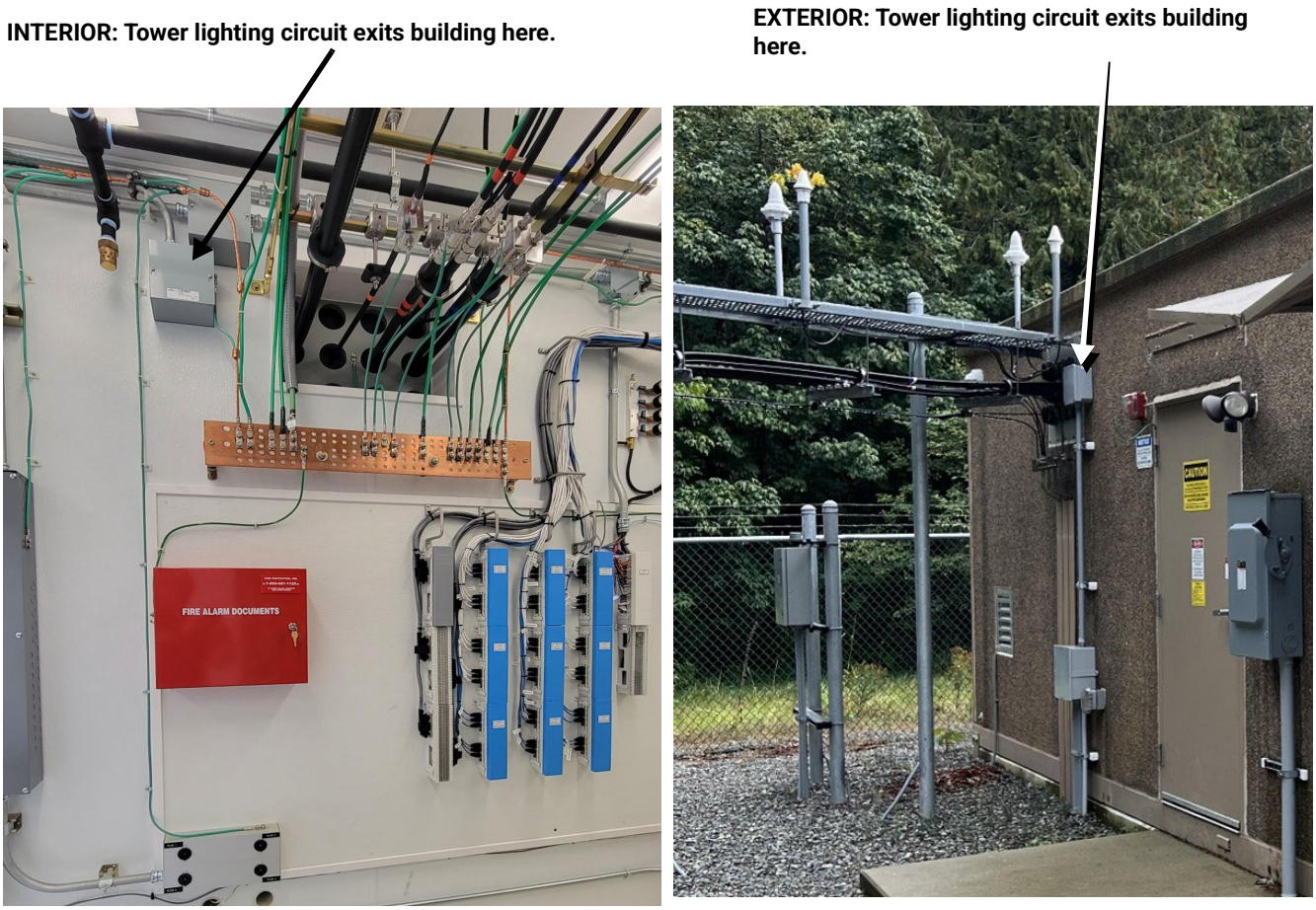


Figure 7-24. Example of Type 2D SPD Installation for Tower Lighting Circuit

7.4.2.5 Type 3 Point of Use Surge Protective Device

The Type 3 SPD serves as the last line of defense in a facility's surge protection system, crucial for safeguarding mission-critical equipment. It is typically installed close to the equipment for optimal protection. Type 3 SPDs are available in many varieties. These may be wire-in receptacle outlet replacement types, plug-in adapters, receptacle outlet panels, Power Distribution Units (PDU), or power strips (see Figures 7-25 through 7-29). General requirements are as follows:

- The device **shall** meet the requirements of Table 7-7 on page 7-30.
- The SPD **shall** use Silicon Avalanche Diode (SAD) technology.
- The device **shall** be UL listed for the stated application or conform to the international CE certification mark.
- Power strip SPDs **shall** be dual-listed to UL 1363 and UL 1449.
- Common Mode (L-G, N-G) circuit protection **shall not** be permitted, except in a Protected Multiple Earth (PME) system.
- Multi-receptacle device housings **shall** be metallic and **shall** have mounting ears, tabs or brackets suitable for rack or cabinet mounting. See Figure 7-26 for an example.



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Figure 7-25. Example of Receptacle SPD

- Each device **shall** have an indicator lamp visible from the front of the device showing that power is applied and that the protection integrity has not been compromised. Alarm relay contacts or SNMP traps to remotely report device status may be used, but are not required.

7.4.2.5.1 Dispatch Operator Position Type 3 SPD Power Strip Additional Requirements

Below are the additional requirements for Type 3 SPDs installed at dispatch operator positions (or equivalent).

- The devices **shall** incorporate an independent ground point on the exterior of the device (APCO ANS 2.106.1-2019, section 3.22.3.4).
- The grounding attachment point **shall** be suitable for the attachment of a two-hole lug sized for a 16 mm^2 csa (#6 AWG) conductor.
- The SPD grounding attachment point **shall** be bonded to the Operator Position Secondary Bonding Busbar using a 16 mm^2 csa (#6 AWG) or larger conductor. See section Figure 5.10.5.1 on page 5-138.

See Figure 7-26 and Figure 7-27 for examples.

NOTE: The grounding attachment point helps to ensure equipotential bonding at the operator position, improving safety for personnel and equipment at the position.



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Figure 7-26. Example of Dispatch Operator Position SPD Power Strip

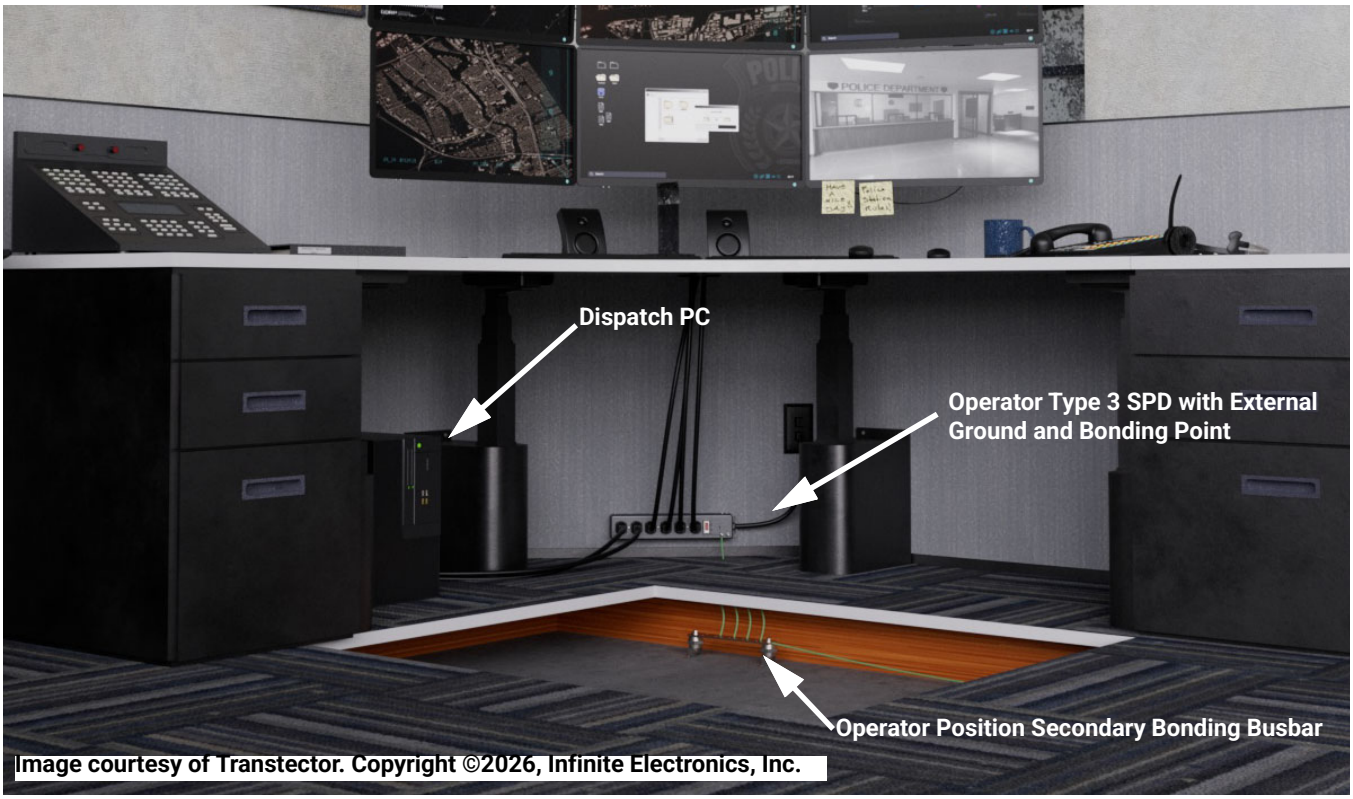


Figure 7-27. Example of Dispatch Operator Position SPD Installation

7.4.2.5.2 Type 3 SPD Installation Requirements and Recommendations

See Table 7-4 on page 7-18 for the Type 3 SPD installation requirements and recommendations.



Figure 7-28. Example of Rack-Mounted Type 3 SPD

NOTE: The system engineer, system manager, and/or system owner **shall** define the critical load(s). A critical load is generally any load that affects system availability and the end user's ability to effectively communicate on the system.





Figure 7-29. Examples of Rack Mounted Power Distribution Units with Type 3 SPD

7.4.3 SPD Specifications for Safety and Performance

NOTE: Table 7-7 reflects the UL 1449 5th Edition and later.

Table 7-7. SPD Specifications

Type	Service Configuration	MCOV	Required Measured Testing (see "AC Power Line SPD Test Certification Requirements and Test Methods" on page 7-73)			
			Voltage Protection Rating (VPR) UL 1449 5th Edition 6 kV/3 kA per UL 1449 5th Ed.	**SCCR** per UL 1449 5th Ed.	**Nominal Discharge Current (I_n)** per UL 1449 5th Ed.	**Maximum Discharge Current (I_{max})**
Type 2A (see "Type 2A (SAD/MOV) Surge Protective Device" on page 7-19)						
Primary modules using Silicon Avalanche Diode (SAD) technology and secondary modules using Metal Oxide Varistor (MOV) technology. Installed at locations as defined in Tables 7-1, 7-2 and 7-3 beginning on page 7-6.	120/240 V 1ϕ	138–144 V	No more than 700 V	22 kAIC minimum	20 kA for SAD module 20 kA for the MOV module	160 kA minimum for the MOV
	120/208 V 3ϕ	138–144 V	No more than 700 V			
	277/480 V 3ϕ	318–346 V	No more than 1500 V			
	230/380V 3ϕ	264–288 V	N/A			
Type 2B (see "Type 2B (MOV) Surge Protective Device" on page 7-20)						
Modules using Metal Oxide Varistor (MOV) technology. Installed at locations as defined in Tables 7-1, 7-2 and 7-3 beginning on page 7-6.	120/240 1ϕ	138–144 V	No more than 1000 V	22 kAIC minimum	20 kA	160 kA minimum
	120/208 3ϕ	138–144 V	No more than 1000 V			
	277/480 V 3ϕ	318–346 V	No more than 1500 V			
	230/380V 3ϕ	264–288 V	N/A			
Type 2C (see "Type 2C (SAD) Subpanel SPD" on page 7-22)						
Modules using Silicon Avalanche Diode (SAD) technology. Installed at locations as defined in Tables 7-1, 7-2 and 7-3 beginning on page 7-6. Only suitable at subpanels that are protected upstream with a Type 2A or 2B SPD.	120/240 1ϕ	138–144 V	No more than 700 V	10 kAIC minimum	10 kA	N/A
	120/208 3ϕ	138–144 V	No more than 700 V			
	277/480 V 3ϕ	318–346 V	No more than 1500 V			
	230/380V 3ϕ	264–288 V	N/A			

Table 7-7. SPD Specifications (continued)

Type	Service Configuration	MCOV	Required Measured Testing (see "AC Power Line SPD Test Certification Requirements and Test Methods" on page 7-73)			
			Voltage Protection Rating (VPR) UL 1449 5th Edition 6 kV/3 kA per UL 1449 5th Ed.	**SCCR** per UL 1449 5th Ed.	**Nominal Discharge Current (I_n)** per UL 1449 5th Ed.	**Maximum Discharge Current (I_{max})**
Type 2D External Branch Circuit SPD (see "Type 2D External Branch Circuit Surge Protective Device" on page 7-24)						
Metal Oxide Varistor (MOV) technology. Installed at locations defined in Table 7-1. Common Mode (L-G, N-G) circuit protection is preferred over Normal Mode (L-N).	120 V	138–144 V	No more than 700 V	N/A	20 kA	100 kA
	230–240 V	276–288 V	No more than 1200 V	N/A		
Type 3 (see "Type 3 Point of Use Surge Protective Device" on page 7-26)						
Silicon Avalanche Diode (SAD) technology. Installed at locations as defined in Table 7-1.	120 V	138–144 V	No more than 500 V 330 V preferred	Required	3 kA	N/A
	230-240V	276–288 V	No more than 800 V	N/A		

Table 7-8. Type 2A, 2B, and 2C SPD Environmental Specifications

Specification	Range
Operating temperature range	-40°C to +65°C (-40°F to +149°F)
Storage temperature range	-40°C to +65°C (-40°F to +149°F)
Operating humidity range	0 to 95%, non-condensing
Altitude range	-152.4 m to 4572 m (-500 ft to +15,000 ft)

NOTE: Type 3 Surge Protective Devices may alternatively be listed to IEC 62368-1 if they are integrated into a device whose primary function is a power distribution unit.

7.5 AC Power SPD Installation Requirements

All Surge Protective Devices (SPD) **shall** be installed per the manufacturer's installation instructions and in accordance with all applicable codes. AC SPD devices **shall** be securely attached to the mounting surface and **shall not** depend on the interconnecting raceway for support.

7.5.1 Location

When selecting the location, consideration must be given to conductor routing, length and required number of bends in each conductor. Type 2A, 2B, and 2C SPDs **shall** be installed as close as practicable to the associated panel to be protected. See “Type 2A (SAD/MOV) Surge Protective Device” on page 7-19, “Type 2B (MOV) Surge Protective Device” on page 7-20 and “Type 2C (SAD) Subpanel SPD” on page 7-22 for specifications and installation requirements.

Type 3 SPDs **shall** be installed as close as practicable to the load. See “Type 3 Point of Use Surge Protective Device” on page 7-26 for specifications and installation requirements.

NOTE: To minimize the impedance path and to improve SPD performance, Type 2A, Type 2B, and Type 2C SPD conductors **shall** be kept as short as practicable with minimal bends. Where practicable, the length of service conductors between the disconnect and the SPD should be less than 1.524 m (5 ft).

7.5.2 Interconnecting Raceway or Conduit

The raceway or conduit between the panelboard (or disconnecting means) and the SPD **shall** be sized for the size and number of conductors to be routed through it. A nonmetallic conduit (such as PVC) or raceway is recommended. The length **shall** be as short as practicable. This raceway **shall** be routed as directly as practicable between the SPD, the disconnecting means (if a separate enclosure is used) and the associated panelboard. The raceway or conduit **shall not** be used as a support for the device.

7.5.3 Circuit Breaker or Disconnecting Means for Type 2A, 2B, and 2C Devices

The SPD **shall** be wired through a 60-Ampere (or larger) circuit breaker or fuses as previously described. The circuit breaker or fuses **shall** meet the requirements of NFPA 70-2026, Article 110.9, or local jurisdictional codes, whichever is more stringent. See the manufacturer’s installation instructions and Figure 7-30



Figure 7-30. Example of SPD Exterior Disconnect

7.5.4 Conductor Size, Length and Routing (Type 2A, 2B, and 2C Devices)

Conductor size, total circuit length and routing are critical to SPD performance. The conductors **shall** be of the minimum size recommended by the manufacturer, however, they **shall not** be smaller than 16 mm^2 csa (#6 AWG). Larger conductor sizes are desirable. The conductors used to connect the SPD **shall not** be longer than necessary and **shall** avoid unnecessary bends (see NFPA 70-2026, Article 242.24). Where practicable, conductor length **shall not** exceed 152.4 cm (5 ft). The conductors **shall** be routed together and **shall** be free of sharp bends or angles of less than 90 degrees. An example of SPD conductor length and routing between the Type 2B SPD and Automatic Transfer Switch, and between the AC load center and Type 2A SPD is shown in Figure 7-31.

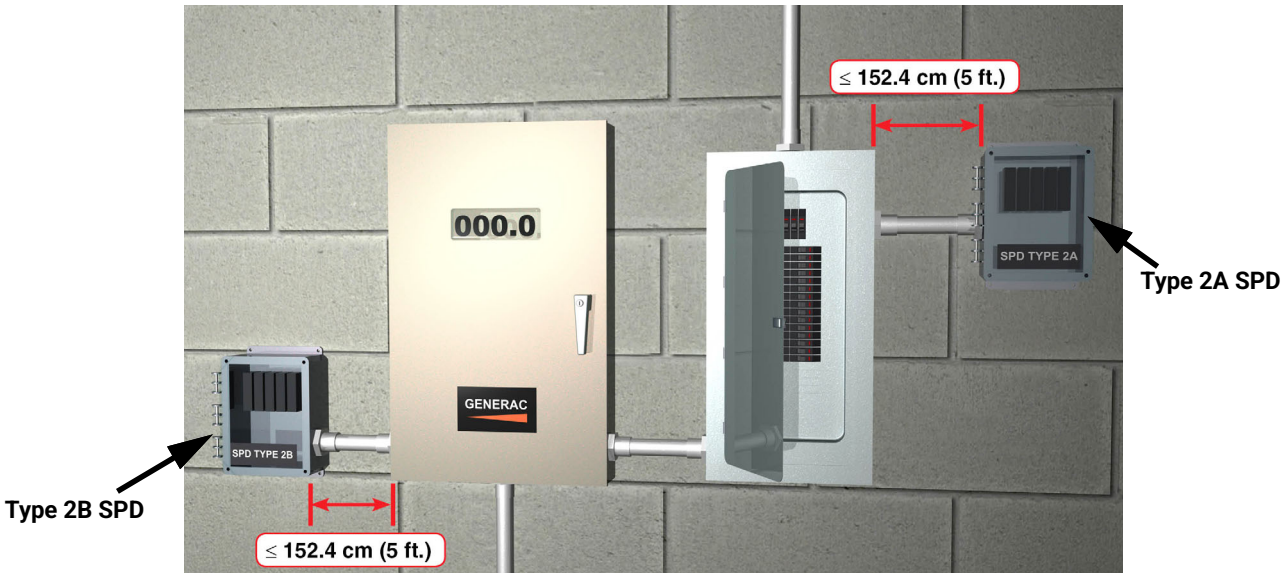


Figure 7-31. Example of SPD Conductor Length

7.5.5 AC Power Performance Evaluation

SPDs **shall** be evaluated using the specific criteria outlined in Table 7-7 on page 7-30 and "AC Power Line SPD Test Certification Requirements and Test Methods" on page 7-73. Certification test results **shall** be provided to Motorola Solutions. Devices that do not meet this minimum criteria **shall not** be furnished, installed, or recommended for Motorola Solutions installations.

NOTE: At the discretion of the Motorola Solutions R56 committee, existing SPD products approved by Motorola under the earlier version of this manual and UL 1449 4th Edition may remain valid for use by Motorola. However, all new products must comply with the standards outlined in this manual and UL 1449 5th Edition.

7.6 Communication Circuit Protection

Telephony, data, signaling, alarm, security, network circuits, and other similar cables entering a shelter, room, equipment area, or pole/pad-mounted cabinets **shall** be protected with a suitable surge protective device (SPD) (see ATIS-0600313.2019, section 8 and ATIS-0600334.2019(R2024), section 11).

- Telephony (NFPA 70-2026, Article 800)
- Alarm (NFPA 70-2026, Article 760)
- Security/surveillance systems
- Site access control systems
- Ethernet Systems (ATIS-0600012.05)
- Broadband (NFPA 70-2026, Article 830)
- Network (NFPA 70-2026, Article 722, 725, and 830)
- Signaling (NFPA 70-2026, Article 725)

SPDs **shall** be installed on all conductive communications and signaling circuits, in use or designated for future use, within 61 cm (24 in.) of entering any building or equipment enclosure. SPDs **shall** be bonded to earth according to the manufacturer's instructions and **shall** meet the minimum specified design and application criteria in accordance with local codes and regulations.

SPDs used for protecting critical communications links **shall not** interrupt the circuit except in the event the SPD self-sacrifices or disconnects the load due to electrical fault. Qualified SPDs **shall** meet the listing and performance requirements described in Table 7-9.

CAUTION: To help prevent injury or possible equipment damage, careful consideration shall be paid to grounding and bonding of the SPD.

IMPORTANT: Cables/conductors designated for future expansion/use **shall** be surge protected or bonded to earth.

IMPORTANT: To prevent transients from coupling to the protected side of a cable, the protected and unprotected sides of the cables must be kept physically isolated from one another as much as practicable and by at least 100 mm (4 in.). The suggested best practice it to run the unprotected side down one side of the rack and the protected side down the other side. See Figure 7-32 for an example installation where the unprotected cables are run to the front of the rack and the protected cables are in the rear of the rack.

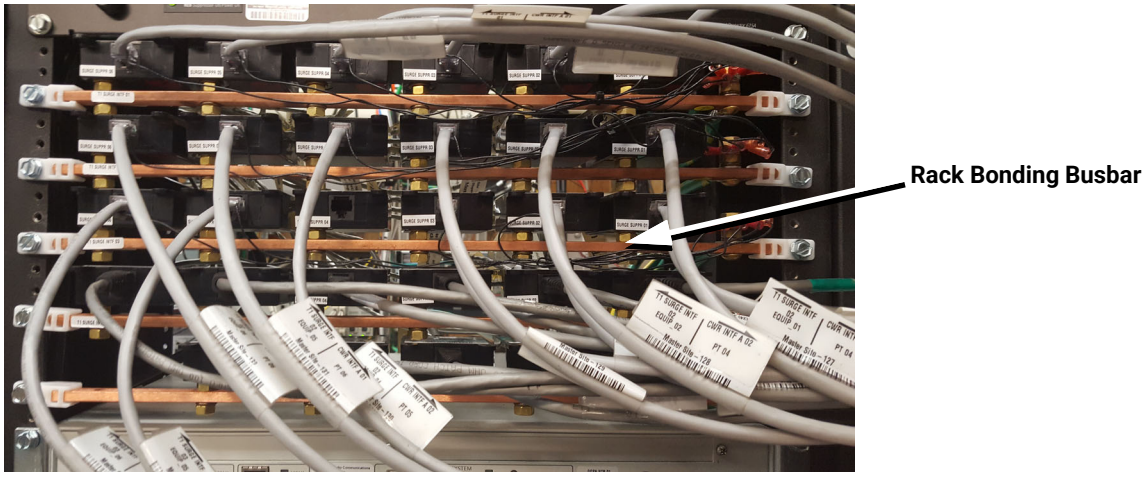


Figure 7-32. Example of Maintaining Physical Separation between Protected and Unprotected Cable Sides

7.6.1 Cable Separation

Where telephone, network, or signaling cables are installed near motors, generators, induction heaters, industrial machinery, or RF transmission cables, it is essential to maintain adequate separation to minimize noise interference and transient voltage (surge) coupling to the cables. See “Network Cable Installation and Routing” on page 9-46 for cable separation requirements and recommendations.

7.6.2 Bonding and Grounding of Communication Circuit SPDs

SPDs for telephone, data, signaling, alarm, security, and network circuits **shall** be grounded/bonded according to the manufacturers’ instructions and “Surge Protective Devices” on page 5-122 and applicable subsections.

7.6.3 Links Provided by the Telephone (Wireline) Service Provider

NOTE: The United States Federal Communications Commission (FCC) directive, Part 68 (47 CFR), requires licensed commercial wireline service providers of high-speed communications circuits to isolate Terminal Equipment (TE), including DS-1, DSL media converters, operated within a Public Switched Telephone Network (PSTN) from Customer edge Premises Equipment (CePE) within 30.48 cm (12 in.) of the point where the cable enters the subscriber's facility. Known as the “12 Inch Rule”, carriers, including cable television providers, **shall** safely terminate exposed overhead and buried cables in accordance with FCC rules, by grounding shields and removing transmission voltages necessary for signal boost and insulation protection.

See Figure 7-33 and Figure 7-34. The Service Termination Edge (or Network Interface Device) is the point where the carrier network ends and the customer premises begins. For traditional telephony (T1/E1), cable (DSL/ADSL), and fiber optic backbones, the transition from a powered network control plane to the customer premises management plane makes bidirectional communication possible through layered protocol necessary for LAN communications (for example, Telnet, SNMP, SSH or XML). Where necessary, a service provider demarcation point extension may be used to boost the network control transmission path beyond the traditional demarcation (see NOTE above) to routers or smart jacks located at strategic points (a telco closet, for example) within larger commercial structures.

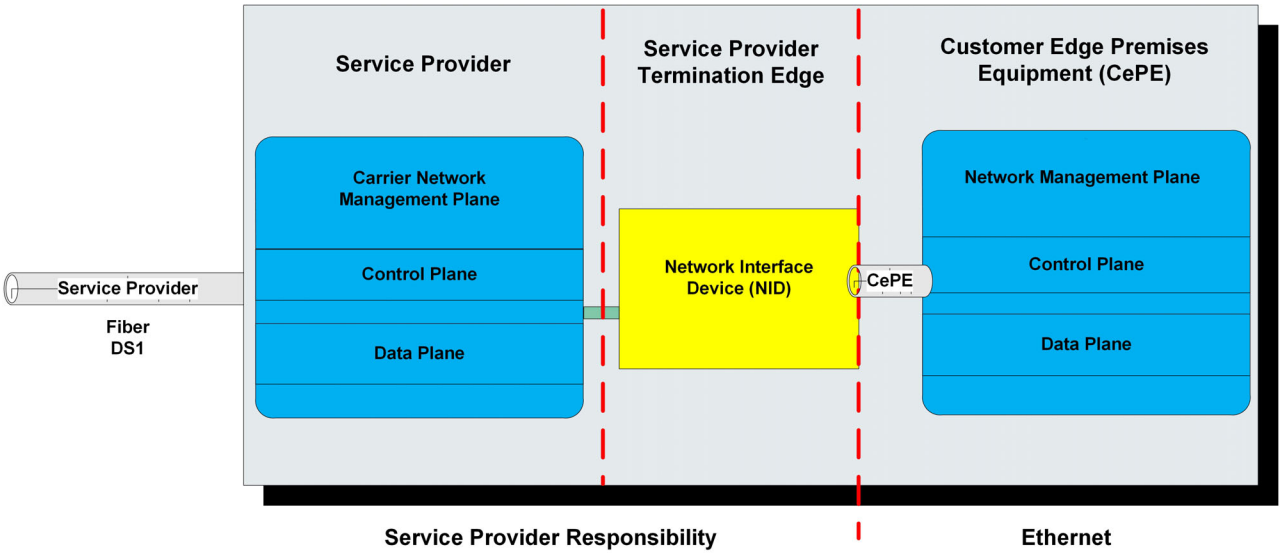


Figure 7-33. Example of Telco Demarcation (Network Interface Device) to Customer Edge Premises Equipment



Figure 7-34. Example of Service Provider Demarcation (Network Interface Device)

NOTE: Installation of Primary SPDs is the responsibility of the service provider.

7.6.3.1 Analog Site Links

Many legacy systems require analog site links (such as tone-controlled base station). Observe the following for analog site links provided by the telephone service provider:

- A Primary SPD **shall** be installed at the telephone service provider demarcation point as required by NFPA 70-2026, Article 742 and 800 (service provider supplied).
- In high-lightning areas, a secondary SPD should be installed at the service provider demarcation point (on the customer side of the primary SPD).
- The telephone service provider ground **shall** be bonded according to “Common Grounding” on page 4-7.
- A secondary SPD **shall** be installed as close as practicable to the protected equipment.
  - **Exception**: a secondary SPD is already installed at the demarcation point and the cable length between the demarcation point and the equipment is less than 9.144 m (30 ft).
- The secondary SPD **shall** meet the following requirements:
  - The SPD **shall** be designed for the purpose.
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements described in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.
- Refer to “Optical Fiber Links” on page 7-38 if the circuit is provided using optical fiber.

7.6.3.2 Digital Site Links

Most digital systems (for example, P25 and TETRA) require digital site links. The digital site link may be ATM, DSL, Ethernet, T1, fractional T1 or other Internet-type connection. Observe the following for digital site links provided by a telephone service provider:

- A primary SPD **shall** be installed at the telephone service provider demarcation point as required by NFPA 70-2026, Article 742 and 800 (service provider supplied).
- In high-lightning areas, a secondary SPD should be installed at the service provider demarcation point (on the customer side of the primary SPD).
- The telephone service provider ground **shall** be bonded according to “Common Grounding” on page 4-7.
- A secondary SPD **shall** be installed as close as practicable to the protected equipment (for example, Site Access Router or Network Monitoring Firewall).
  - **Exception**: a secondary SPD is already installed at the demarcation point and the cable length between the demarcation point and the equipment is less than 9.144 m (30 ft).
- The secondary device **shall** meet the following requirements:
  - The SPD **shall** be designed for digital links (for example, data speed and voltage levels).
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.

IMPORTANT: Ensure the SPD is rated for the data speed of the circuit. The SPD **shall not** negatively impact data rate.

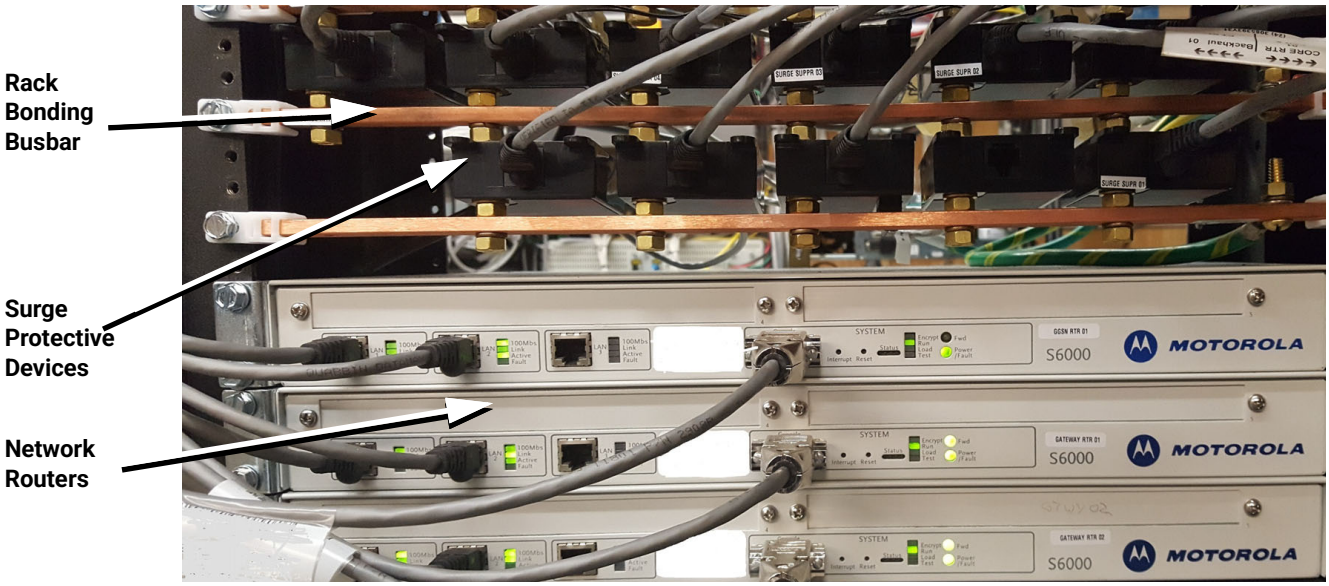


Figure 7-35. Secondary Surge Protective Devices Installed Near Protected Equipment

- Refer to “Optical Fiber Links” on page 7-38 if the circuit is provided using optical fiber.

IMPORTANT: Primary surge protection provided by the telephone service provider does not negate the need for secondary SPDs (see “Secondary Telephone Exchange Protection” on page 7-41).

7.6.3.3 Optical Fiber Links

Many site links are provided by an electrically isolated source, such as optical fiber. An intrinsic benefit of optical fiber links is that they offer excellent isolation from lightning-induced ground potential rise, line-induced lightning strikes, RF, and electrical noise coupling.

Primary surge protection is not required on these types of links because of the electrical isolation from outside electrical disturbances. The optical fiber cable metallic shield, jacket, or drain (if applicable) **shall** be bonded/grounded according to “External Ground Busbar” on page 4-46 and “Telecommunication Cable Metallic Shields” on page 5-127 (NWSM 30-4106:2017, section 2.6.9).

NOTE: The best engineering design is to use all-dielectric optical fiber cables.

In high lightning areas, for cable runs exceeding approximately 30 m (100 ft) between the Network Interface Device (NID) and customer network equipment, secondary surge protection is recommended at both ends as an added layer of protection. For critical site links, secondary surge protection should be considered regardless of the lightning activity.

Where used, the secondary device **shall** meet the following requirements:

- The SPD **shall** be designed for link type (for example, data speed and voltage levels).
- The SPD **shall** be of solid state construction.
- The SPD **shall** meet the listing and performance requirements described in Table 7-9 on page 7-44.
- The SPD **shall** protect all cable conductors.
- The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.

IMPORTANT: Ensure the SPD is rated for the data speed of the circuit. The SPD **shall not** reduce the data rate.



Figure 7-36. Typical Carrier Optical Network Terminal

7.6.3.3.1 Optical Fiber Links Terminated Outside the Radio Shelter

Where the fiber demarcation is located outside of a structure or cabinet (such as at a remote H-frame or telco pedestal), and distributed to the building using copper conductors, observe the following:

- The cable between the NID and radio shelter/cabinet **shall** be outdoor rated Shielded Twisted Pair (STP).
- The cable shield **shall** be bonded according to "External Ground Busbar" on page 4-46 and "Telecommunication Cable Metallic Shields" on page 5-127 or be bonded to the Primary Bonding Busbar (PBB) or entry point Secondary Bonding Busbar (SBB). See Figure 7-37.
- Within 61 cm (24 in.) of entering the radio shelter/cabinet, the cable **shall** be protected with a secondary SPD (see Table 7-9 on page 7-44).
- In high lightning areas, for cable runs exceeding approximately 30 m (100 ft) between the entry point SPD and customer network equipment, secondary surge protection is recommended at the site's network equipment as an added layer of protection. For critical site links, secondary surge protection should be considered regardless of the lightning activity.
- The secondary SPD **shall** meet the following requirements:
  - The SPD **shall** be designed for link type (for example, data speed and voltage levels).
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements described in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to "Surge Protective Devices" on page 5-122.

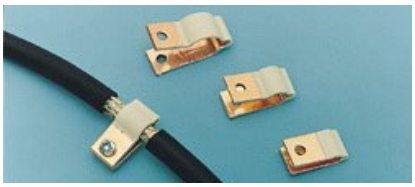


Figure 7-37. Example of Shielded Cable Bonding Kit

IMPORTANT: Ensure the SPD is rated for the data speed of the circuit. The SPD **shall not** reduce data rate.

7.6.4 Microwave Links

Many site links are provided by an electrically isolated source, such as microwave. Primary surge protection is not required on these types of links because of the electrical isolation from outside electrical disturbances. The microwave RF feedline **shall** be bonded/grounded according to "Grounding and Bonding of RF Transmission Lines and Communications Cables" on page 4-104. The microwave equipment and rack **shall** be bonded according to Chapter 5, "Internal Bonding and Grounding (Earthing)".

- In high lightning areas, for cable runs exceeding approximately 30 m (100 ft) between the microwave equipment and customer network equipment, secondary surge protection is recommended at both ends as an added layer of protection. For critical site links, secondary surge protection should be considered regardless of the lightning activity.
- Where used, the secondary SPD **shall** meet the following requirements:
  - The SPD **shall** be designed for link type (for example, data speed and voltage levels).
  - The SPD **shall** be of solid state construction.
  - The SPD should meet the listing and performance requirements described in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to "Surge Protective Devices" on page 5-122.

IMPORTANT: Ensure the SPD is rated for the data speed of the circuit. The SPD **shall not** reduce data rate.

7.6.5 Inter-building Cabling Links

Site links may originate in one building via telephone service provider, fiber, microwave and so on and be distributed to another building via copper conductors (for example, STP). The site links in the originating building **shall** be surge protected as described in the section for each link type. The inter-building cabling **shall** use Shielded Twisted Pair (STP) cables or a type of optical fiber link.

NOTE: Inter-building links of all-dielectric optical fiber are preferred because of their intrinsic immunity to transient surges and ground potential rise (see IEEE 1692-2023).

The following are the inter-building cabling surge protection and installation requirements:

- Within 61 cm (24 in.) of each building entry, inter-building cabling **shall** terminate to a demarcation point.
- At each demarcation point (both buildings), the cable **shall** be protected with a secondary SPD (see Table 7-9 on page 7-44).
- In high lightning areas, for cable runs exceeding approximately 30 m (100 ft) between the entry point SPD and customer network equipment, secondary surge protection is recommended at the site's network equipment as an added layer of protection. For critical site links, secondary surge protection should be considered regardless of the lightning activity.
- The secondary SPD **shall** meet the following requirements:
  - The SPD **shall** be designed for link type (for example, data speed and voltage levels).
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** be meet the listing and performance requirements of Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.
  - The SPD **shall** be designed for link type (for example, data speed and voltage levels).
- Refer to “Optical Fiber Links” on page 7-38 if the inter-building link is provided using optical fiber.

IMPORTANT: Ensure the SPD is rated for the data speed of the circuit. The SPD **shall not** reduce data rate.

IMPORTANT: If the buildings do not share a common grounding electrode system, the shield on the cable at one of the buildings **shall** be isolated as described in “Telecommunication Cable Metallic Shields” on page 5-127. Also see Caution in “Network Cable Installation and Routing” on page 9-46.

7.6.6 Telephone Exchange Protection

Primary surge protection of telephone exchange circuits is the responsibility of the telephone service provider (see NFPA 70-2026, Articles 742 and 800).

IMPORTANT: Primary surge protection provided by the telephone service provider does not negate the need for secondary surge protective devices.

7.6.6.1 Secondary Telephone Exchange Protection

Copper-based mission-critical and 911 system telephone lines require additional surge protection beyond the primary protection provided by the utility. The following are surge protection requirements for mission-critical and 911 system telephone lines.

IMPORTANT: The following requirements also apply to non-mission-critical telephone lines if the lines interface to mission-critical equipment (such as Admin lines on a 911 telephone system).

- Secondary SPDs **shall** be installed on 911 and other mission-critical lines.
- Secondary SPDs **shall** be installed as close as practicable to the telephone exchange equipment.
- The secondary SPD(s) **shall** meet the following requirements:
  - The SPD **shall** be designed for link type (for example, data speed and voltage levels).
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements described in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.

7.6.7 Computer Network Protection (Ethernet)

Small computer networks (in the same room or area) are not typically exposed to transients. As the computer network extends to other rooms and/or floors within the building, the exposure to transients increases. This exposure is increased if a communications tower is co-located with the building. Computer network cabling **shall** maintain the greatest physical separation from the tower as practicable, especially where the cable is installed parallel to the tower (vertical).

- Intra-room (within the same room) and/or intra-rack computer network cabling does not typically require SPDs.
- In high lightning areas, computer networking cabling extending to another room or area (inter-room), should have an appropriate secondary SPD installed at each end if the cable exceeds 30.5 m (100 ft) as an added layer of protection.
- Where used, the secondary SPD **shall** meet the following requirements:
  - The SPD **shall** be designed for link type (for example, data speed and voltage levels).
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements described in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors or short unused conductors to earth.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.
- Any outside connection to/from the computer network **shall** be surge protected as described in the section for each link type. Such connections may be the following:
  - Network monitoring link
  - Remote site link
  - Wide Area Network link

- Inter-building computer network cables **shall** be protected as described in “Inter-building Computer Network Protection” on page 7-42. Some examples are as follows:
  - A remote dispatch operator position installed in a different building.
  - A network management terminal installed in a different building.



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Figure 7-38. Example of Ethernet Surge Protective Device

IMPORTANT: SPDs **shall not** be installed on each end of a twisted pair cable shorter than 3.048 m (10 ft) unless the STP cable exits the communications shelter or building.

7.6.7.1 Inter-building Computer Network Protection

Computer networking cables (STP) are sometimes run from one building to another. A typical application might be from the radio building/shelter to the main building Radio Network System Administrator’s office for the purpose of running a radio network management terminal. Computer networking cabling entering or exiting the communications building/shelter **shall** be surge protected.

The following are the surge protection and installation requirements for inter-building computer network cabling:

- The inter-building computer networking cable **shall** be Shielded Twisted Pair (STP).
- Within 61 cm (24 in.) of each building entry, inter-building cabling **shall** terminate to a demarcation point.
- At each demarcation point (both buildings), the cable **shall** be protected with a secondary SPD:
  - The SPD **shall** be designed for link type (for example, Ethernet).
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements described in Table 7-9 on page 7-44.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.
- The SPD **shall** accept shielded connectors, making an electrical bond to the connector shields.

CAUTION: Avoid installing an inter-building shielded cable where practicable, because it may create a dangerous ground loop condition due to different electrical services and different grounding electrode systems.
If the buildings do not share a common grounding electrode system, the shield on the cable at one of the buildings SHALL be isolated as described in “Telecommunication Cable Metallic Shields” on page 5-127. Consultation with Motorola Solutions Engineering or other engineering firm is recommended in these situations.

7.6.8 Alarm and Control Circuits

Sites commonly have external alarm or control circuits for monitoring or controlling site equipment (for example, generator, gates, motion detectors, tower lighting, and so on). These alarms typically terminate to an M66 or 110 punch block near the Primary Bonding Busbar (PBB). These alarm circuits **shall** be surge protected using a secondary SPD as follows:

- The alarm or control circuits **shall** terminate to an M66 punch block or similar demarcation point within 61 cm (24 in.) of building entry.
- To help maintain single-point grounding integrity, the alarm or control circuit entry point **shall** be located as close as practicable to the PBB.
- Secondary SPDs **shall** be installed on all alarm or control circuits (inputs and outputs) entering or exiting the communications site. The secondary device **shall** meet the following requirements:
  - The SPD **shall** be designed for the purpose.
  - The SPD **shall** be of solid state construction.
  - The SPD **shall** meet the listing and performance requirements described in Table 7-9.
  - The SPD **shall** protect all cable conductors.
  - The SPD **shall** be bonded to earth according to “Surge Protective Devices” on page 5-122.
- Cable shields (if applicable) **shall** be bonded according to “External Ground Busbar” on page 4-46 or be bonded to the Primary Bonding Busbar (PBB) or entry point Secondary Bonding Busbar (SBB).

Alarm or control circuits that extend to a security/network monitoring center (or similar) via telephone service provider (or other service provider) links **shall** be protected as described in this chapter for the specific link type.

IMPORTANT: Unused alarm circuits that enter or exit the building **shall** be surge protected or shorted to earth at the demarcation point (M66 or 110 punch block).

NOTE: Alarm circuits for internal alarms (for example, door, temperature and so on) do not require surge protection.

7.6.9 Minimum Technical Requirements for Communication Circuit SPDs

Table 7-9 summarizes the characteristics required for SPDs installed on communication circuits at the site. Ensure that the SPDs selected conform to the performance qualifications listed, and are installed where indicated.

Table 7-9. Communication Circuit SPD Summary

Link Type	SPD Location	SPD Type	Listing Requirement	Manual Reference	Voltage Protection Level Performance Requirements
Telco Analog Site Link	At Building Entry	Primary (See NOTE 1)	UL 497	"Analog Site Links" on page 7-36	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet Vpl **shall** be no greater than 400 V
	As close to the protected equipment as practicable	Secondary	UL 497A or UL 497B		
Telco Digital Site Link	At Building Entry	Primary (see NOTE 1)	UL 497	"Digital Site Links" on page 7-37	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 400 V.
	As close to the protected equipment as practicable	Secondary	UL 497A or UL 497B		
Optical Fiber	As close to the protected equipment as practicable (see NOTE 2)	Secondary	UL 497A or UL 497B	"Optical Fiber Links" on page 7-38	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 400 V.
Optical Fiber Links Terminated Outside the Radio Shelter (see NOTE 3)	At Building Entry	Secondary	UL 497A or UL497B	"Optical Fiber Links Terminated Outside the Radio Shelter" on page 7-39	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet Vpl **shall** be no greater than 400 V.
	As close to the protected equipment as practicable	Secondary	UL 497A or UL497B		

NOTE 1: Primary SPD is the responsibility of the service provider.
NOTE 2: SPD is recommended in high lightning areas if cable from NID (or microwave) to customer equipment is longer than 30 m (100 ft).
NOTE 3: The fiber demarcation point is located outside the building (for example, on an H-frame). Copper conductors (STP) are used to extend the link into the building.
NOTE 4: SPD is recommended in high lightning areas if cable from microwave multiplexer to customer equipment is longer than 30 m (100 ft).
NOTE 5: SPD is recommended in high lightning areas if cable from building demarcation point to customer equipment is longer than 30 m (100 ft).
NOTE 6: SPD is recommended in high lightning areas if cable from inter-building cabling demarcation point to the link source is longer than 30 m (100 ft).

Table 7-9. Communication Circuit SPD Summary (continued)

Link Type	SPD Location	SPD Type	Listing Requirement	Manual Reference	Voltage Protection Level Performance Requirements
Microwave Links	As close to the protected equipment as practicable (see NOTE 2)	Secondary	UL 497A or UL497B	"Microwave Links" on page 7-39	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 400 V.
	As close to the microwave multiplexer equipment as practicable (see NOTE 4)	Secondary			
Inter-building Cabling Links	Within 61 cm (24 in.) of building entry (both buildings)	Secondary	UL 497A or UL497B	"Inter-building Cabling Links" on page 7-40	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet Vpl **shall** be no greater than 200 V
	As close to the protected customer equipment as practicable (see NOTE 5)	Secondary	UL 497A or UL497B	"Inter-building Cabling Links" on page 7-40	
	As close to the link source equipment as practicable (see NOTE 6)	Secondary	UL 497A or UL497B		
Secondary Telephone	As close to the protected equipment as practicable	Secondary	UL 497A or UL497B	"Secondary Telephone Exchange Protection" on page 7-41	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 400 V.

NOTE 1: Primary SPD is the responsibility of the service provider.
NOTE 2: SPD is recommended in high lightning areas if cable from NID (or microwave) to customer equipment is longer than 30 m (100 ft).
NOTE 3: The fiber demarcation point is located outside the building (for example, on an H-frame). Copper conductors (STP) are used to extend the link into the building.
NOTE 4: SPD is recommended in high lightning areas if cable from microwave multiplexer to customer equipment is longer than 30 m (100 ft).
NOTE 5: SPD is recommended in high lightning areas if cable from building demarcation point to customer equipment is longer than 30 m (100 ft).
NOTE 6: SPD is recommended in high lightning areas if cable from inter-building cabling demarcation point to the link source is longer than 30 m (100 ft).

Table 7-9. Communication Circuit SPD Summary (continued)

Link Type	SPD Location	SPD Type	Listing Requirement	Manual Reference	Voltage Protection Level Performance Requirements
Computer Network (Ethernet)	Recommended in high lightning areas on each end of an inter-room cable if the cable is longer than 30.5 m (100 ft)	Secondary	UL 497A or UL 497B	"Computer Network Protection (Ethernet)" on page 7-41	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 50 V for signal-only Ethernet and no greater than 200 V for PoE.
Computer Network (Ethernet) Outside Connection	Computer network cabling that extends outside the site **shall** be protected as described in the following sections: •"Digital Site Links" on page 7-37 •"Optical Fiber Links" on page 7-38 •"Optical Fiber Links Terminated Outside the Radio Shelter" on page 7-39 •"Microwave Links" on page 7-39 •"Inter-building Cabling Links" on page 7-40 •"Computer Network Protection (Ethernet)" on page 7-41				Refer to specific requirements for link type.
Inter-building Computer Network	Within 61 cm (24 in.) of building entry (both buildings)	Secondary	UL 497A or UL 497B	"Inter-building Computer Network Protection" on page 7-42	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 50V for signal-only Ethernet and no greater than 200V for PoE.
Alarm or Control Circuits (External)	Within 61 cm (24 in.) of building entry	Secondary	UL 497A or UL 497B	"Alarm and Control Circuits" on page 7-43	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 100V.

NOTE 1: Primary SPD is the responsibility of the service provider.
NOTE 2: SPD is recommended in high lightning areas if cable from NID (or microwave) to customer equipment is longer than 30 m (100 ft).
NOTE 3: The fiber demarcation point is located outside the building (for example, on an H-frame). Copper conductors (STP) are used to extend the link into the building.
NOTE 4: SPD is recommended in high lightning areas if cable from microwave multiplexer to customer equipment is longer than 30 m (100 ft).
NOTE 5: SPD is recommended in high lightning areas if cable from building demarcation point to customer equipment is longer than 30 m (100 ft).
NOTE 6: SPD is recommended in high lightning areas if cable from inter-building cabling demarcation point to the link source is longer than 30 m (100 ft).

Table 7-9. Communication Circuit SPD Summary (continued)

Link Type	SPD Location	SPD Type	Listing Requirement	Manual Reference	Voltage Protection Level Performance Requirements
Alarm or Control Circuits that Extend Outside the Site	Alarm circuits that extend to an alarm monitor service or device via telephone service provider (or other service provider) or other link **shall** be protected as described in the section for the type of link.				Refer to specific requirements for link type.
Video Security and Access Control (STP Cables)	Within 61 cm (24 in.) of building entry	Secondary	UL 497A or UL 497B	"Video, Security, and Access Control" on page 7-48	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 100V.
Broadband Point-to-Point and Multi-point (STP Cables) Power over Ethernet (PoE)	Within 61 cm (24 in.) of building entry	Secondary	UL 497A or UL 497B	"Broadband Point-to-Point and Multi-point Wireless Links" on page 7-50	Supplier **shall** include Voltage Protection Level at Rated In on published datasheet. Vpl **shall** be no greater than 50V for signal-only Ethernet and no greater than 200V for PoE.
	Within 61 cm (24 in.) of outdoor radio	Secondary	UL 497A or UL 497B		
NOTE 1: Primary SPD is the responsibility of the service provider. **NOTE 2:** SPD is recommended in high lightning areas if cable from NID (or microwave) to customer equipment is longer than 30 m (100 ft). **NOTE 3:** The fiber demarcation point is located outside the building (for example, on an H-frame). Copper conductors (STP) are used to extend the link into the building. **NOTE 4:** SPD is recommended in high lightning areas if cable from microwave multiplexer to customer equipment is longer than 30 m (100 ft). **NOTE 5:** SPD is recommended in high lightning areas if cable from building demarcation point to customer equipment is longer than 30 m (100 ft). **NOTE 6:** SPD is recommended in high lightning areas if cable from inter-building cabling demarcation point to the link source is longer than 30 m (100 ft).					

NOTE: When selecting an SPD for signal circuits or low voltage DC power circuits (no more than 62 VDC), the maximum voltage limiting of the SPD **shall** match closely to the operating voltage of circuit to be protected, up to +25%. Ensure that the SPD is a solid state voltage limiting circuit, not a fault limiting circuit, fuse, or crowbar device.

7.7 Video, Security, and Access Control

Each video, security, and access control system cable entering a communications facility **shall** be surge protected (see ATIS-0600334.2019(R2024), section 11.5). Where an RF cable entry panel is available, these cables **shall** enter the facility through an available cable port. Where an RF cable entry port is not available, cables **shall** enter as close as practicable to the point where the power and telephone conductors enter a facility. See Figure 7-1 on page 7-3 for examples.

NOTE: Under an engineer's guidance, if the video, security, and access control equipment, including the related cables, are installed in a protected location such as under a roof eave, an SPD may not be required at the building entry point. However, a secondary SPD should be installed at the interior equipment, such as at the IP camera router. If the cable is shielded, it **shall** be bonded to the nearest practical location on the Internal Bonding and Grounding system, such as to the IPBB, Halo Ground Ring, an SBB, or the PBB (see Chapter 5 for details). See Figure 7-39 and Figure 7-40 for examples.

Where cables enter the building through an RF cable entry panel, they **shall** be bonded to the External Ground Busbar (EGB) using an appropriate grounding kit, as described in the section “External Ground Busbar” on page 4-46.

If an RF cable entry panel is not present at the site, the cables **shall** enter the building as near as practicable to the electrical system or telecommunications (telco) entry point, using a suitable entry device such as a feed-through conduit. If the cable is accessible outside the building, it **shall** be bonded to the grounding electrode system using an appropriate grounding kit before entering the building. This typically requires installing a small busbar near the cable entry point and bonding it to the grounding electrode system using conductors and techniques described in Chapter 4, “External Grounding (Earthing) and Bonding.”

If the cable is inaccessible outside the building, it **shall** be bonded as close as practicable to the PBB, entry point SBB, the IPBB, or the Halo Ground Ring using conductors and techniques described in Chapter 5, “Internal Bonding and Grounding (Earthing)”.

For some applications, such as building-mounted cameras using a dedicated conduit feed-through to enter the shelter, grounding the cable shield at the entry point may not be practicable. In these applications, the shield **shall** be bonded to the PBB, an entry point SBB, the IPBB, or the Halo Ground Ring at the nearest practicable location. See Figure 7-39 and Figure 7-40 for examples.



Figure 7-39. Outdoor Camera Example



Figure 7-40. Corner-Mounted Camera Example

SPDs **shall** be selected based on the application. Fixed camera systems can be powered with AC, DC, or Power over Ethernet (PoE). Consult with the equipment manufacturer before selecting the SPD. If the camera is critical to the customer operation and is installed in an exposed location, such as on the tower or at a remote fence post, it is recommended to install an SPD as close as practicable to the camera. Video, Security, and Access Control SPDs **shall** meet the requirements of Table 7-9 on page 7-44 for Shielded Twisted Pair (STP) cable and Table 7-10 on page 7-62 for coaxial cable.

7.8 Broadband Point-to-Point and Multi-point Wireless Links

Broadband wireless links are a low-cost alternative to microwave links. Broadband wireless links are used for local area networks, security systems, and for metering circuits. Backhaul and access point products are available for licensed or unlicensed frequencies, are relatively inexpensive, and are easy to install. Failure to protect against surges as directed in this chapter will reduce network performance and maintainability, and subject co-located equipment to potentially catastrophic lightning damage. See Figure 7-41, Figure 7-42, and Figure 7-43 for examples.

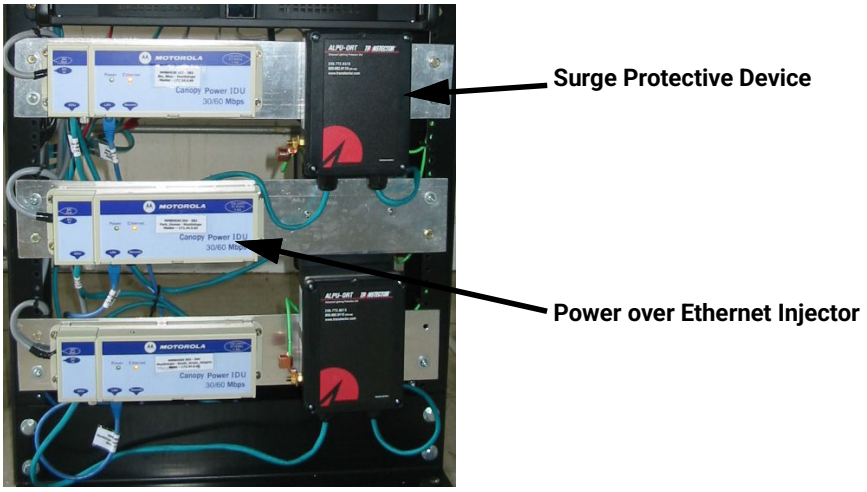


Figure 7-41. Example of SPD for Power over Ethernet Injector

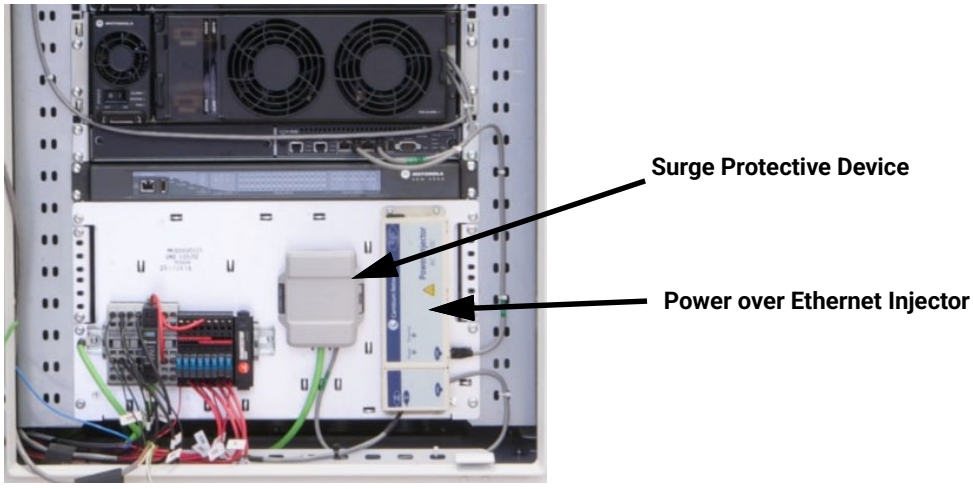


Figure 7-42. Example of Surge Protective Device for Power over Ethernet Injector in Outdoor Cabinet

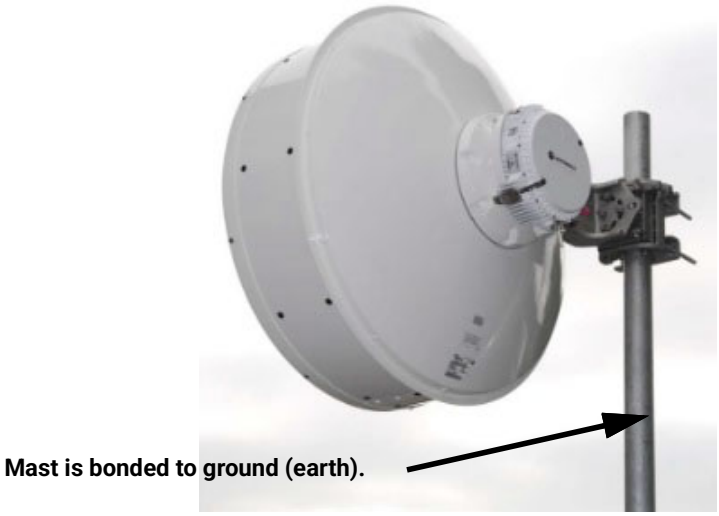


Figure 7-43. Example of Broadband Wireless Radio

Broadband radio installations **shall** meet the following requirements:

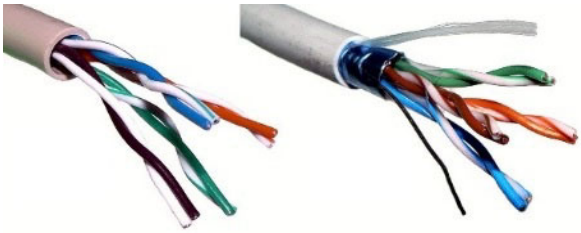
- Installation **shall** meet the manufacturer's requirements.
- Installation **shall** use shielded twisted pair cables (STP), such as CAT 5/6a/8, as applicable (unshielded **shall not** be used). See Figure 7-44.
- Tower-mounted devices (including associated external SPDs) **shall** be bonded to the tower according to “Bonding of RF Preamplifiers and Other Active Devices on Towers” on page 4-102 and “Tower-Mounted Devices” on page 4-139.
- Internally installed devices **shall** be bonded and grounded according to Chapter 5, “Internal Bonding and Grounding (Earthing)”.
- Grounding and bonding conductors **shall** meet the minimum bending radius requirements as described in Chapter 4, “External Grounding (Earthing) and Bonding”, and Chapter 5, “Internal Bonding and Grounding (Earthing)”.
- RF and STP cables **shall** meet the minimum bending radius requirements as described in Chapter 9, “Equipment Installation”.
- RF and STP cables **shall** be cut to length, unless otherwise directed by the equipment manufacturer.
- RF and STP cable shields **shall** be bonded to the tower as close as practicable to the outdoor wireless radios (see “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104).
- RF and STP cable shields **shall** be bonded to the tower (if applicable) as described in “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104.
- RF and STP cable shields **shall** be bonded at the point of entry into the communications facility as described in “External Ground Busbar” on page 4-46 and “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104.
- STP cables **shall** maintain a minimum separation from other cables as described in “Cable Separation” on page 7-34. Maintaining minimum separation between STP cables, current carrying conductors, and RF transmission lines is important to Ethernet and Power over Ethernet (PoE) performance.
- Surge Protective Devices (SPD) **shall** be installed as follows:
  - Within 61 cm (24 in.) upon entry to the communications facility.
  - As close as practicable to the outdoor radio unit; within 91.44 cm (3 ft) is recommended.
  - See Figure 7-45 and Figure 7-50.

SPDs protecting wireless broadband radios and switches **shall** meet the minimum specifications of Table 7-9 on page 7-44 for STP cables and Table 7-10 on page 7-62 for coaxial cables. SPDs on STP **shall** be solid state devices.

SPDs used for outdoor Ethernet or PoE **shall** be solid state circuits housed in outdoor-rated enclosures. See Figure 7-45.

IMPORTANT: Unshielded Twisted Pair (UTP) **shall not** be used for cable runs extending outside the facility.

IMPORTANT: Shielded Twisted Pair (STP) cable used between the cable entry port and broadband radios **shall** be rated for outdoor use (Figure 7-44 and Figure 7-45), preferably a rigid shield type. Cable shields **shall** be bonded as close as practicable to the radio and to the cable entry point to buildings and cabinets. See “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104 for more information.



UTP Cable **STP Cable**

Figure 7-44. Unshielded Twisted Pair (UTP) and Shielded Twisted Pair (STP) Cables

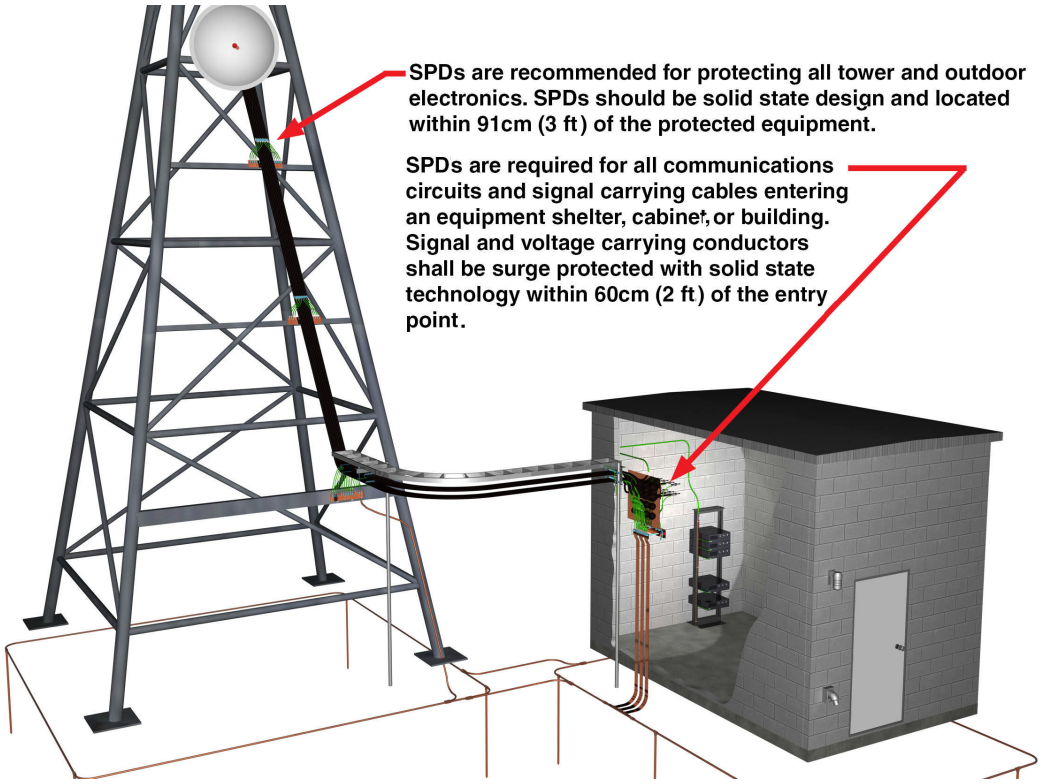


Figure 7-45. SPD Locations for Broadband Wireless Radios

7.9 Satellite and Television Broadband Services

Satellite and television broadband service receivers **shall** be installed in accordance with this chapter and NFPA 70-2026 (see Figure 7-46).

Satellite and television broadband service Customer edge Premises Equipment (CePE) demarcation point **shall** be surge protected as follows:

- Cable shields **shall** be bonded at the point of entry into the communications facility as described in "External Ground Busbar" on page 4-46 and "Grounding and Bonding of RF Transmission Lines and Communications Cables" on page 4-104. See NFPA 70-2026, Article 750 and other related articles.
- An SPD **shall** be installed within 61 cm (24 in.) upon entry to the communications facility.

NOTE: An SPD for satellite and television is typically 75 ohms, versus 50 ohms for typical Land Mobile Radio.

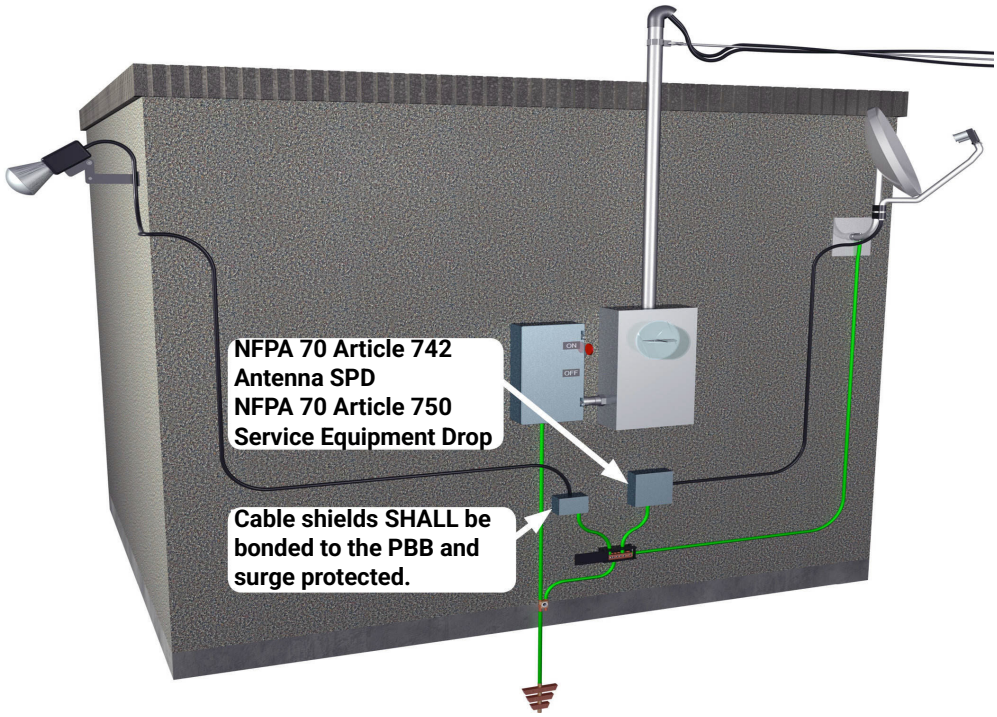


Figure 7-46. Bonding and Surge Protection for Cable and Satellite Television, Telephony and Broadband Cables

7.10 RF Surge Protection

Coaxial cables, waveguides and wireless broadband cables typically enter a building or shelter through a dedicated building entrance panel (see Figure 7-47). Each RF coaxial cable **shall** be protected from surges with an RF SPD (ATIS-0600313.2019, section 6.4; IEEE 1692-2023, section 8.8; MIL-HDBK-419A; and NFPA 780-2026, section 4.19.4).

For dedicated communications buildings or shelters, the RF SPD **shall** be installed within 61 cm (24 in.) of entry into the facility. See Figures 7-47 through 7-55 for examples.

IMPORTANT: RF coaxial and waveguide shields **shall** be bonded to the tower (if applicable) as described in “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104. RF and waveguide shields **shall** be bonded at the point of entry into the communications facility as described in “External Ground Busbar” on page 4-46 and “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104. See Figure 7-47.

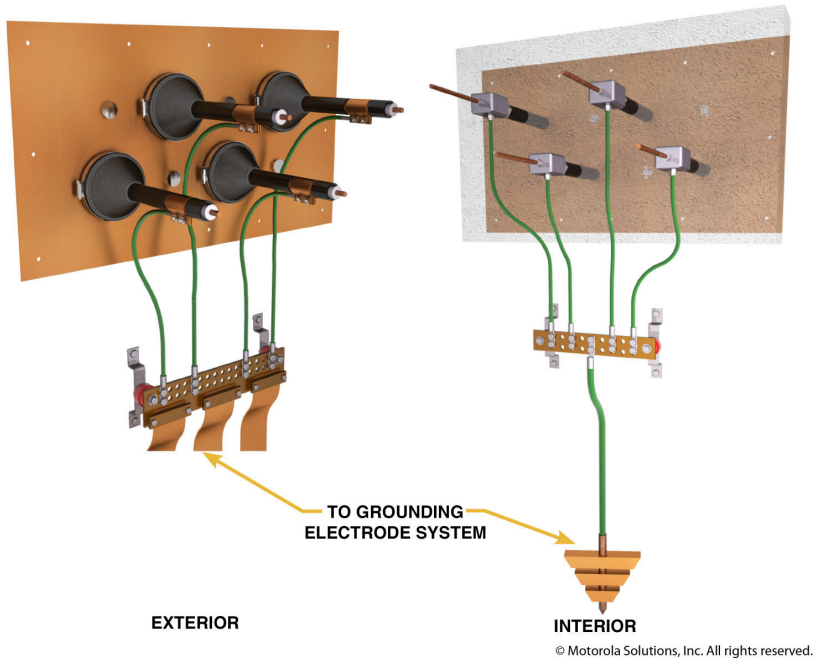


Figure 7-47. Transmission Line Grounding at Building Entry Point and Surge Protective Device Installation

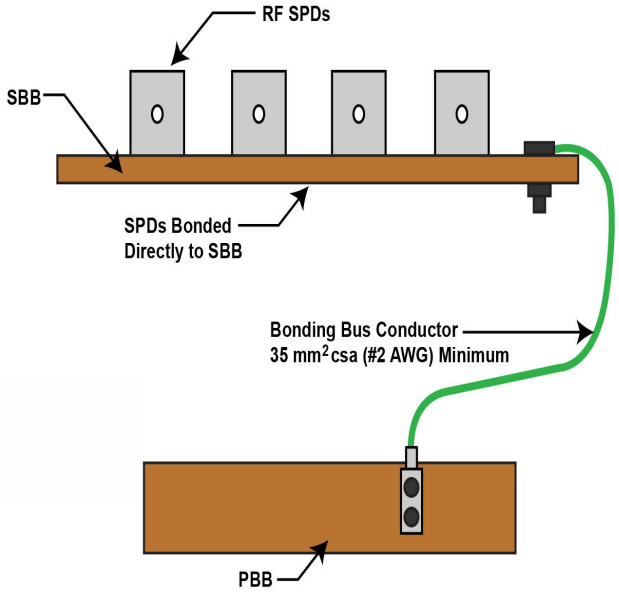


Figure 7-48. Bonding of RF Surge Protective Devices to Secondary Bonding Busbar with Bonding Bus Conductor

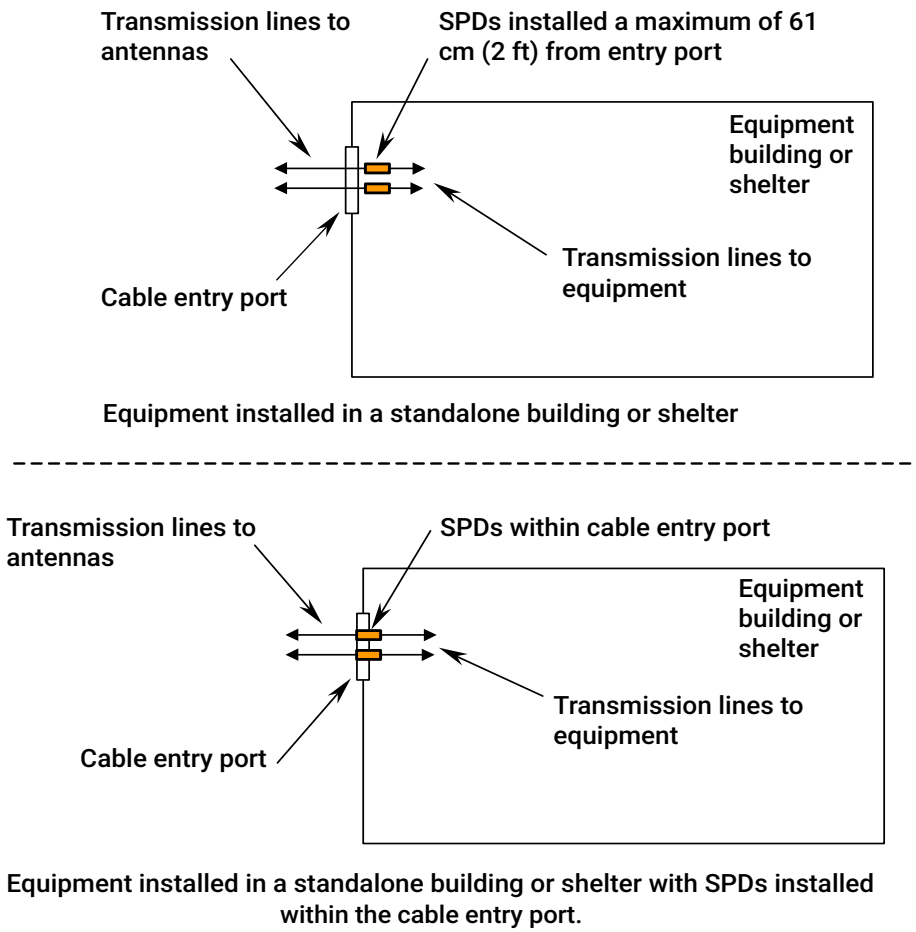


Figure 7-49. Installation Locations for RF Transmission Line Surge Protective Devices

For equipment installed in an equipment room or area within a larger building, the SPD **shall** be positioned in a location that allows for easy maintenance and ensures the most direct and downward connection to the earth.

The optimal location will depend on factors such as the building's construction type and the specific placement of the equipment room. In steel-framed buildings, this may involve positioning and bonding the SPD near a convenient vertical steel column. In other building types, it could involve selecting a location near the exterior wall that enables a direct down conductor installation to the common grounding electrode system.

The building plans should be reviewed to verify that the vertical steel column is adequately bonded to the common grounding electrode system. See Figure 7-51 and Figure 7-52.

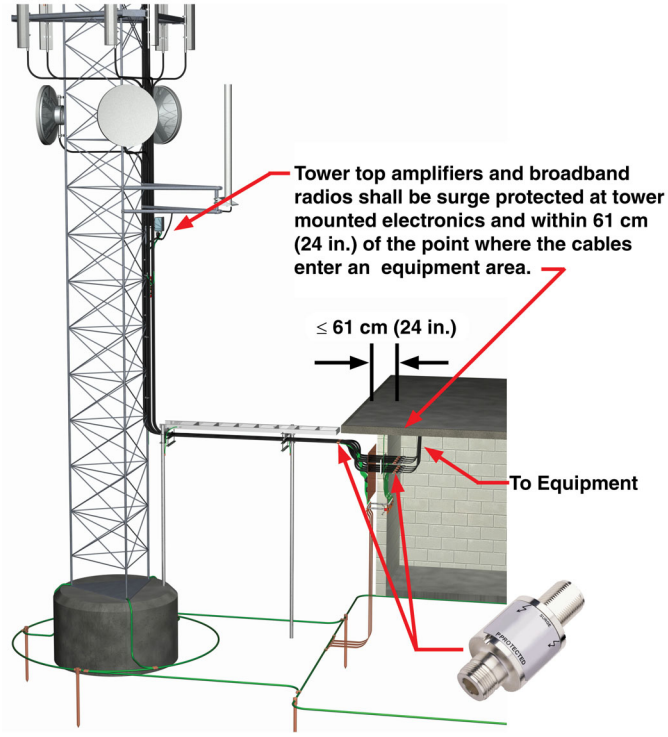


Figure 7-50. Example of Typical Installation of RF SPDs for Standalone Shelter or Building

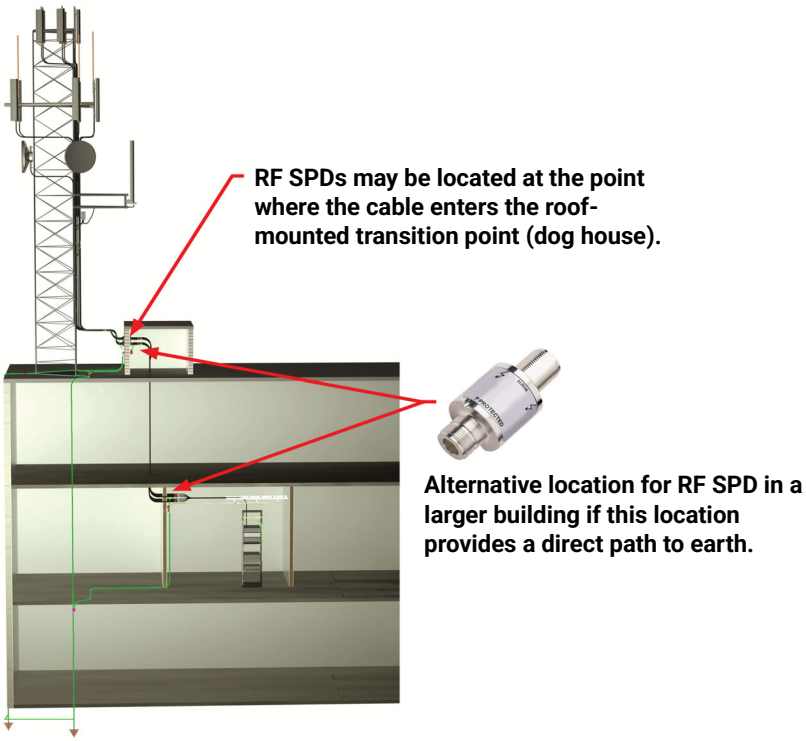


Figure 7-51. Example of Typical Installation of RF SPDs for a Larger Structure

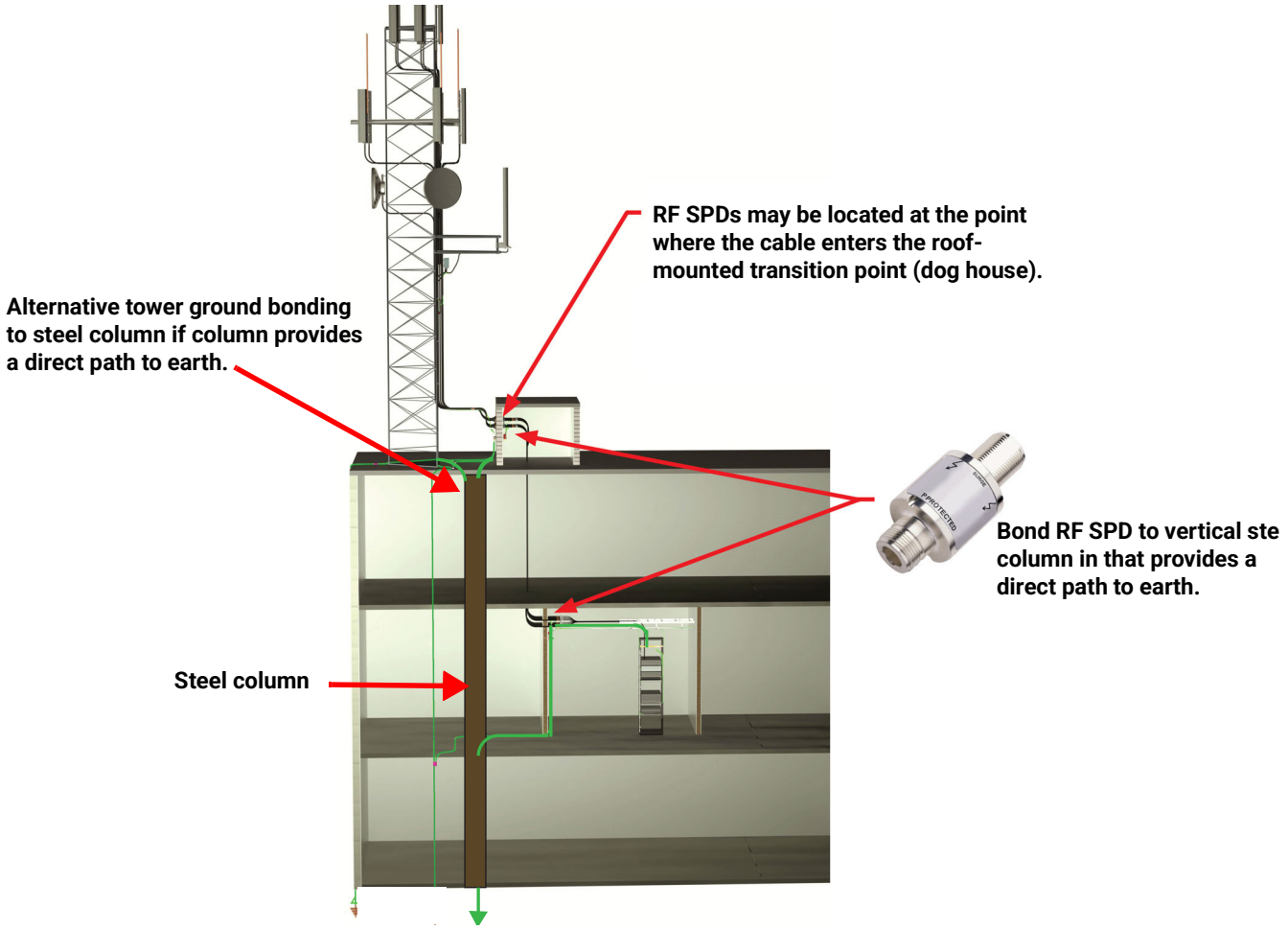


Figure 7-52. Example of Installation of RF SPDs for a Larger Structure, SPDs Bonded to Structural Steel Column

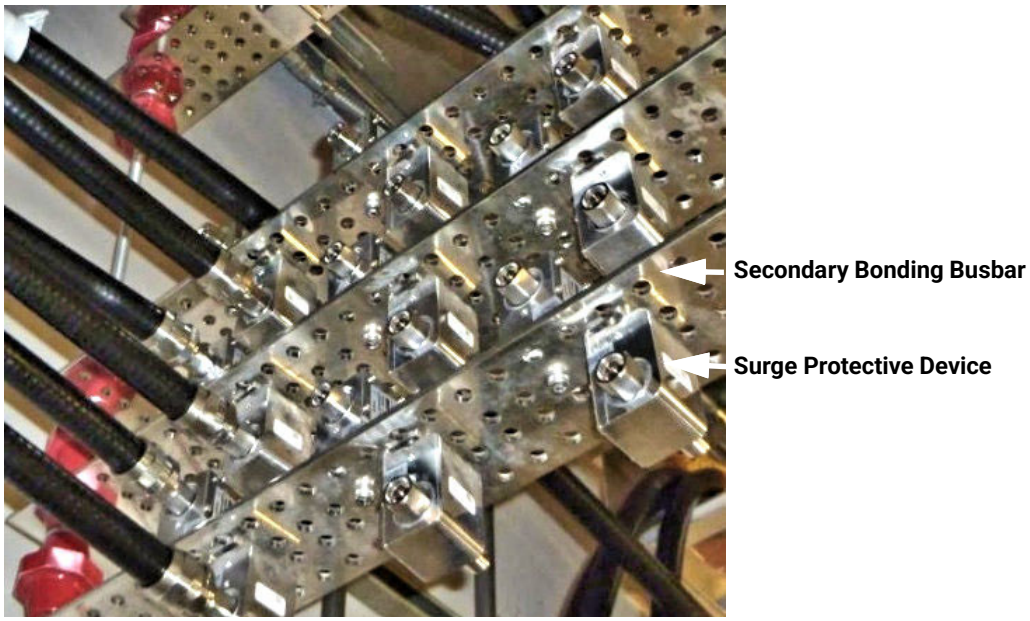


Figure 7-53. Example of RF Surge Protective Device Entry Trapeze Assembly

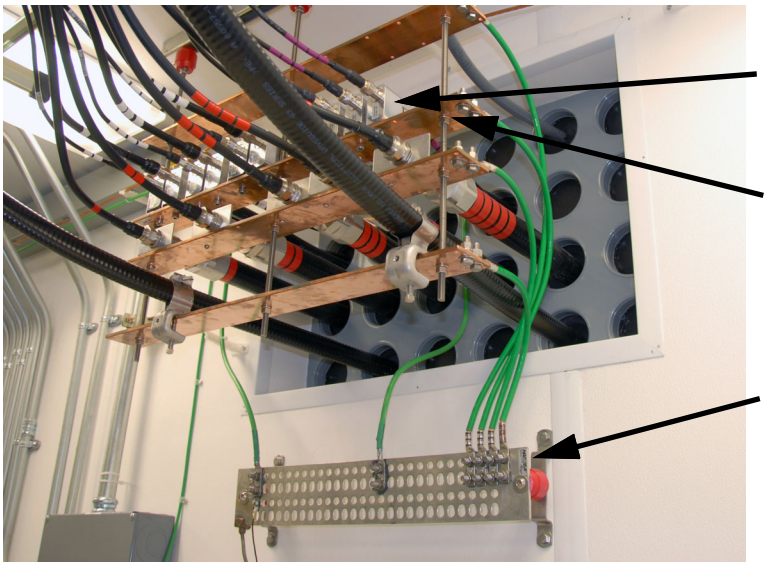


Figure 7-54. Example of RF Surge Protective Devices Bonding and Grounding Directly to Secondary Bonding Busbars

NOTE: Skin effect is the tendency of an electrical current to pass through the outer portion or "skin" of a metallic conductor, rather than through the center. The skin effect is a phenomenon associated with high-frequency signals (higher than 50 kHz or so). The higher the frequency, the greater the effect. Flat strap has less skin effect than a round conductor, and is therefore the preferred method to ground an RF SPD (see Figure 7-55). See *Newton's Telecom Dictionary*.

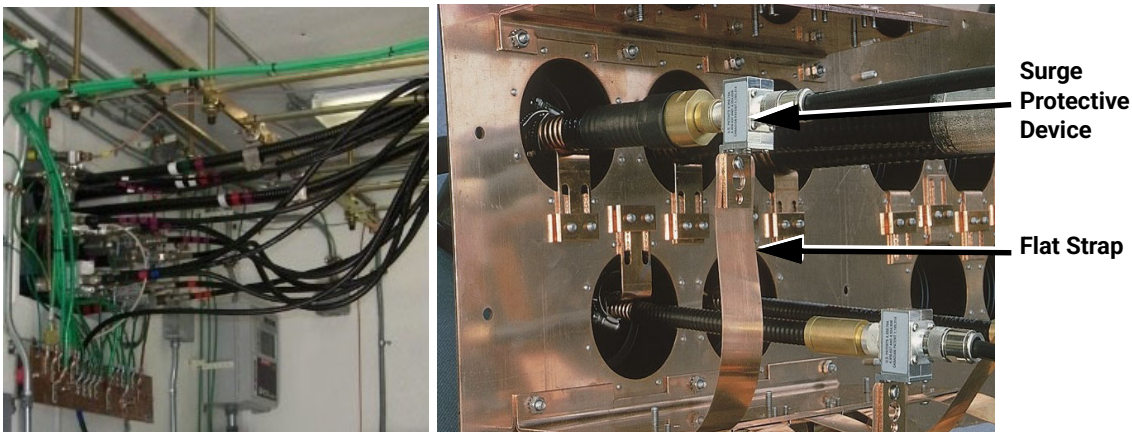


Figure 7-55. Examples of RF SPD Bonding - Round Conductor and Flat Strap (Preferred)

IMPORTANT: All coaxial cables (including unused spares) entering the communications facility **shall** be bonded and grounded as described in Chapter 4, "External Grounding (Earthing) and Bonding". These coaxial cables **shall** also have RF SPDs installed as described in this chapter. Unused coaxial cables entering the communications facility **shall** be terminated at the RF SPD with a short or 50 ohm load.

7.10.1 RF Surge Protection Design

Coaxial SPDs are low impedance filters or lightning arresters designed as either DC Pass or DC Block (see Figure 7-56). The DC Pass SPD is designed to allow a prescribed level of DC power to travel on the coaxial cable to power tower-mounted electronics (for example, a tower-top amplifier). DC Block is designed to block all DC signals, allowing only RF frequencies to pass through the device. RF SPDs equalize lightning voltage between the shield and the center pin and allow for wideband lightning events to be shunted away from the equipment it is protecting. See Table 7-10 on page 7-62 for recommended RF SPD requirements.

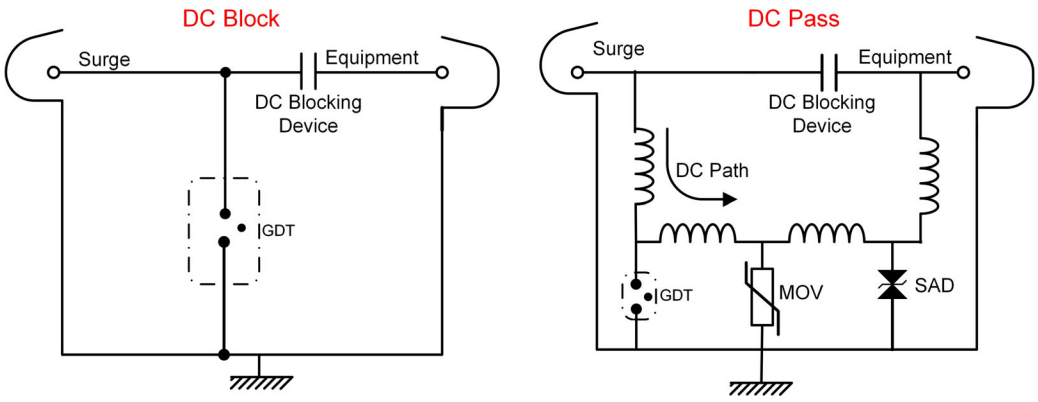


Figure 7-56. Examples of DC Block and DC Pass RF SPD Circuits

7.10.2 RF Surge Protection Technology Overview

Three common technologies are used in the design of RF surge protective devices:

- Simple Gas Tube Designs
  - Replaceable Gas Tube (RGT), DC pass
  - Non-replaceable gas tube, DC Pass (not recommended for critical deployments)
  - Low frequency gas tube, DC block
- Quarter Wave Stub
  - DC Short
  - DC Pass – Hybrid incorporating a gas tube
- Broadband High Band Pass Filter
  - DC Block
  - DC Pass - RF filter incorporating hybrid solid state and gas tube

7.10.2.1 Gas Tube RF SPDs

A straight gas tube-based coaxial protector without DC blocking (Figure 7-57) has DC continuity from the surge-side connector center pin to the equipment-side connector center pin. The fast rise-time lightning pulse can produce a high magnitude voltage across the gas tube before the gas can ionize and begin to conduct. Because there is no DC blocking mechanism, this high voltage impulse is applied directly to the equipment input before the gas tube “turns on.”

Do not assume that a 90V gas tube will provide a 90V protection level for the equipment, because the voltage rating is based on a static DC voltage measurement. The gas tube is essentially a voltage dependent switch that reacts to the dv/dt of a lightning impulse. The typical voltage breakdown level for a 5kV/µs impulse is approximately 700 V_p.

Straight gas tube protection devices allow DC power to be supplied to the tower-top electronics, but also allow higher let-through energy to pass to the equipment as compared to other RF SPD types. It is important to understand the operating characteristics of this protection technology. Tower-top electronics consists of semiconductor-based preamplifiers, power supplies, diplexers, telemetry and so on. Coordination of protection levels of the gas tube-based devices and the susceptibility of the protected electronics must be taken into account.



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Figure 7-57. Example of Typical Replaceable Gas Tube Type RF SPD

IMPORTANT: Gas tube arresters are generally not recommended for mission-critical applications due to their inherent operating characteristics. Lightning strikes create extremely fast, high-voltage transients, with rise times often peaking in under 8 microseconds. This rapid surge can allow destructive energy to bypass the gas tube and damage sensitive equipment before the gas inside has time to ionize and divert the surge. Furthermore, gas tube arresters have a finite lifespan and degrade with each surge event. For this reason, if they are used, the gas discharge tube component should be replaced every one to two years to help ensure reliable operation.

The let-through energy of gas tube-style RF SPDs can be greatly decreased by adding a blocking capacitor. This component narrows the RF passband and blocks DC power from reaching tower-top electronics. Whenever feasible, using a blocking capacitor is preferable to a standard gas tube SPD for enhanced equipment protection. See Figure 7-58.



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Figure 7-58. Example of Gas Tube RF SPD with DC Blocking Capacitor

7.10.2.2 Quarter Wave Stub

The “Quarter Wave Stub” coaxial protector is based on the well-known bandpass/band-reject principle. Using a coaxial **T** fitting and calculating the length of a quarter-wave coaxial section from the horizontal center conductor to the grounded base of the **T** can form a bandpass filter at a given frequency. Because most of the energy in a lightning strike is from DC to 1 MHz, it falls on the lower frequency reject side of the bandpass filter and is conducted to ground. However, because the equipment input is usually DC-shorted to chassis or earth and because the quarter-wave stub is connected to earth with an inductive copper conductor, there will be divided DC and low-frequency energy flowing into the equipment input.

Quarter-wave devices cannot be used where DC currents and voltages are required to power RF electronics. As tuned devices, they have relatively narrow operating bandwidths (approximately ±10% of the operating frequency).



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Figure 7-59. Example of Quarter Wave Stub Type RF SPD

7.10.2.3 Filter-based Coaxial Protectors

Filter-based lightning protection devices are characterized by their broadband performance characteristics and can cover multiple transmit/receive frequency bands. These cavity-based designs act as bandpass filters and consist of tuned inductive capacitance (LC) networks operating on a bandpass/band-reject principle, with an operating band as broad as 2.7 GHz. Utilizing the inductive current discharge circuit to shield/ground, followed by a DC blocking capacitive component on the center pin, ensures not only broadband RF performance, but also the desired surge suppression characteristics. Designs based on this principle allow a closer match to 50 ohms over a broader range than the quarter-wave technique. These devices can also be designed for use in applications where DC power is supplied to the RF electronics via the coaxial cable's center conductor, by combining DC blocking for the RF and a separate path protected by a gas discharge tube for the DC power.

The SPD **shall** be selected based on the application.



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Figure 7-60. Example of DC Block High Pass Filter Type RF SPD



Image courtesy of Polyphaser. Copyright ©2026, Infinite Electronics, Inc.

Figure 7-61. Example of DC Pass High Pass Filter Type RF SPD

7.10.3 RF SPD Qualifications

The RF SPD used **shall** meet the specific requirements of the application (see ATIS-0600334.2019(R2024), section 7.8.1.3, for more information). Motorola Solutions recommends the following minimum specifications:

Table 7-10.Minimum RF SPD Qualifications

RF SPD Qualifications		
Parameter	**Value**	**Notes**
Listing	UL 497E	
Mounting	Flange or bulkhead	Site specific according to the entry panel style.
Connector Type	Application specific	Type N, 7-16 DIN, or 4.3-10 for RX and single channel TX. 7-16 DIN or 4.3-10 type for combined TX channels (multi-carrier), single channel Tx, and Rx. Adapters **shall not** be used.
Frequency Range	Application specific	Operating frequency range of the system.
Continuous RF Power Rating	Application specific	To be determined by the system engineer.
Maximum Peak Instantaneous Power Rating	Application specific to be determined by the system engineer.	Must be considered when selecting suitable lightning protectors for multi-carrier transmitter combiner applications for P25 Phase 2, TETRA, and similar digital modulations. Consultation with the system engineer and/or SPD manufacturer is recommended.
Return Loss (VSWR)	26 dB (1.1:1) for DC Blocking 21 dB (1.2:1) for DC passing	Over the specified frequency range of the SPD.
Maximum Insertion Loss	0.1 dB for DC Blocking 0.3 dB for DC Passing	Over the specified frequency range of the SPD.
DC Pass	Application specific	Typical for systems using tower mounted amplifier or tower-top amplifier.
Surge Rating	40 kA maximum for a single test strike. 20 kA for multiple test strikes.	Using an IEC 61000-4-5 defined 8/20 µs waveform.
Let through Energy	No more than 0.005 µJ for DC Block No more than 200 µJ for DC Pass	Using a 3 kA 8/20 µs waveform.
Passive Intermodulation Rating **NOTE:** See "Perform PIM Analysis and PIM Sourcing for Antenna Network Components" on page 8-6 for more information and requirements.	Application specific. Where required: less than -150 dBc (-107 dBm)	Using IEC 62037-1 defined testing. PIM Rating required on the TX line for combined TX channels (multi-carrier). Passive Intermodulation Rating for RX channels is optional.
Minimum Weatherization	IEC 60529 IP67 Telcordia GR-487 Issue 6	
Restriction of Hazardous Substances (RoHS) Compliant	Yes	

IMPORTANT: Incorrect connector torque can result in degraded return loss and/or Passive Intermodulation performance.

NOTE: See “RF Cabling” on page 9-57 for information regarding connector installation techniques needed for optimal return loss and PIM performance.

7.10.4 Tower Electronics

Tower electronics (for example, a tower-top amplifier or tower mounted amplifier, access points, or wireless router) **shall** be bonded to the tower as described in “Tower-Mounted Devices” on page 4-139 (see Figure 7-62). Tower electronics **shall** be protected from surge events. Appropriate SPDs **shall** be installed and bonded to the tower as close as practicable to the tower mounted electronics and within 61 cm (24 in.) of the entry point to a communications facility.

RF SPDs **shall** meet the requirements of “RF Surge Protection” on page 7-53. Twisted pair cable SPDs **shall** meet the appropriate requirements detailed in Table 7-9 on page 7-44.

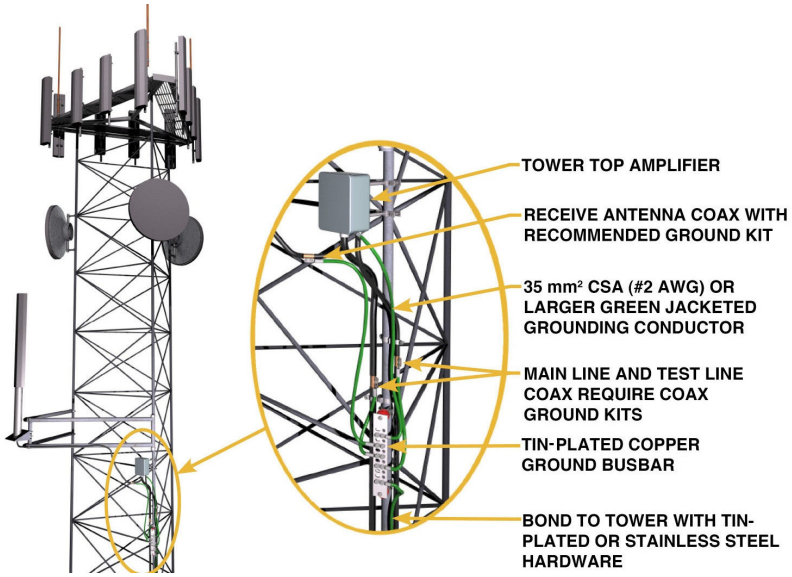


Figure 7-62. Tower Amplifier Grounding and Bonding

IMPORTANT: Though many tower-mounted amplifiers have RF SPDs integrated into the design, an RF SPD **shall** be installed at the communications facility entry point as described in this chapter.

7.10.5 GPS Receiver Protection

Global Positioning System (GPS) receivers are used for site timing and synchronization. Failure of a GPS receiver can render the radio site or system unusable. SPDs **shall** be installed on GPS signal cables as described in “RF Surge Protection” on page 7-53. The design of the GPS receiver system typically includes an amplified GPS antenna unit and low-loss transmission line. The GPS antenna includes a GaAsFET device wideband RF amplifier. The RF amplifier is fed with low-voltage DC, typically 5V (but as high as 15 VDC). The GPS receiver system can incorporate a multiplex arrangement using a single coaxial transmission line, which also couples the incoming GPS signal from the antenna to the receiver, or by RS422 twisted pairs.

Coaxial and twisted pair cables **shall** be bonded according to “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104.

IMPORTANT: In some installations, the GPS receiver may require optimization to compensate for the delay caused by the SPD and the site-specific variation in the length of the transmission line.

7.10.6 Tower Lighting

IMPORTANT: Tower strobe light controllers should be located outside of the shelter (see Figure 7-63).

If the tower lighting controller is installed within the building, shelter, room, or equipment area, it **shall** be located as close to the cable entry panel as practicable. All control unit metallic housings **shall** be bonded to the Internal Perimeter Bonding Bus (IPBB), Halo Ground Ring, Primary Bonding Busbar (PBB), or Secondary Bonding Busbar (SBB), based on their location.

Strobe lighting systems may utilize voltages exceeding 600 VDC. Therefore, installation of a surge suppressor on these power conductors to the strobe light heads is not reasonable and will not adequately reduce surge voltages that may enter the shelter. For this reason, it is recommended that tower lighting controllers be located outside the shelter (see Figure 7-63).

Voltage transients on the AC power, alarm, and control units located outside the shelter or building can be effectively suppressed by installing a suitable SPD at the conductors' entry points into the shelter, building, or equipment area.

Tower lighting AC power **shall** have a Type 2D SPD installed as described in "Type 2D External Branch Circuit Surge Protective Device" on page 7-24. The SPD **shall** meet the requirements of Table 7-7 on page 7-30.

Alarm or control cables **shall** be surge protected as described in "Alarm and Control Circuits" on page 7-43. The SPD **shall** meet the requirements of Table 7-9 on page 7-44.

Some tower lighting manufacturers offer an optional surge suppression device that may be installed within the tower lighting control unit. Although this device may be suitable for protecting the control unit circuitry, it does not adequately protect against energy that may enter the shelter through the tower lighting controller power or control conductors.

IMPORTANT: Tower lighting cables **shall not** be bundled along with transmission lines or other conductors anywhere within cable ladders or the building interior.

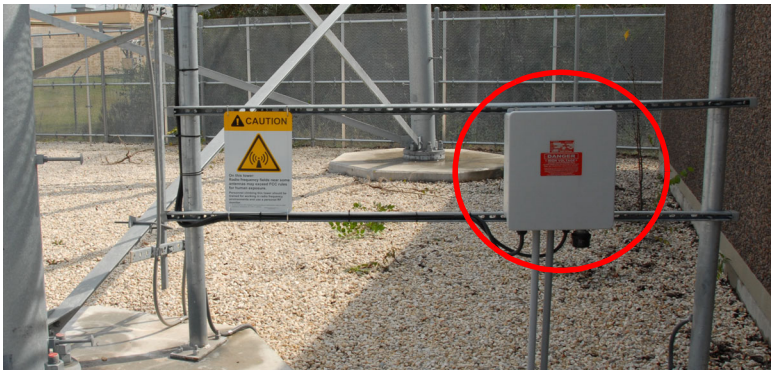


Figure 7-63. Tower Light Controller Installation

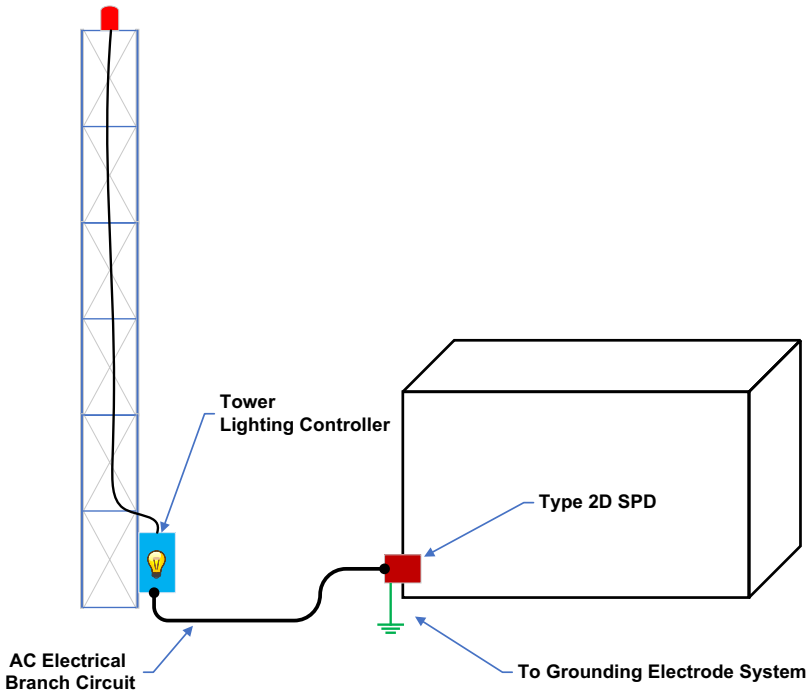
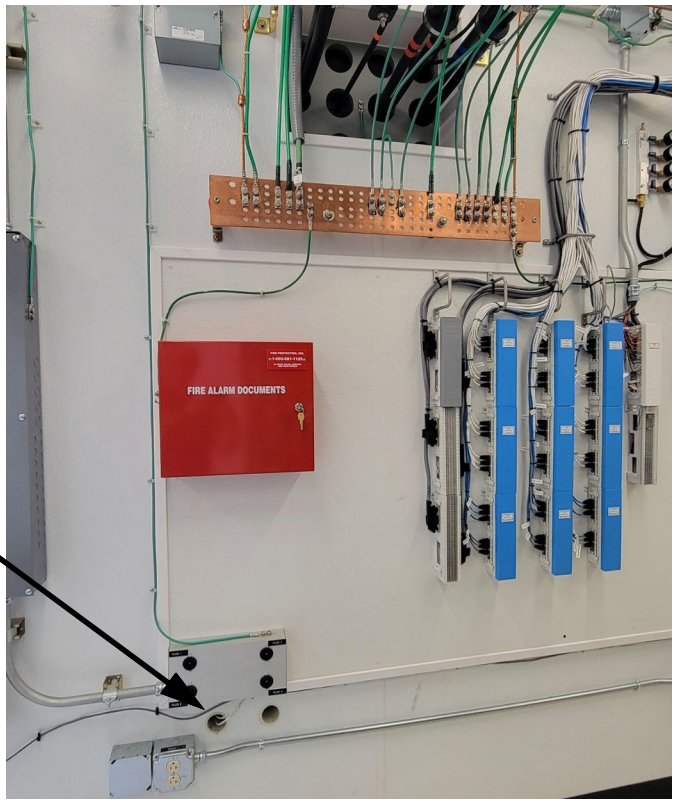


Figure 7-64. Example of Surge Protective Devices for Tower Lighting



Tower Lighting Alarm and Control cables exit building here.

Figure 7-65. Example of Tower Lighting Alarm and Control Cable Exit Point (Interior)



Figure 7-66. Example of Tower Alarm and Control SPD Installation Location (Exterior)

7.11 Surge Protection for Dispatch Centers and Operator Positions

Dispatch and command operation centers often house network core sites, data management and storage, personnel, and multiple antenna systems. The mission-critical nature of dispatch centers and the inherently higher risk to personnel from lightning discharge require a well-engineered common bonding and grounding backbone, and surge protection designed for overvoltage mitigation.

For improved safety of personnel, optimum protection and system availability, the following **shall** be considered for new designs and facility upgrades:

- Site design recommendations given in “Design Considerations to Help Reduce Effects of Lightning” on page 2-16.
- Internal bonding and grounding as defined in “Bonding and Grounding for Dispatch Centers and Network Operator Positions” on page 5-137.
- External grounding and bonding as defined in Chapter 4, “External Grounding (Earthing) and Bonding” and “Dispatch Centers Co-Located With Communications Towers” on page 4-135.
- Electrostatic Discharge (ESD) precautions as defined in Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”.
- Surge Protective Devices (SPD) as described in the following subsection.

7.11.1 Minimum SPD Requirements for Dispatch Centers and Operator Positions

- Type 2A, 2B, and 2C SPDs as shown in Table 7-2 and Table 7-3 on page 7-16, and associated figures.
- Type 3 SPD(s) as shown in Table 7-4 on page 7-18, and Operator Position Type 3 with grounding point as shown in Table 7-3 on page 7-16. See Figure 7-26 on page 7-27 and Figure 7-27 on page 7-28. The Type 3 Operator Position device external ground stud or connection point **shall** be bonded to the operator position bonding busbar (see ATIS-0600321.2020).
- Telephony, Video, Security, Access Control, Ethernet, PoE, Cable Television and Alarm Circuits **shall** be surge protected as described in this chapter.
- See Figure 7-67 and Figure 7-68 for examples of typical SPD installations at a dispatch center.

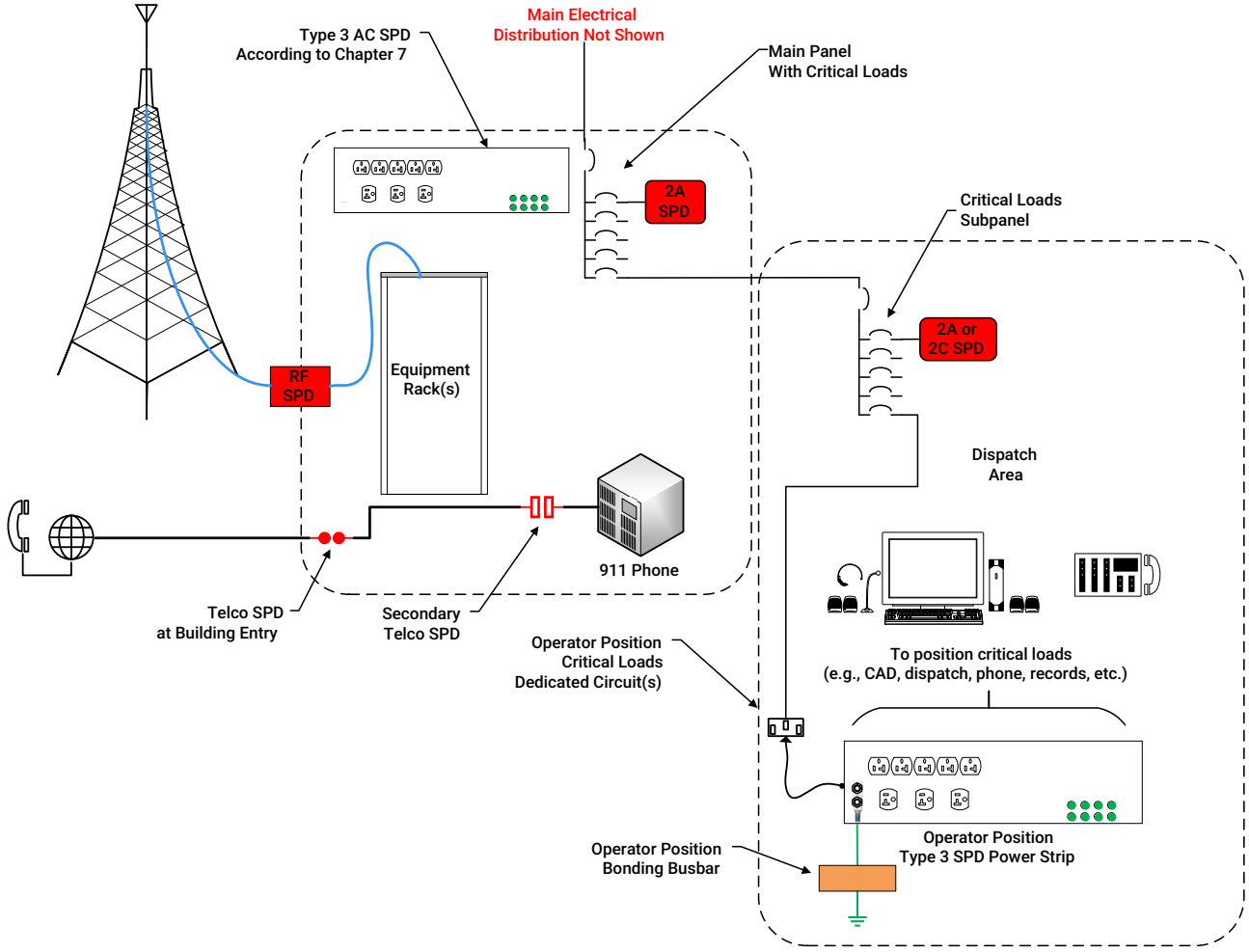


Figure 7-67. Example of Surge Protection Planning for Dispatch and Operations

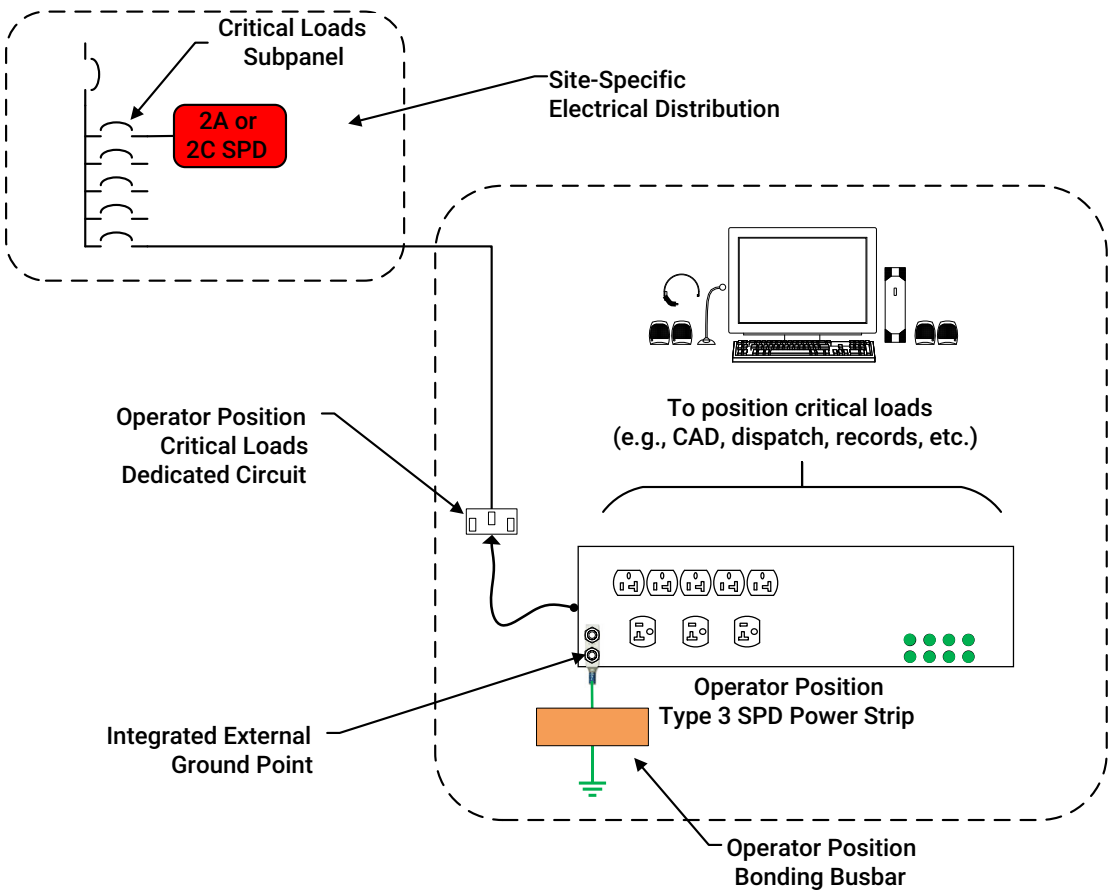


Figure 7-68. Example of Operator Position Surge Protection

IMPORTANT: Measures to control ESD **shall** be taken when designing for the dispatch environment. Most ESD problems are mitigated through bonding and grounding techniques, relative humidity control (40% to 55% relative humidity is ideal), attention to the resistivity of flooring and furniture, and selection of video display terminals (LCD or LED instead of CRT). See Appendix C, "Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers", for more information.

7.12 DC Systems Surge Protection

Battery-powered networks offer enhanced isolation from electrical noise, voltage regulation fluctuations, and electrical faults. These systems stabilize voltage by absorbing variations, while localized DC distribution with battery backup improves component longevity and ensures system availability during electrical grid disruptions. However, surge events, such as lightning-induced Ground Potential Rise (GPR), pose significant risks. DC power supplies, designed with lower Maximum Continuous Operating Voltage (MCOV) thresholds, are particularly susceptible to transient overvoltages and electromagnetic fields. To address these vulnerabilities, Motorola Solutions recommends implementing tailored surge protection practices for DC systems powering outdoor electronics and localized DC distribution, such as +24V or -48V configurations, as detailed in the following subsections.

7.12.1 Solar Powered Sites

Surge protection is essential for RF sites powered by solar panels to prevent damage from lightning-induced surges. Conductors from the solar panels can create a pathway for lightning into the building or shelter. Installing surge protective devices (SPDs) at the entry point helps to ensure transient overvoltages are safely diverted, protecting sensitive electronics and maintaining the reliability of the site. See Figure 7-69 for an example of surge protection at a solar powered site.

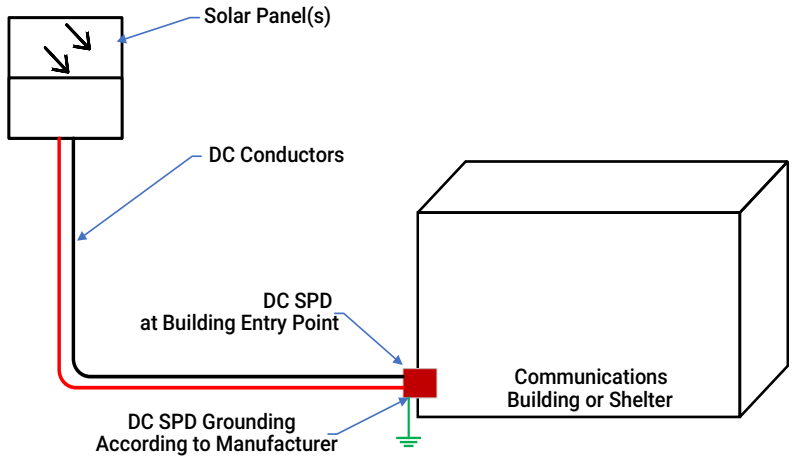


Figure 7-69. Solar Site

7.12.2 DC Powered Outdoor Equipment

Tower-mounted electronics must be bonded and surge-protected in accordance with “Tower Electronics” on page 7-63.

Critical electronic devices—identified by the system engineer, system manager, or system owner and installed in exposed locations such as rooftops, utility poles, or similar areas—**shall** be equipped with surge protection installed as close to the equipment as practicable. Additionally, all associated cables **shall** be surge-protected at the building entry point, as described in this chapter.

The appropriate SPD **shall** be selected based on the application, voltage level, and cable/conductor type. See “Recommended DC SPD Technology and Location” on page 7-70.

IMPORTANT: Electronics designed for outdoor use often incorporate a basic level of surge protection. Board-level surge protection, while simplifying installation, also has inherent problems. Board-level SPDs afford limited isolation from lightning-induced EM fields. An SPD board failure may necessitate replacing the entire radio. Therefore, external SPDs **shall** be installed as described in the above paragraph.

7.12.3 Localized DC Distribution

DC distribution systems consist of AC to DC converters, battery banks, low-voltage main distribution frames and distributed DC load centers. AC surge protection **shall** be installed at the locations as shown in Table 7-1 through Table 7-3, beginning on page 7-6. DC powered equipment deemed critical by the authority having jurisdiction (AHJ) **shall** be surge protected. See NFPA 70-2026, Articles 708.1 and 708.8 for more information.

If the system does not fall under the Critical Operations Power Systems (COPS) requirements in NFPA 70-2026, Article 708 (or equivalent), Motorola Solutions recommends the following surge protection:

- DC SPDs for critical loads are recommended where the critical loads are located more than 9.144 m (30 ft) from the DC power distribution point.

- In regions with high lightning activity, DC SPDs for critical loads are strongly recommended for distances beyond 9.144 m (30 ft) from the DC power distribution point.
- For all geographic locations, DC SPDs for critical loads are strongly recommended where the loads are more than 15.2 m (50 ft) from the DC power distribution point.
- DC SPDs are recommended for any loads located beyond 15.2 m (50 ft) from the DC power distribution point.
- An example of DC SPD installation recommendations is shown in Figure 7-70

IMPORTANT: The DC Power System **shall** be bonded and grounded according to “DC Power Systems” on page 5-94 and applicable subsections.

NOTE: The system engineer, system manager, the system owner, or the AHJ **shall** define the critical load(s). A critical load is generally considered any load that affects system availability and the end-user’s ability to effectively communicate on the system.

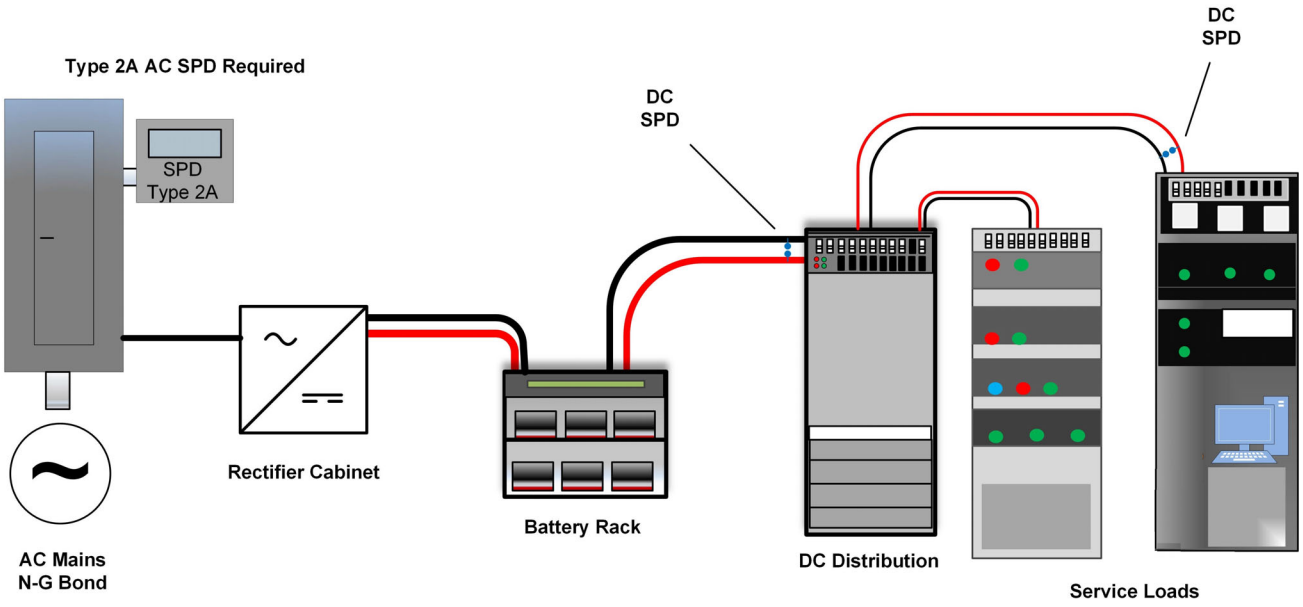


Figure 7-70. Example of Recommended DC SPD Installation

7.12.4 Recommended DC SPD Technology and Location

The recommended DC SPD should be constructed using a Metal Oxide Varistor (MOV), Silicon Avalanche Diode (SAD) or an SAD/MOV matrix device.

When selecting a DC SPD, it is important to consider wire size and the SPD’s Maximum Continuous Operating Voltage (MCOV). DC systems can carry a considerable amount of energy. The SPD voltage rating **shall** be closely coordinated with the circuit voltage and polarity of the battery plant.

Key specifications of the DC SPD are as follows:

- SPD minimum conductor size of 5.26 mm^2 csa (#10 AWG) for parallel connected SPD or sized for peak current load for series connected SPD.
- See Table 7-11 for the recommended DC SPD minimum specifications.

Table 7-11.Recommended DC SPD Specifications

Type	SPD Construction	MCOV	Voltage Protection Rating (VPR) or Voltage Protection Level (VPL)	SCCR Per UL 1449 5th Edition	Nominal Discharge Current (In) Per UL 1449 5th Edition or UL 497B	Notes
External DC Distribution Conductors, Solar Conductors, etc.	MOV	60 - 90V for -48VDC systems. 35 - 55V for +24VDC systems.	400 V	30 kAIC	20 kA	DC conductors run from one building to another. DC conductors from a solar panel(s)
Localized DC Distribution Conductors	SAD	60 - 90V for -48VDC systems. 35 - 55V for +24VDC systems.	< 150V @ 2.5 kA 8/20µs	N/A	5 kA	Internal DC distribution conductors with no connection outside the building.
Outdoor Mounted Electronic Devices	SAD	60 - 90V for -48VDC systems.	< 100V @ 500 A 8/20µs	N/A	5 kA	SPD mounted near outdoor electronic devices such as point-to-point microwave, remote radio head, WIFI router, security camera, and similar devices. SPD specifications not already covered by coaxial protectors, telco-style, or CAT 5/6/8-style SPDs.

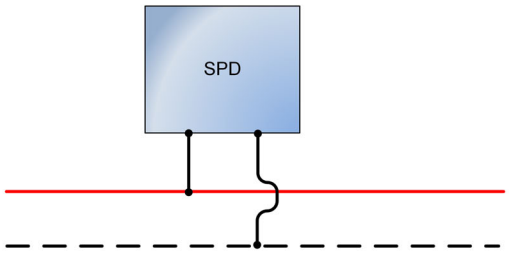
DC SPDs are **required** as follows:

- As described in “DC Powered Outdoor Equipment” on page 7-69.
- As described in “Localized DC Distribution” on page 7-69.
- For any DC conductor penetrating the shelter wall within 60.96 cm (24 in.) of entering the shelter (see Figure 7-72).

To maximize the protection effectiveness, the SPD should be installed near the equipment to be protected.

Suitable surge suppression devices are available from several surge suppression device manufacturers. Devices **shall** be selected based on the specific application and requirements specified in this section.

DC surge events occur on the ungrounded side of the DC circuit (for example, Negative for -48VDC and Positive for +24VDC and +12VDC). This level of protection is sufficient for load protection, or within 1.8 m (6 ft) of the protected load.



The All Mode SPD is recommended for DC supply protection, after the DC ground has been established. Solid state SPDs between the DC positive and negative combined with an SPD to ground helps to mitigate induced EMI.

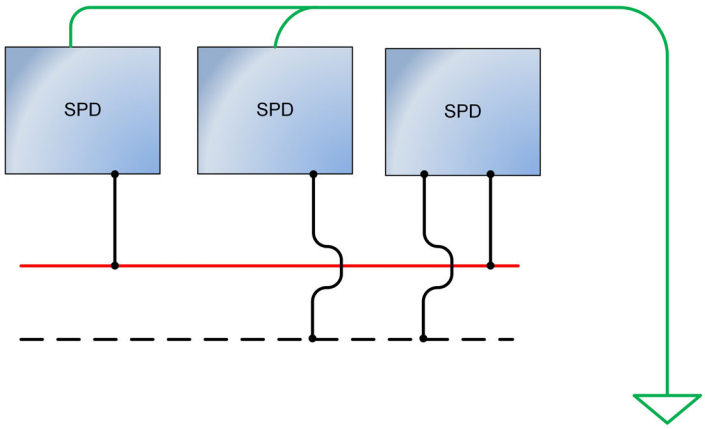


Figure 7-71. DC Surge Protection Modes

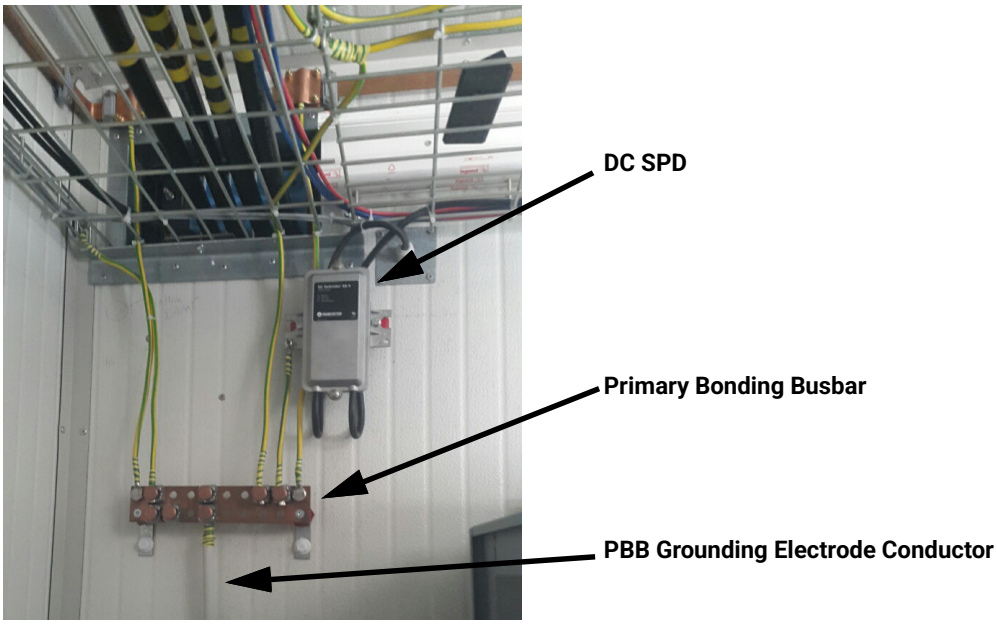


Figure 7-72. Example of DC SPD Installed on DC Conductor Entering a Shelter

7.13 AC Power Line SPD Test Certification Requirements and Test Methods

This section outlines the mandatory tests for Motorola Solutions certification of AC power line Surge Protective Devices (SPDs). These performance tests are designed to ensure SPDs meet the requirements specified herein and are required in addition to, and exceed, the safety testing outlined in UL 1449 5th Edition.

AC power line SPDs that are recommended, distributed, or installed by Motorola Solutions **shall** meet the specifications cited in “AC Power Surge Protection Requirements” on page 7-5. These devices **shall** also be tested to demonstrate compliance with the I_{max} test criteria.

To be considered for use at a communications site, manufacturers **shall** submit their AC power line SPDs for testing by an independent Nationally Recognized Testing Laboratory (NRTL), NAVLAP or A2LA accredited laboratory, or a Certified UL Client Data Program laboratory. This testing, conducted at no cost to Motorola Solutions, must verify compliance with the specifications cited in “AC Power Surge Protection Requirements” on page 7-5 and Table 7-7. The manufacturer **shall** provide the certified test procedures and results to Motorola Solutions for review. SPDs confirmed through this process to meet the referenced specifications will be considered compliant with Motorola Solutions' device requirements.

Motorola Solutions **shall** have the opportunity for its representative(s) to witness and verify the test data compiled by the independent laboratory. The manufacturer may request that test results be deemed proprietary and remain confidential. To facilitate scheduling for witnessing, the manufacturer **shall** notify Motorola Solutions 30 days prior to the test date. Following test completion, the manufacturer has 30 days to compile and submit the test data to Motorola Solutions for review. Motorola Solutions will notify the manufacturer of its acceptance or rejection of the test data within 60 days of submission.

Motorola Solutions reserves the right, at its own option and expense, to purchase additional units from the manufacturer’s standard production line and have them tested by an independent laboratory of its choice using the same test criteria. If these units fail to meet the requirements defined in “AC Power Surge Protection Requirements” on page 7-5 and Table 7-7 on page 7-30, the manufacturer **shall** be notified. In such cases, or at its discretion, Motorola Solutions may discontinue recommending, distributing, or installing the product.

7.13.1 Component Level Surge Test

7.13.1.1 General

This test will test the individual surge module(s) of Type 2A SAD/MOV, Type 2B MOV, and Type 2C SAD SPDs to show that they meet the requirements in this document. The SAD module(s) are required to meet 20 kA (10 kA for Type 2C) single impulse with the VPL deviating less than 10% in pre- and post-nominal current (I_n) testing. The MOV module(s) are required to meet 160 kA single impulse with the VPL deviating less than 10% in pre-test and post-test I_n testing. All referenced surge currents are based on 8×20 µs waveforms.

7.13.1.2 I_n (Nominal Current Test)

The module(s) must first be subjected to an I_n test impulse as described in UL 1449 5th Edition. The test current I_n is 3 kA 8×20 µs. The clamping voltage measured 150 mm (6 in.) from the module(s) connection is then recorded and the current waveform plotted.

7.13.1.3 Component Surge Test Calibration

The surge generator must be calibrated to the test current and the current waveform plotted as per UL 1449 5th Edition. Calibration should be performed with the actual lead wires used to connect the module(s). This will allow the delivered current to closely match the short circuit current. Calibration for the SAD module(s) **shall** be 20 kA (10 kA for Type 2C). Calibration for the MOV module(s) **shall** be 160 kA. No AC is required for this test. The clamping voltage measurement is not required for this test.

7.13.1.4 Module(s) Testing

The SAD module(s) are then subjected to the 20 kA (10 kA for Type 2C) impulse. The MOV module(s) are then subjected to the 160 kA impulse.

7.13.1.5 Pass Criteria

The modules are then subjected to the I_n 10 kA test as described in "I_n (Nominal Current Test)" on page 7-73. The VPL is then measured and recorded. The current/voltage waveform is plotted. The Pre-test I_n VPL is compared to the Post-test I_n VPL. The modules pass the requirement if the Post-test VPL is within 10% of the Pre-test VPL.

7.13.2 Maximum Discharge Current Test

7.13.2.1 General

The Maximum Discharge Current test is designed to test the maximum surge capability of the SPD. Maximum Discharge Current, or I_{max}, is the crest value of a current through the SPD. I_{max} for Type 2A SAD/MOV and Type 2B MOV SPDs is 160 kA. The SPD **shall** be mounted and connected as per the manufacturer's installation instructions during testing.

If manufacturer provides electrical conductors as a part of the product, testing and measurements **shall** be conducted on the full length of conductor provided.

If no electrical conductors are provided, testing and measurements **shall** be conducted at the terminal block.

Testing **shall** be performed in free air, 20°C, ± 15°C.

During the testing, maintenance or modifications **shall not** be performed.

All referenced surge currents are based on 8×20 μs waveforms.

7.13.2.2 I_n Pre-test (I Nominal Current Test)

The SPD must be first be subjected to an I_n test impulse as described in UL 1449 5th Edition. The test current I_n is 3 kA 8×20 μs. The clamping voltage measured 150 mm (6 in.) outside of the enclosure. The VPL is then recorded and the current and voltage waveform plotted.

7.13.2.3 I_{max} Surge Generator Calibration

The surge generator **shall** be calibrated as specified in UL 1449, 5th Edition, section 37.3. Tolerances and waveform are described in UL 1449, 5th Edition, section 37.3. This test is for Type 2A SAD/MOV and Type 2B MOV SPDs only. Calibration should be performed with the actual lead wires used to connect the module(s). This will allow the delivered current to closely match the short circuit current.

Calibrate the Surge Generator with an 8×20 μs short circuit current of I_{max} 160 kA. Denote and record the charge voltage of the surge generator. Measure, record and plot the short circuit current including peak amplitude, rise time, and duration.

7.13.2.4 I_{max} Discharge Test

Connect the Positive Terminal of the Surge Generator to the L1 terminal or conductor of the SPD.

Connect the Negative Terminal of the Surge Generator to the N terminal or conductor of the SPD.

1. Apply a surge current of I_{max} 160 kA with a positive polarity, no AC applied. Measure, record and plot the delivered current.
2. Connect the SPD to the voltage, phase and power circuit configuration as detailed on the data label.
3. Energize the SPD for a period of 30 minutes. Ensure that all intended functions of the SPD still operate, including SPD surge and power applied status indicators, both visual and remote.

7.13.2.5 Pass Criteria

After I_{max} testing the SPD is allowed to cool to room temperature. The SPD is then subjected to the I_n 10 kA Post-test as described in “In Pre-test (I Nominal Current Test)” on page 7-74. The VPL is measured and recorded. The current and voltage waveform is plotted. The Pre-test I_n VPL is compared to the Post-test I_n VPL. The SPD passes the requirement if the Post-test VPL is within 10% of the Pre-test VPL.

During the Residual Voltage Measurement, Preconditioning, and I_{max} Operating Duty Cycle Tests, the following conditions **shall not** occur:

- Emission of flame, molten metal, glowing or flaming particles through any openings (pre-existing or created as a result of the test) in the product.
- Ignition of the enclosure.
- Creation of any openings in the enclosure that results in accessibility of live parts.
- Opening, temporary or permanent, of overcurrent protective components.
- Errors resulting from a failure, temporary or permanent, in the indication circuitry.
- A supplementary protection device opening.

7.14 Electromagnetic Pulse (EMP) Considerations

7.14.1 Scope and Compliance

While this manual provides comprehensive standards for lightning protection and grounding, protection against a High-Altitude Electromagnetic Pulse (HEMP) or Nuclear Electromagnetic Pulse (NEMP) involves specialized hardening that is beyond the primary scope of this document.

If EMP mitigations are required for a site, the following standards should be used to ensure full compliance:

- **MIL-STD 188-125-1/2**: The primary military standards for hardening fixed and transportable ground-based facilities.
- **IEC 61000-4-x series** (Testing and Measurement Techniques) and **IEC 61000-5-x series** (Installation and Mitigation Guidelines).
- **Department of Homeland Security EMP Protection Guidelines**: Recommended guidelines for civilian and commercial infrastructure applications.

7.14.2 Technical Recommendations

To mitigate the risk of EMP-induced damage to microelectronics and communication systems, the following measures should be implemented:

- **Surge Protection:** Surge Protective Devices (SPDs) specifically rated for EMP/HEMP pulse characteristics should be used on all power and signal inputs/outputs.
- **Bonding and Grounding:** Extensive bonding and grounding of all metallic objects within the equipment area is essential to reduce the effects of induced currents. Chapter 5, “Internal Bonding and Grounding (Earthing),” provides detailed procedures.
- **System Scalability:** For commercial applications, EMP protection is often more economically feasible when scaled down to protect only the most critical assets, such as specific server rooms or equipment enclosures.

7.14.3 Professional Consultation

Due to the extreme complexity of EMP hardening and the requirement that standards like MIL-STD 188-125 be applied in their entirety to be effective, consultation with a specialized engineering firm is highly recommended for any site requiring HEMP/NEMP resilience.

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CHAPTER

8

Minimizing Site Interference

This chapter provides information on preventing Radio Frequency (RF) interference at a communications site. The requirements of this chapter help eliminate interference and are separate from the RF engineering aspects of site design. The following topics are included:

- “Interference Protection Recommendations” on page 8-1
- “General Site Environmental Requirements” on page 8-3
- “Other Band Architecture Overview” on page 8-3
- “Mitigating External Intermodulation and TN/RD Interference” on page 8-8

This chapter describes the minimum filtering, design, and installation techniques that should be applied at fixed sites to minimize interference. For additional information, refer to the **dBSpectra TECHBOOK Series.**

NOTE: The requirements and recommendations in this chapter apply to analog and to digital systems.

8.1 Interference Protection Recommendations

Unlike mobile units that can be moved to an interference-free area, fixed sites must incorporate equipment and techniques to reduce the likelihood of interference. In most cases, minimizing unwanted transmitter emissions and filtering signals before the receiver will mitigate this interference. This is especially critical at sites with multiple antennas. If these measures have been taken and the receiver still picks up noise, then external noise sources in the surrounding environment must be identified and eliminated.

A communication site should have standards required of all users and recommended to other communications sites in the general vicinity. For example, another site within a 400 m (1/4 mile) radius may interfere with your site or may receive interference from your site unless protective equipment and techniques are used.

The engineering techniques described in this chapter represent best commercial practices. The protective equipment to be used is available from numerous vendors and meets Motorola Solutions’ criteria for product performance, reliability and support. Contact the local Motorola Solutions Engineering team or other engineering firm for additional details and support.

The most common causes of receiver interference are transmitter noise, receiver desensitization, and unwanted intermodulation caused by objects in the site environment. Other common interference terms are Co-Channel and Adjacent Channel interference. Analysis of the existing and proposed frequencies at an antenna site may help the site design process.

The following sections describe the requirements for preventing problems in each area.

8.1.1 Minimum Transmitter Protection Requirements

A properly designed site incorporates several techniques to reduce the likelihood of the transmitters causing interference to a receiver signal. Each transmitter should have an isolator, low pass filter, and bandpass cavity setup (see Figure 8-1). The number of isolators and bandpass cavities needed for filtering a transmitter depends on the transmitter equipment and frequencies at the communication site and other transmission sites in the vicinity. For help, contact the local Motorola Solutions Engineering team.

An isolator is used on a transmitter to reduce the radio energy allowed to enter the final amplifier stage from the antenna system. This action, in turn, reduces the signal levels of other undesirable radio signals entering the final amplifier stage. This helps prevent mixing two or more different frequencies within the non-linear device (final amplifier stage). The mixing process is called transmitter intermodulation (IM), and it can result in interfering frequencies for receivers. In some situations, the isolator can produce second harmonic spurious emissions, harming receiver reception. To protect against this, a low pass filter should be used between the isolator stage and the antenna system.

A bandpass cavity is a high Q resonant circuit, designed to pass a narrow band of frequencies with very little energy loss while attenuating all other non-resonant frequencies. Bandpass cavities should be installed between the transmitter and antenna system to reduce spurious signals and transmitter sideband noise. Spurious signals and sideband noise may otherwise radiate from the transmitter and degrade the performance of nearby receivers. Using a bandpass cavity also minimizes transmitter intermodulation because the cavity attenuates all off-frequency signals from other nearby transmitters.

Requirements for installing transmitters within various frequency bands are listed below. See Figure 8-1 for the configuration of the filtering devices.

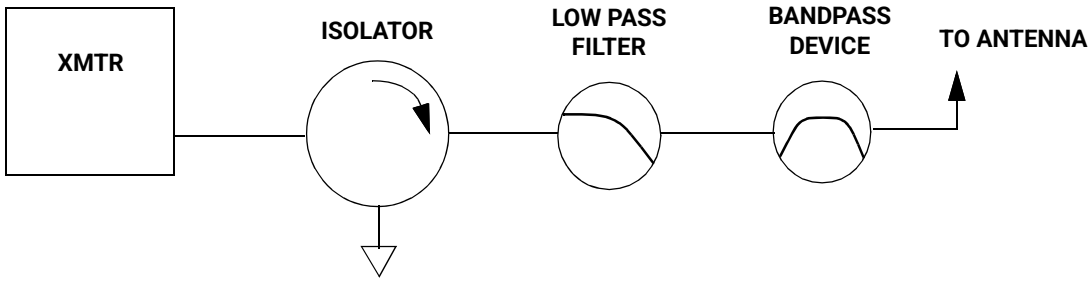


Figure 8-1. Configuration of Transmitter Filtering Devices

- **25-54 MHz** - Transmitters in this range **shall** have an isolator with a minimum of 20 dB reverse isolation followed by a low pass filter and a bandpass cavity setup, which provides a minimum of 20 dB of attenuation at 1 MHz from the transmit frequency.
- **66-88 MHz** - Transmitters in this range **shall** have an isolator with a minimum of 25 dB reverse isolation followed by a low pass filter and bandpass cavity setup, which provides a minimum of 20 dB of attenuation at 1 MHz from the transmit frequency.
- **130-225 MHz** - Transmitters in this range **shall** have a set of isolators with a minimum of 50 dB reverse isolation followed by a low pass filter and a bandpass cavity setup, which provides a minimum of 25 dB of attenuation at 1 MHz from the transmit frequency.
- **276-284 MHz** - Transmitters in this range **shall** have a set of isolators with a minimum of 50 dB reverse isolation followed by a low pass filter and a bandpass cavity setup, which provides a minimum of 25 dB of attenuation at 1 MHz from the transmit frequency.
- **400-512 MHz** - Transmitters in this range **shall** have a set of isolators with a minimum of 50 dB reverse isolation followed by a low pass filter and a bandpass cavity setup, which provides a minimum of 15 dB of attenuation at 1 MHz from the transmit frequency.
- **764-960 MHz** - Transmitters in this range **shall** have a set of isolators with a minimum of 50 dB reverse isolation followed by a low pass filter and a bandpass cavity setup, which provides a minimum of 15 dB of attenuation at 1 MHz from the transmit frequency.

8.1.2 Minimum Receiver Protection Requirement

A properly designed fixed site requires each receiver input to be connected to a crystal filter, window filter, and/or bandpass cavity to minimize or eliminate receiver desensitization (see Figure 8-2). These devices create a narrowband window to allow only the desired receive signal to enter the receiver. If the interference is very close to the receiver frequency, a dual or triple bandpass cavity setup or notch filter may be required. This is typically less costly than moving the receiver antenna to an alternate location. If additional support is necessary, contact the local Motorola Solutions Engineering team.

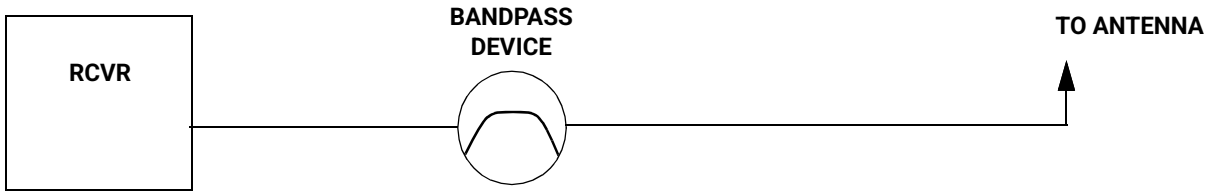


Figure 8-2. Configuration of Receiver Filtering Device

8.2 General Site Environmental Requirements

A properly designed communication site uses preventive measures to minimize and eliminate locations where radio signals can mix and create intermodulation frequencies or broadband noise. The following preventive measures **shall** be followed:

- All materials **shall** be free of rust.
- Braided wire **shall not** be used because it can corrode and cause intermodulation signals.
- Metal-to-metal connections **shall** be rigid.
- All loose metal **shall** be removed from the site.
- Chain link type fence material should be vinyl clad if the fence is found to be a source of interference.
- Connection of dissimilar metals should only be made after reviewing “Dissimilar Metals and Corrosion Control” on page 4-55 (and its subsections) for each metal. The connections must be rigid and tight.
- Bare metallic cable ties **shall not** be used unless they are stainless steel.
- Noisy or cracked power line insulators (glass type) **shall** be replaced. (Contact the electrical utility.) Cracked insulators are very likely a source of broadband noise.

If implementing the recommendations in this section does not eliminate broadband noise, contact the local utility company to have them perform a noise sweep of the general area.

8.3 Other Band Architecture Overview

Some additional RF site design techniques are required to mitigate radio frequency interference for sites utilizing frequencies below 700 MHz. This is typically called Other Band Architecture (OBA) and may include trunking, conventional, data, and paging systems.

With the limited frequencies available in the 700 MHz, 800 MHz, and 900 MHz bands, expansion into other bands is occurring. The 450 MHz and 150 MHz bands are being utilized for trunking. This utilization of older bands has introduced multi-carrier operation in bands that were initially used for single carrier or limited multi-carrier. Interference obstacles within these bands require different solutions than those used at 700 MHz and above.

8.3.1 Spectrum Usage History

The 700 MHz, 800 MHz, and 900 MHz frequency spectra were coordinated to facilitate combining and trunking system design. These frequency band plans facilitate using multiple transmitters connected to a single antenna and receivers connected to a single receive antenna. This allows the use of standard combining and multicoupling schemes. These bands are divided by a defined spacing between the transmit and receive channel pairs (30 MHz for 700 MHz, 45 MHz for 800 MHz, and 39 MHz for 900 MHz). This spacing helps isolate the intermodulation interference that occurs when two or more frequencies mix in non-linear devices, producing carriers on the existing receiver frequencies.

The VHF and UHF bands were not organized with the same standards as the 700 MHz, 800 MHz and 900 MHz bands. Therefore, standard combining and multicoupling schemes cannot be utilized, and extensive frequency planning must take place during system design. These items may add significant design time and cost to a project. The UHF and VHF frequency bands have far less immunity to interference because the spacing between transmit and receive channels is not a defined constant. Catastrophic interference may result if systems are not correctly designed. Interference will affect sites with OBA systems if not addressed.

8.3.2 Forms of Interference

Interference can have many sources. All forms of interference must be monitored regularly for reliable communication. Interference is typically classified as internal or external. Internal interference is generated within the system's components. External interference is generated externally and radiates into the affected system. Internal interference can be prevented with good radio system design practices. All external interference must be eliminated at the source.

Examples of interference include internal and external intermodulation (IM), transmitter sideband noise (TN), receiver desensitization (RD), co-channel interference, and passive intermodulation (PIM). These are briefly described below.

- **IM:** usually caused locally within the system or onsite. This form of interference is caused by the mixing of multiple transmitters, producing an on-frequency carrier.
  - Internal IM is generated within system components. This can occur within the transmitter power amplifier, the transmitter combining isolator, and the receiver when strong off-frequency signals enter the receiver's front end and mix.
  - External IM is generated outside the transmitter or receiver system components. This interference can be produced in non-linear components on the site. Rusty tower joints, rusty fences, guy wires, corroded connectors, and inadequate grounding can also be sources of intermodulation. In all cases, the only solution for external IM is finding and eliminating the source.
- **Transmitter Sideband Noise:** All transmitters emit some noise. To reduce this noise and protect co-located receivers, bandpass filtering should be added to transmitters (see Figure 8-1).
- **Receiver Desensitization:** A strong signal on a closely-spaced channel reduces a receiver's ability to process weaker signals. Unlike the other types of interference, there are no audible indications of interference; there is only a reduction in receiver sensitivity.
- **Co-channel:** Multiple transmitters within the same coverage area assigned the same frequency.
- **Adjacent Channel:** Interference from users on a frequency assignment next to the operating frequency.
- **PIM:** Another type of intermodulation is evident in passive system components. Common mixing points are connectors, cables, surge protective devices, combiners, and antennas. Using high-quality (PIM rated) components can help mitigate these issues.

8.3.3 OBA Interference Mitigation

The following subsections provide information on designing a new system utilizing OBA frequencies.

8.3.3.1 Document the Frequency Layout

All available frequencies that may be used, and those already in use, should be defined and documented. A thorough “frequency inventory” consisting of the following activities should be performed:

- Collect/search for available frequencies.
- Conduct site audits of existing frequencies used onsite.
- Document existing user antenna locations to aid in the antenna/combining design.

8.3.3.2 Create a Band Plan

After identifying all frequencies, create a band plan for specific transmit/receive pairs. The tasks listed below should be performed.

- Arrange frequencies in contiguous transmit and receive blocks to create guard bands.
- Create the band plan (specific transmit/receive pairs).
- Minimize implicit band plan elements used for system expansion (maximum of 16 elements).
- Maximize guard bands between transmit frequency blocks and receive frequency blocks.
- Maximize transmit/receive frequency separation for each channel to help control combining size and cost.
- Assign channel pairs to sites.
- Avoid narrow separations from existing frequencies onsite whenever practicable. This helps keep combining size/cost down.

8.3.3.3 Perform an Intermodulation Analysis

Intermodulation (IM) products are generated whenever two or more frequencies mix at a radio site. Under the most adverse conditions (or in the worst case), the reception of the desired on-channel frequency can be suppressed by the FM capture effect of stronger undesired IM products. If the intensity of the IM product is lower than that of the desired signal, it may still cause audible interference. In a digital system, undesired IM products may increase the desired signal’s Bit-Error Rate (BER). Increased BER may result in “digital artifacts” in the audio, and complete loss of audio in severe cases.

An IM analysis can help detect interference products and the root frequencies that can mix to cause interference. Motorola Solutions Engineering can perform the intermodulation analysis. The following guidelines apply when working with the IM analysis results:

- Run third, fifth and seventh order IM.
- Determine PIM risk and design.
- Avoid third-order IM within a single combiner.
- Avoid third-order IM onsite or tower if possible.
- Avoid fifth- or seventh-order IM within a combiner.

8.3.3.4 Perform Transmitter Noise / Receiver Desense Analysis

Systems affected by Transmitter Noise/Receiver Desense (TN/RD) conditions show signs of reduced radio coverage. A TN/RD analysis can provide the information needed to determine existing or planned two-way radio systems that have the potential to cause interference. This knowledge will help systems engineers select equipment necessary to correct or prevent interference.

Motorola Solutions Engineering can perform the TN/RD analysis. The design guidelines listed below apply when working with the TN/RD analysis results.

- Design for all frequencies onsite, not just customer frequencies.
- Design Transmitter Combiner Network according to the recommendations and guidelines below.
  - 45 dB minimum selectivity at each Guard Band plus 45 dB minimum transmit-to-receive antenna isolation (90 dB total)
  - Insertion loss balanced within 4.5 dB across ports
  - Fewer than 7 channel ports on each combiner
  - Tx-to-Tx frequency separation of 90-100 kHz minimum
  - Use a second Tx antenna to mitigate third-order IM if needed.
  - Use greater vertical separation between transmit and receive antennas to mitigate fifth- and seventh-order IM risk. 6 vertical meters (20 feet) provides 55 dB of isolation.
- Design Receiver Multicoupler Network according to the recommendations and guidelines below.
  - 65 dB minimum selectivity at each Guard Band plus 45 dB minimum transmit-to-receive antenna isolation (110 dB total)
  - 15 dB reserve gain available
  - 45 dB third-order Intercept Point in Amplifier
  - < 2 dB noise figure in Amplifier
  - Use greater vertical separation between transmit and receive antennas to mitigate fifth- and seventh-order IM risk. 6 vertical meters (20 feet) provides 55 dB of isolation.

8.3.3.5 Perform PIM Analysis and PIM Sourcing for Antenna Network Components

Follow these best practices during antenna network design and installation.

- Use Passive Intermodulation (PIM) rated components, including antennas, connectors, surge protective devices, and combiners.
- Cables should be continuous, with as few connections, jumpers, and adapters as practicable.
- Use PIM-rated 4.3-10 or 7-16 DIN connectors on all transmit network components.

NOTE: 4.3-10 connectors are less susceptible to PIM versus torque than 7-16 DIN connectors; therefore, Motorola Solutions prefers the 4.3-10 connector.

Follow these antenna mounting recommendations as practicable.

- Mount transmit antennas on the top of the tower.
- Mount transmit antennas as far apart from one another as practicable.
- Mount antennas as far from the tower as practicable.
- Mount the receive antenna as far from the transmit antenna as practicable.

Follow these PIM reduction practices as practicable.

- Follow manufacturer installation instructions for connectors.
- Use manufacturer-approved connector preparation tools.
- Torque connectors according to manufacturer specifications for both connector assembly and coupling. See “Torque” on page 9-59.
- Clean all connections before assembly/re-assembly. See “RF Cabling” on page 9-57.

8.3.4 Optimization and Testing

When installing a new system, the following should be performed and documented:

- Measure Effective Receiver Sensitivity (ERS) on the receivers.
- Measure TN/RD degradation from **all** transmitters onsite.
- Perform Frequency Domain Reflectometer (FDR) testing on antenna systems, verifying all installed components meet the manufacturer's specifications. See “Antenna System Commissioning” on page 9-60.
- Perform PIM analysis on transmit systems where PIM is likely, such as at locations with a high RF density. See Figure 8-3 for an example of a high RF density site. See Figure 8-4 for an example of a PIM tester.

IMPORTANT: PIM testing **shall** only be performed by trained and certified personnel.



Figure 8-3. Example of a high RF density site



Figure courtesy of Anritsu

Figure 8-4. Example of PIM Tester

8.3.5 Maintenance

Throughout the life of a system, system maintenance should include the considerations listed below.

- Frequency changes should be considered a redesign.
- Frequency additions to the site must be evaluated.
- Interference degradation must be monitored with periodic effective receiver sensitivity (ERS) tests.
- Perform periodic Frequency Domain Reflectometer (FDR) testing on antenna systems, verifying the antenna system has not degraded from original installation testing (commissioning). See “Antenna System Commissioning” on page 9-60.
- Perform PIM analysis on transmit systems where PIM is suspected.
- Inspect the site and remove discarded or unused hardware and components, such as tower sections, antennas, mounts, and miscellaneous hardware.
- Inspect the site for rusty components such as bolts, nuts, fences, mounts, etc. and correct as needed.

8.4 Mitigating External Intermodulation and TN/RD Interference

Motorola Solutions provides some general guidelines to mitigate the effects of interference caused by intermodulation and TN/RD from the existing user community. Guidelines for each type of external interference are provided in the following subsections. Motorola Solutions Engineering can assist in mitigating external IM and TN/RD interference problems.

In most cases, minimizing the level of undesirable energy emitted by the local transmitters and filtering out undesirable signals entering the receiver eliminates received interference in the receiver environment. Interference is more likely to be a problem at sites with multiple antennas.

8.4.1 Intermodulation

Every transmitter at a site **shall** have a dual-stage isolator with a second harmonic filter or bandpass cavity on the isolator output. Strong IM can be generated from the transmitter power amplifier (PA). The dual-stage isolator greatly reduces the amount of external RF energy entering a transmitter PA and consequently, the level of IM generated. The radio site must be clear of any dissimilar metal connections, rusty metallic areas, rusty fence bolts, rusty building and tower bolts, loose guy wires, and so on. Many R56 site improvements help reduce or eliminate these sources where multiple frequencies mix to produce intermodulation products. Jacketed hardline transmission lines (with solid shield) **shall** be used instead of RG-8 (or equivalent) cable. For antenna configurations combining two or more transmit frequencies, the system **shall** utilize 4.3-10 or 7-16 DIN connectors. Type N connectors **shall not** be used on the transmit path because they are a mixing point source of IM products.

Every receiver should have a bandpass cavity to prevent strong transmitter signals from swamping (overloading) the receiver and forming IM products. Transmit and receive antenna isolation helps prevent harmful interference from IM products. A good practice is to have a transmit-to-receive antenna isolation of at least 45 dB. This is achieved by mounting the tip of the lower antenna 3 m (10 ft) vertically below the base of the upper antenna. The idea is to reduce the level of IM reaching any given receiver. Because tower space is limited, the best way to achieve this for all site users is to develop a combining system where the receive antenna(s) occupy a defined receive-only zone on the tower, and transmit antenna(s) occupy a defined transmit-only zone. The receive and transmit antennas are separated by at least 3 vertical meters (10 ft) to provide 45 dB of isolation. The more vertical separation between transmit and receive antennas, the better the isolation. For example, 6 m (20 ft) of vertical separation provides 55 dB of antenna isolation.

8.4.2 Transmitter Noise/Receiver Desense (TN/RD)

All transmitters onsite should have sufficient transmitter noise filtering to reduce harmful on-channel noise to all receivers onsite. This is best achieved through a bandpass cavity that reduces the on-channel transmitter noise below the interference level (see Figure 8-1). Transmitter noise problems are on-channel to a receiver frequency. Therefore, transmitter noise problems must be addressed at the source (the transmitter). A good practice is to reduce the transmitter sideband noise by approximately 90 dB. This number varies depending on the base station model and make. Maintaining a minimum separation of 3 vertical meters (10 ft) between transmit and receive antennas reduces the required cavity suppression to 45 dB, as the physical separation provides the remaining isolation.

All receivers should have bandpass cavities to prevent receivers from being desensitized by nearby strong RF carriers (see Figure 8-2). A good practice is to provide sufficient filtering to the 110 dB level. This number will vary depending on the model and make of the base station. Receive antenna to transmit antenna isolation of at least 45 dB, achieved by 3 m (10 ft) of vertical separation, is recommended. This reduces the amount of receiver bandpass cavity filtering required by 65 dB. Because tower space is limited, the best way to achieve this for all site users is to develop a combining system where the receive antenna(s) occupy a defined receive-only zone on the tower, and transmit antenna(s) occupy a defined transmit-only zone. The receive and transmit antennas are separated by at least 3 vertical meters (10 ft) to provide 45 dB of isolation. For example, 6 m (20 ft) of vertical separation provides 55 dB of antenna isolation.

8.4.3 Simplex Multi-Frequency Stations

Simplex multi-frequency stations cannot be combined or have cavities installed. Because cavity filters are tuned to operate at one frequency, they cannot be used on multi-frequency stations. These stations must be evaluated carefully because little can be done to mitigate any interference.

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CHAPTER 9

Equipment Installation

This chapter describes requirements and standard methods for communications equipment installation. This chapter includes the following topics:

- “General Installation Considerations” on page 9-3
- “Facility Readiness” on page 9-4
- “General Considerations for Layout, Work Areas, and Spacing” on page 9-5
- “Seismic Considerations” on page 9-10
- “Level, Plumb and Squareness” on page 9-20
- “Equipment Anchoring” on page 9-21
- “Equipment Installation Within Racks or Cabinets” on page 9-26
- “Ancillary Equipment Mounting” on page 9-26
- “Equipment Cabling” on page 9-26
- “Tower Lighting Systems” on page 9-70
- “Equipment Removal” on page 9-70
- “Site Security Surveillance Systems” on page 9-71
- “Utility Pole-Mounted Equipment Installation and Clearances” on page 9-72
- “Electrostatic Discharge Considerations” on page 9-77

9.1 Introduction to Equipment Installation

Modern public safety communication systems, encompassing E911 and various data systems, boast an unprecedented array of features and functionalities. The integration of computers and computer networking technology has significantly enhanced mission-critical flexibility. Nevertheless, the reliance on computers, computer-based equipment, and networks presents distinct challenges in ensuring safe and dependable operation.

Properly installed equipment is essential for the safety of installation, maintenance, and dispatch personnel. Following good installation practices is necessary to maximize equipment availability, reliability, and safety.

NOTE: Before beginning communication equipment installation, all requirements in “Facility Readiness” on page 9-4 must be satisfied.

NOTE: This chapter assumes that all site and structure preparations have been performed (including battery systems, generators, line surge protective devices, tower systems and site/structure grounding systems).

All building construction or alterations **shall** be completed before the start of the installation activity. The site **shall** provide a reasonably waterproof and dust-free environment within the installation activity area. (Telcordia GR-1275-CORE.i12)

9.1.1 Safety for Equipment Installation

The safety requirements and suggestions in this section **shall not** be interpreted as a complete list of safety requirements. The installer **shall** comply with all applicable national and local safety codes, including Occupational Safety and Health Administration (OSHA) standards (or equivalent) and local safety rules, regulations, and codes.

9.1.1.1 General Safety Requirements

The following is a list of general safety requirements:

- All site preparation, installation, maintenance, and removal activities **shall** be performed by trained and qualified personnel.
- The project manager **shall** be responsible for supervising project team members and ensuring that they comply with the requirements outlined in this manual.
- All manufacturers' instructions regarding safety **shall** be adhered to.
- All required safety items **shall** be on site and readily accessible during work in progress.
- All safety hazards discovered on site **shall** be noted and brought to the attention of the site owner and/or project manager.
- Eye and face protection **shall** be worn when workers are exposed to eye or face hazards such as flying objects, molten metal, liquid chemicals, acids, caustic liquids, chemical gases or vapors, or potentially injurious light radiation (OSHA 29 CFR 1910.133).
- Ear protection **shall** be worn while operating or working near power tools or machinery that requires the use of hearing protection (for example, running diesel or turbine engines, hammer drills, and so on).
- A dust mask or other appropriate respirator **shall** be worn as required to protect workers from inhaling hazardous particulates and/or contaminants (see OSHA 29 CFR 1910.134).
- Hard hats **shall** be worn anytime work is being performed overhead and when required by federal, state, or local regulations.
- Safety procedures and precautions **shall** be followed when scaffolds or ladders are used. Refer to Telcordia GR-1275-CORE.i12, section 4.3, for more information.

IMPORTANT: Before commencement of project activities, the Motorola Solutions Project Manager **shall** convene a safety meeting for all project personnel.

9.1.1.2 Fire Safety

The following are the general fire safety guidelines and requirements:

- All applicable federal, state, and local codes pertaining to fire safety **shall** be adhered to.
- Halls, stairs, passageways, fire exits, and space surrounding fire alarm boxes, fire-fighting equipment, fuse boxes, and AC cabinets **shall not** be obstructed in any way.
- Installer employees **shall** be made aware of the location of fire-fighting equipment, including portable fire extinguishers, during the construction and installation process.
- All trash and packing materials **shall** be removed daily.
- Combustible materials **shall not** be stored near heat-producing equipment (for example, indoor generators, stovepipes, flues, or uncovered steam pipes).
- Flammable materials **shall not** be used for building or equipment protection.
- Materials such as fire-retardant hardboard or metal **shall** be used to protect the flooring when moving heavy equipment or cable into and out of a work area. These materials **shall** be removed from the site after use.
- Protective coverings around working equipment **shall** be made of fire-retardant and electrostatic discharge (ESD)-resistant material.
- All cable penetrations **shall** be closed as soon as practicable, but no later than the end of each working shift.
- Fire doors **shall not** be propped open or prevented from closing at any time or in any manner.
- See “Fire Protection and Safety” on page 3-21 for more information.

9.1.1.3 Hazardous Materials

All activities must be in full compliance with all applicable federal, state, and local laws designed to protect human health and the environment, including, but not limited to, laws regulating the handling, packaging, storage, transportation, and disposal or recycling of toxic and hazardous materials.

- Where applicable, a Safety Data Sheet (SDS) **shall** be available on site.
- The project manager **shall** ensure all personnel working on site are informed regarding any potentially hazardous materials.
- The project manager **shall** make periodic inspections to identify and clear any hazardous or potentially hazardous conditions created by the installation/removal activities.

9.1.2 Installation Practices

To help ensure a safe and quality installation, the following installation practices **shall** be observed.

- Tools **shall** be used only for their intended purpose.
- Tools **shall** be the appropriate type and size for the job and be in good working condition (Telcordia GR-1275-CORE.i12, section 8).
- When using tools, the manufacturer's instructions for application, adjustment, and use must be strictly adhered to (Telcordia GR-1275-CORE.i12, section 8).
- Where applicable, all measuring or testing equipment and tools **shall** contain calibration stickers indicating when the next calibration is due and when the equipment was last calibrated (Telcordia GR-1275-CORE.i12, section 8).
- Low AC and DC voltages (less than 60 volts) are not normally considered as hazardous as high voltages, but can still cause serious injury or death. The installer **shall** utilize tools insulated by the manufacturer and protective materials to prevent accidental shorts. It is recommended that rubber floor mats be used for personal protection against electrical shock when performing work on or near exposed live equipment (Telcordia GR-1275-CORE.i12, section 17.3.1).
- The installer **shall** remove all exposed metallic items, such as rings, watches, dangling keys, and jewelry, during all job activities near power equipment and batteries (Telcordia GR-1275-CORE.i12, section 17.3.1).
- Metal measuring tapes **shall not** be used in areas with exposed live conductors or circuits (Telcordia GR-1275-CORE.i12, section 17.3.1).
- Walkways, aisles, entrances, and exits **shall** be kept clear of tools, equipment, and debris (Telcordia GR-1275-CORE.i12, section 4).
- Personnel **shall not** walk or stand on cable trays, raised floor stringers, straps, panning, ducts, cables, wires, or optical fiber cable/jumpers.
- Holes in floors or ceilings created for cable penetrations **shall** be sealed to prevent items from falling through to the surface below.
- Floors **shall** be free of excess installation materials, such as screws, wire trimmings, and metal shavings from drilling.

9.2 General Installation Considerations

- Cable trays, equipment racks, cabinets, and braces **shall not** obstruct lighting, smoke detectors, HVAC ducts, circuit breaker panels, etc.
- Bolts, nuts, and screws **shall** be tightened and torqued to the manufacturer's specifications. Fastening hardware **shall not** be so tight as to distort any part.
- The threads on bolts, screws, rods, and similar fastening devices **shall** be engaged through to the final thread of the fastening device.

- The cut ends of cable trays, racks, equipment frames, and other similar components **shall** have all sharp edges and burs removed. The cut ends of surfaces **shall** be painted.
- Exposed ends of threaded rods **shall** be capped.
- When drilling concrete or masonry in equipment rooms, it is recommended that the concrete dust be continuously vacuumed during the drilling process (for example, by holding the vacuum nozzle adjacent to the hole being drilled).

9.3 Facility Readiness

Following all construction work, both exterior and interior, the site and facility (structure or shelter) **shall** be in a suitable condition for the installation of communication equipment. The following must be completed before the communication equipment installation:

- The shelter exterior **shall** have final backfill and grade.
- The path between the shelter and the access road **shall** be free of trackable debris.
- The interior of the facility **shall** be free of excessive dust or debris.
- The site exterior area **shall** have all refuse related to the installation tasks removed before occupancy.
- Building construction or alterations that affect the equipment installation area **shall** be completed before the start of the installation activity.
- The site **shall** provide a reasonably waterproof environment within the equipment installation area (Telcordia GR-1275-CORE.i12, section 2.3).
- Equipment entering the equipment room or shelter **shall** be free of dust, dirt, and foreign substances.
- Equipment **shall** be protected from dust, dirt, and debris during installation, removal, maintenance, and construction activities. If the equipment is to be covered or wrapped, anti-static material suitable for the purpose **shall** be used. If a protective barrier is constructed, any heavy-gauge plastic material may be used, provided the material does not come into contact with the equipment.
- Cleaning methods **shall** generate minimal amounts of airborne dust. Vacuum cleaners should be equipped with High-Efficiency Particulate Air (HEPA) filters.
- Materials that may cause an Electrostatic Discharge (ESD) condition **shall not** come into contact with the equipment or be stored in the equipment room. Some examples of these materials include plastics and polystyrene.
- All federal, state, and local laws, ordinances, regulations, and codes (building, fire, and so on) **shall** be adhered to during the course of an installation, removal, maintenance, or construction.
- Should any federal, state, or local law, ordinance, regulation, or code conflict with any of the requirements in this manual, the installer **shall** identify this conflict and contact the site owner and/or project manager for resolution.

9.3.1 Installations at Existing Sites

Installing equipment into existing sites can pose significant challenges. All sites **shall** conform to the requirements and guidelines outlined in this manual, except where the facility was built before the publication of this edition of the manual. In that case, the site **shall**, at a minimum, conform to the edition of Standards and Guidelines for Communications Sites (R56) that was effective at the time the facility was built. New installations in an existing site **shall** conform to the most current version of this manual.

Existing facilities **shall** be maintained in accordance with the applicable regulations, requirements, and specifications of the following regulations:

- NFPA 70 (National Electrical Code®)
- Occupational Safety and Health Act (OSHA)
- Federal, state, and local codes as enforced by the authority having jurisdiction (AHJ).

9.4 General Considerations for Layout, Work Areas, and Spacing

To ensure adequate equipment maintenance and personnel safety, equipment spacing guidelines **shall** be followed. When laying out a site, consider all code requirements for spacing and the most efficient use of space. Special attention **shall** be given to future expansion regarding cable runway heights, electrical outlet placement, and equipment placement.

9.4.1 Spacing Requirements

Spacing of equipment is crucial for maximizing the room's efficiency, facilitating maintenance, and ensuring personnel safety. The following specifications have been established to meet NFPA® codes and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards. All applicable local regulations **shall** also be followed. Figure 9-1 shows an example.

NOTE: By special permission from the authority having jurisdiction, smaller working spaces may be permitted where all exposed live parts operate at not more than 30 volts rms, 42 volts peak, or 60 VDC.

IMPORTANT: Communications equipment **shall not** be installed within the required clear working space of an electrical panelboard. The required clear working space **shall** remain free of debris and **shall not** be used for storage. For equipment operating above 150 V to ground, consult NFPA 70-2026, Article 110.26, or the AHJ for spacing requirements.



Figure 9-1. Example of Equipment Spacing

9.4.1.1 Spacing Requirements for Electrical Power Equipment (AC or DC)

- A clear working space **shall** be provided around all electrical panelboards and/or DC power plants.
- The minimum width of the working space **shall** be the width of the panelboard(s) or 762 mm (30 in.), whichever is greater, and permit opening of any doors or hinged panels to 90° (NFPA 70-2026, Article 110.26). See Figure 9-2. The same requirements apply to DC power plants, batteries, and uninterruptible power supply (UPS) systems.

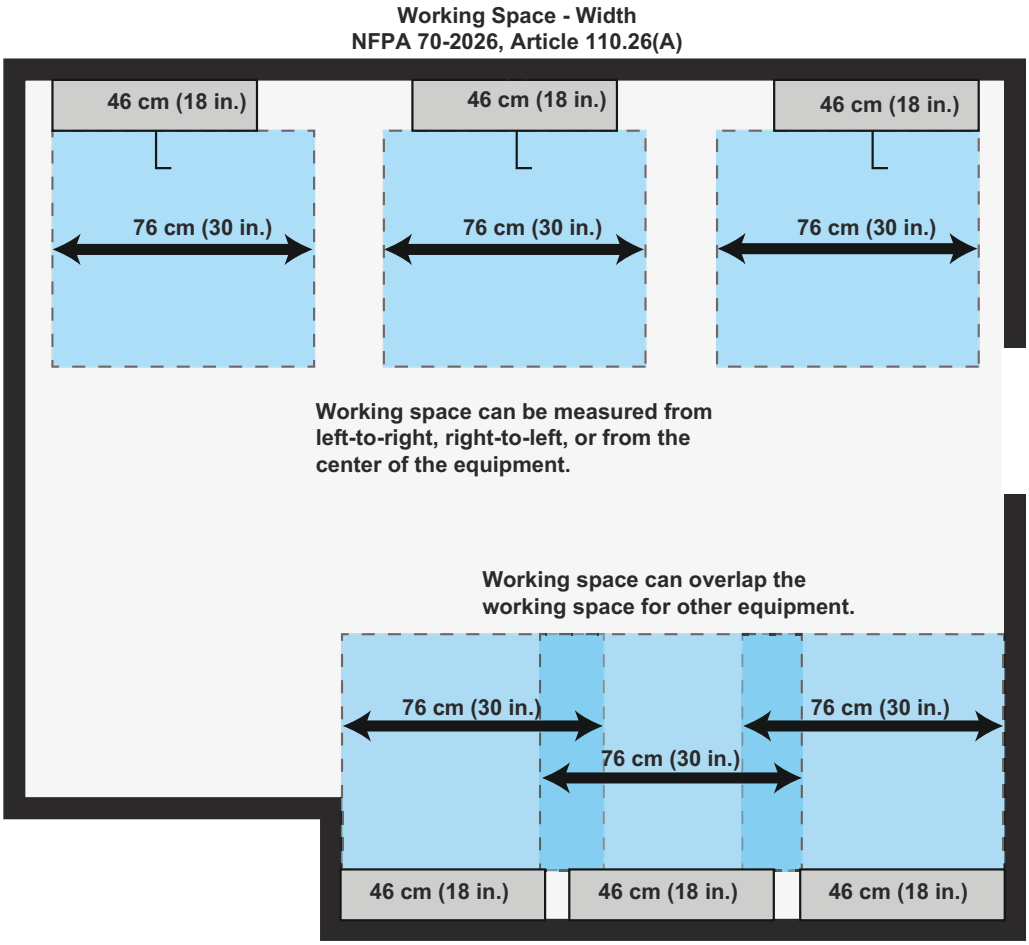


Figure 9-2. Width of Working Space

- The working space **shall** be clear and extend from the grade, floor, or platform to a height of 2.0 m (6.5 ft) or the height of the equipment, whichever is greater. Other equipment associated with the electrical installation and located above or below the electrical equipment **shall** be permitted to extend not more than 150 mm (6 in.) beyond the front of the electrical equipment. See Figure 9-3 on page 9-7.

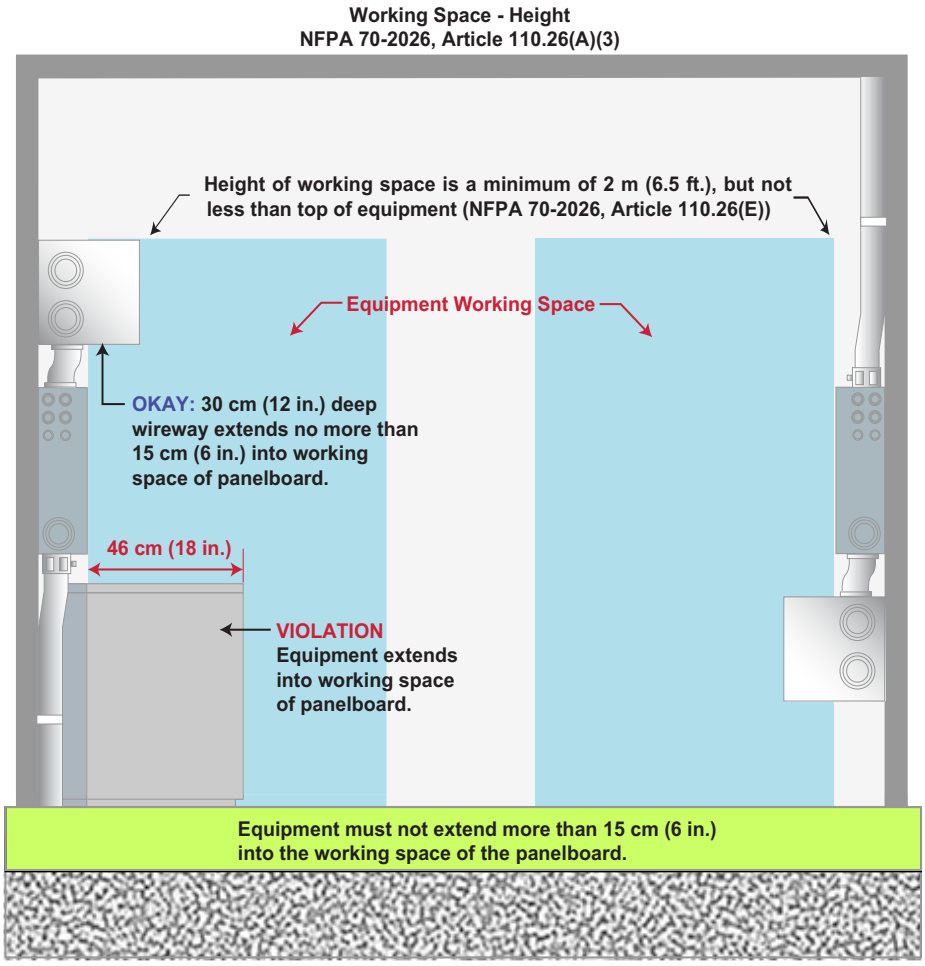


Figure 9-3. Height of Working Space

9.4.1.2 Spacing Requirements for Other Equipment

- Where required for electrical servicing, a minimum working space of 914 mm (36 in.) deep by 76 cm (30 in.), or the width of the equipment, whichever is greater, **shall** be maintained at interior-mounted air conditioners (NFPA 70-2026, Article 110.26). Additional clearance may be needed for air handling purposes as specified by the manufacturer (also see ASHRAE requirements).
- A 762 mm (30 in.) minimum aisle width **shall** be maintained on all non-egress or aisle ways (Telcordia GR-63-CORE.i05, section 2.2). See Figure 9-4 on page 9-8.

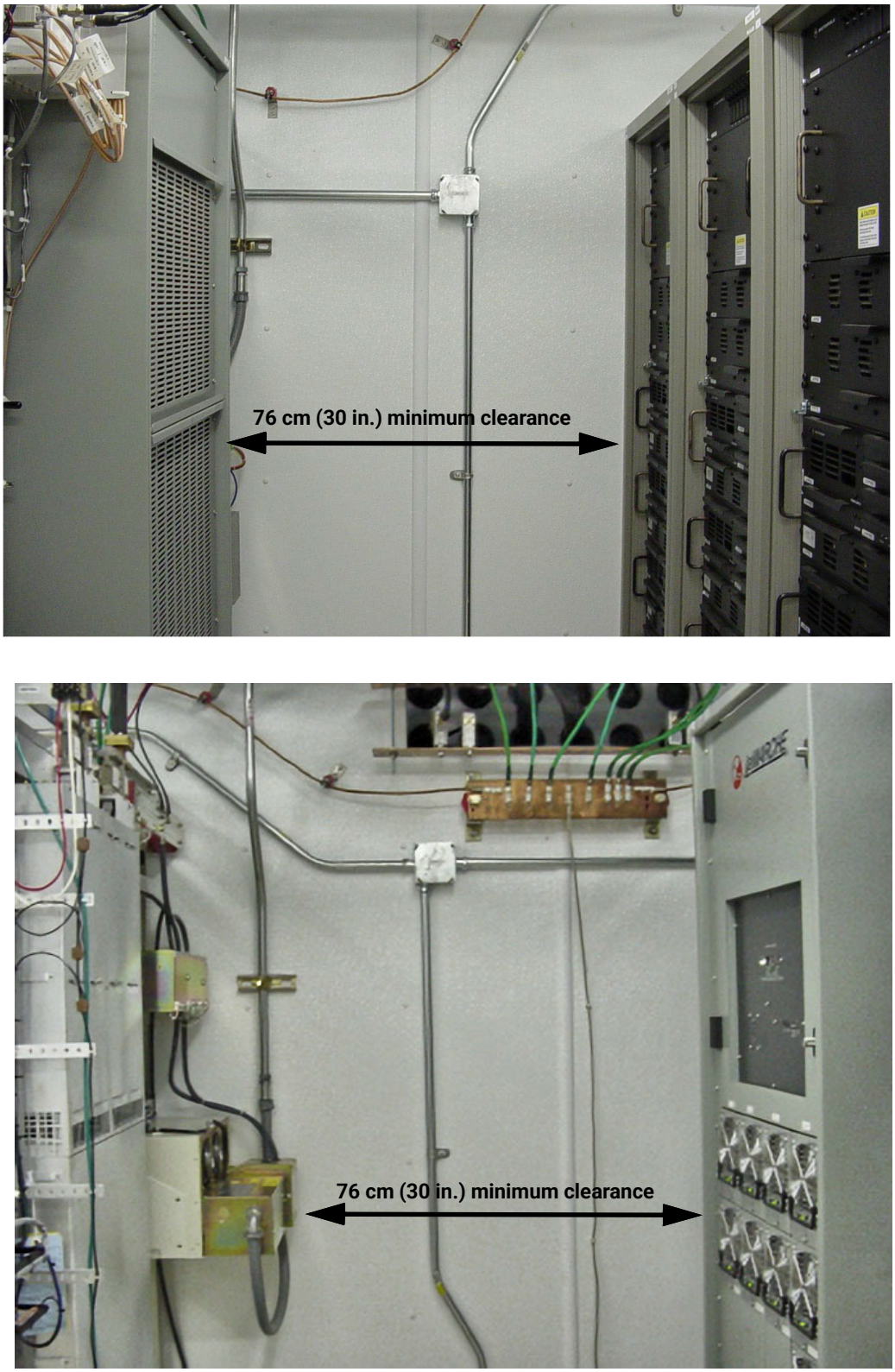


Figure 9-4. Examples of Aisle Width

NOTE: Base stations and other equipment designed for front service access only and/or wall mounting do not require working space at the rear of the equipment. Equipment requiring rear access for servicing **shall** have a minimum working space of 762 mm (30 in.) at the rear of the equipment.

- A 914 mm (36 in.) aisle **shall** be maintained between at least one end of an equipment row and building wall or other obstruction; longer aisles may require additional access breaks. Larger aisles and additional access breaks in a row may be required as the row becomes longer, such that a fire in the aisle does not prevent egress. Comply with local codes regarding fire egress specifications. See Figure 9-5.

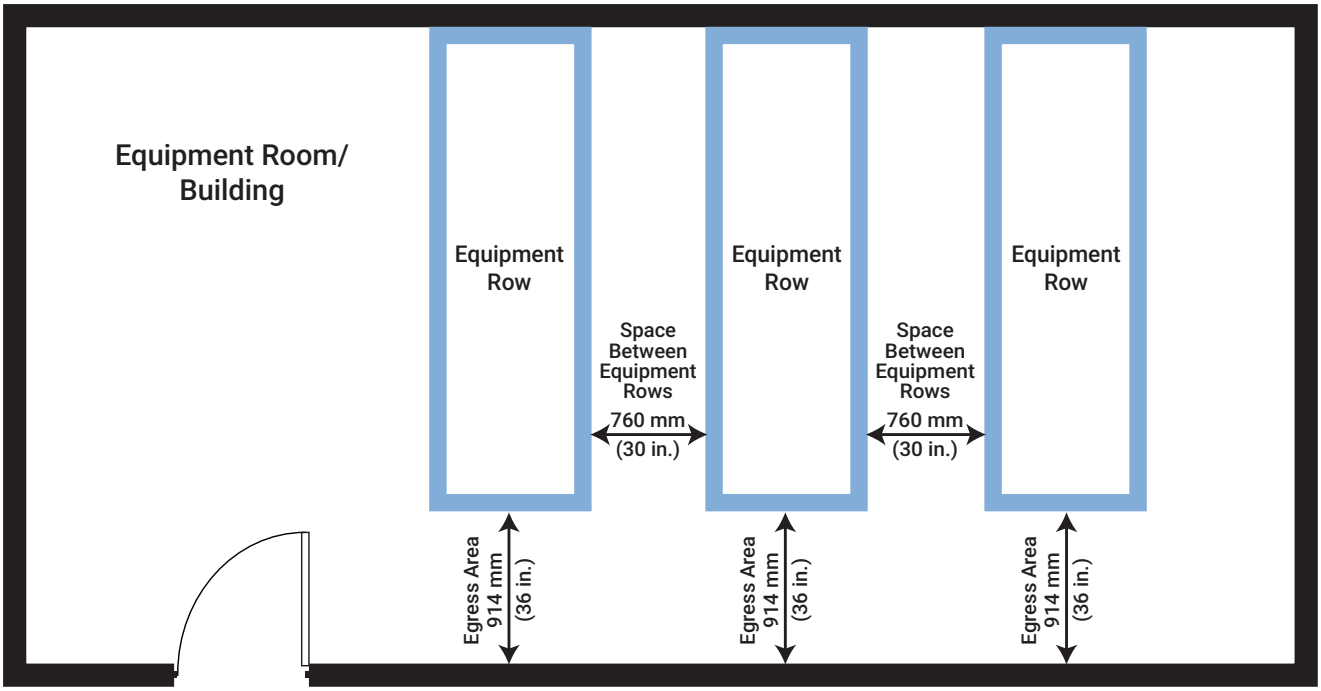


Figure 9-5. Example of Equipment Layout

- Ingress and egress to equipment rooms **shall** conform to NFPA 70-2026 Article 110 and local building and fire codes.
- US installations at facilities that are normally occupied **shall** comply with the access requirements of the Americans with Disabilities Act (ADA). General requirements of ADA include 914 mm (36 in.) wide doors; ramps and safety rails; 914 mm (36 in.) minimum turn-around clearance for wheelchairs, and specific placement of telephones, fire extinguishers, light switches, and so on. In some localities, ADA compliance in architectural plans may be required to obtain a construction permit.

NOTE: Local codes may require clearance beyond that stated in this section. In such cases, the local code **shall** prevail.

9.5 Seismic Considerations

In seismically active areas, special equipment installation methods may be necessary. Typically, this applies to areas classified in the International Building Code (IBC) as Seismic Design Categories C, D, E, and F. These methods are essential to ensure system availability during a seismic event. No requirements are specified for IBC Seismic Design Categories A and B because they do not pose a significant earthquake risk.

During an earthquake, equipment endures motions that can overstress the equipment's framework, circuit boards, cabling, and connectors. The amount of motion and stress depends on the structural characteristics of the building and framework that house the equipment, as well as the severity of the earthquake.

Determining whether seismic-rated equipment racks and cabinets (also known as server racks) are necessary for your facility depends on a key factor: the Seismic Design Category (SDC) of your building, as outlined in the IBC. The higher the SDC, the more rigorous the seismic requirements become for non-structural components, such as equipment racks and cabinets, to ensure they remain operational and do not pose a life-safety hazard during an earthquake.

In summary, if your building falls under Seismic Design Categories C, D, E, or F, you will likely need to install seismic-rated equipment racks and cabinets or use special seismic mounting solutions. For buildings in SDC A or B, these requirements generally do not apply.

9.5.1 Understanding the Shift from Seismic Zones to Seismic Design Categories

The term “seismic zone” is an outdated concept from the 1997 Uniform Building Code (UBC). The current standard, the International Building Code (IBC), employs a more refined and location-specific system known as Seismic Design Categories (SDCs). These categories range from A (lowest seismic risk) to F (highest seismic risk) and provide a more accurate assessment of ground shaking potential at a specific location.

NOTE: Seismic requirements in previous editions of this manual were based on the Uniform Building Code (UBC) Seismic Zone Maps (see Figure 9-6). The UBC was replaced by the International Building Code (IBC) in 2000. Although Telcordia and other industry standards still reference the UBC Seismic Zone Maps, this edition of the R56 manual uses the updated IBC Seismic Design Categories. UBC Seismic Zones 1 through 4 do not directly correspond to the IBC Seismic Design Categories A through F, although they are similar. Figure 9-7 provides maps showing the seismic design categories for the United States and its territories.

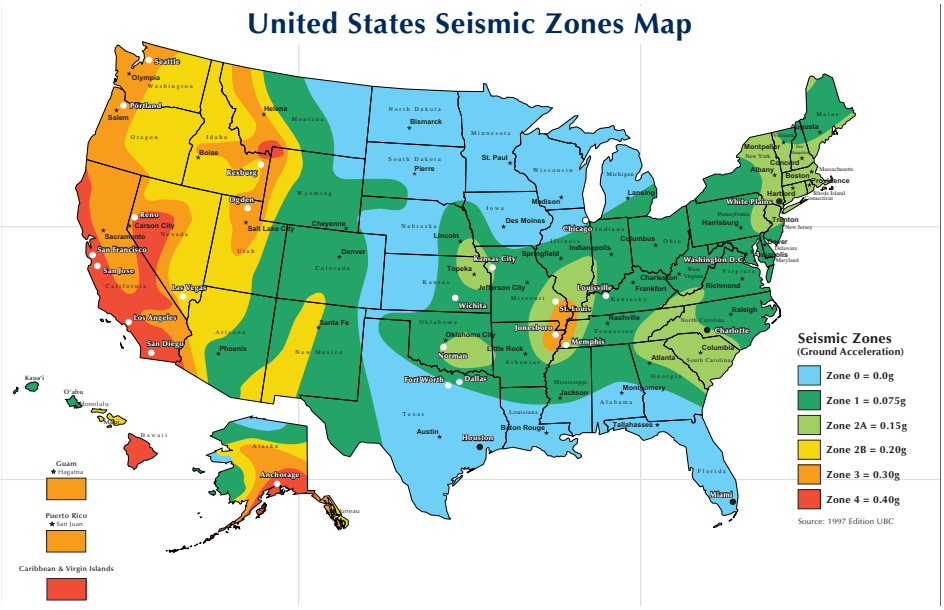


Figure 9-6. Obsolete United States Seismic Zone Map

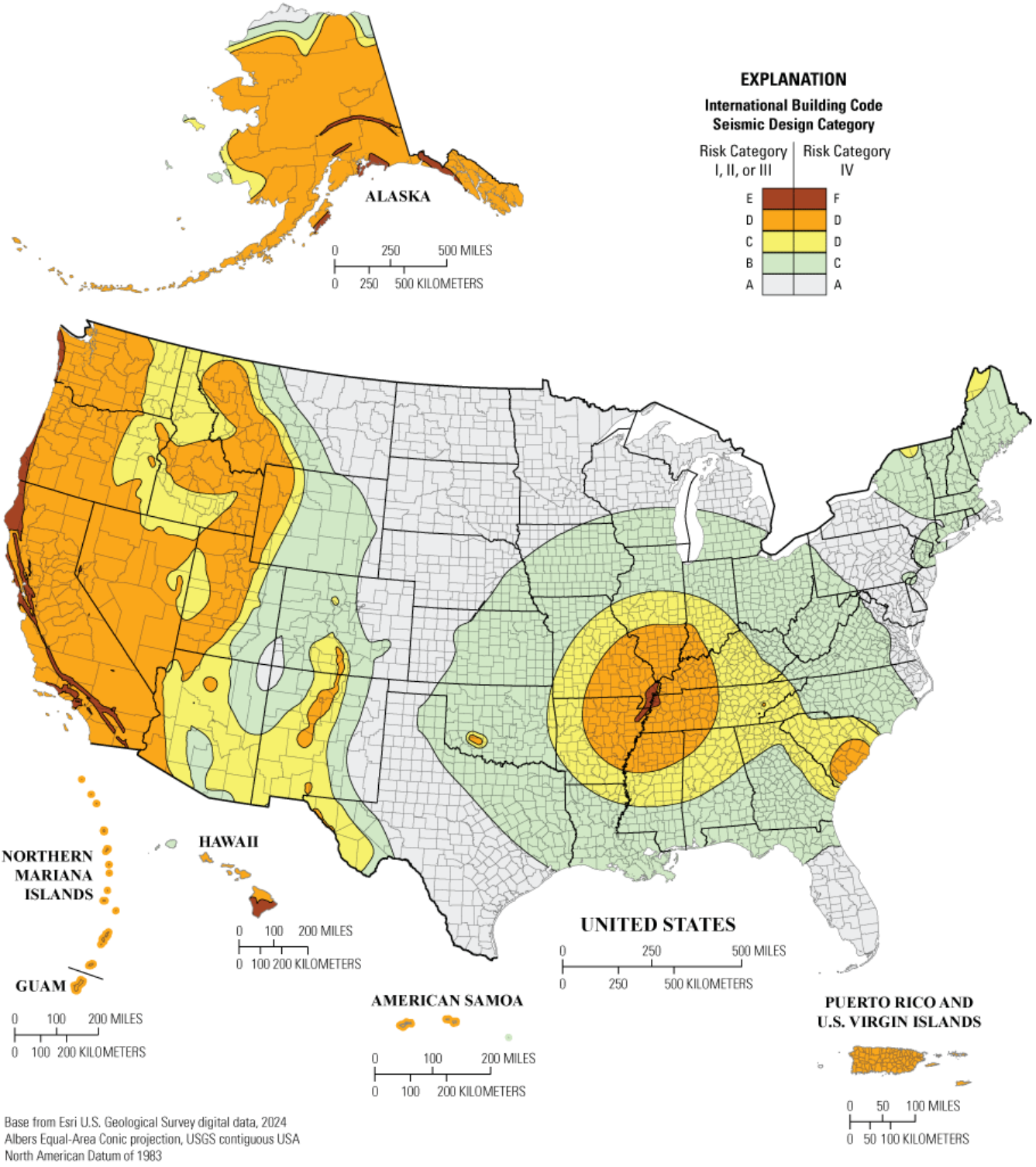


Figure 9-7. USGS Seismic Design Category Map for United States and its Territories

Unlike the broad zones of the past, SDCs are determined by a combination of three key factors:

- **Building Risk Category:** This classifies a building based on its use and the potential hazard to human life in case of failure. For example, a hospital (Risk Category IV) has higher importance than a storage warehouse (Risk Category I).
- **Mapped Spectral Response Acceleration Parameters (Ss and S1):** These values indicate the anticipated ground motion at a specific location for short-period (Ss) and 1-second period (S1) ground shaking. They are derived from seismic hazard maps maintained by the U.S. Geological Survey (USGS).
- **Site Soil Class:** This categorizes the soil conditions at the building site, ranging from hard rock (Class A) to soft soils (Class F), which can significantly amplify ground shaking.

Earthquake-resistant designs should be contracted to a firm specializing in this type of work. Follow the design recommendations of the seismic engineering firm. In other cases, observe the following general considerations:

Table 9-1 provides a general comparison between seismic zones and seismic design categories.

IMPORTANT: Table 9-1 is for informational and comparison purposes only. It does not replace a seismic assessment for a specific site. A direct one-to-one conversion is not possible because the two systems use fundamentally different methodologies.

IMPORTANT: Outside the United States, seismic design must comply with the requirements of the local authority having jurisdiction.

Table 9-1. Seismic Zone to Seismic Design Category General Comparison

UBC Seismic Zone (1997 & Prior)	Corresponding IBC Seismic Design Category (SDC)	General Level of Seismic Activity
Zone 0	A	Very Low
Zone 1	B	Low
Zone 2A/2B	C	Moderate
Zone 3	D	High
Zone 4	D, E, or F	Very High
General comparison for informational purposes only.		

UBC Zones were broad, regional maps based on general seismic hazard. IBC SDCs are site-specific and provide a more accurate risk assessment by factoring in:

- **Specific Ground Motion:** Using mapped spectral acceleration values (Ss and S1).
- **Soil Type (Site Class):** The soil at the site can significantly amplify ground shaking.
- **Building Importance (Risk Category):** Essential facilities, such as hospitals, have higher requirements than lower-risk structures, such as storage sheds.

For instance, a single location in the old UBC Zone 4 could be classified as SDC D, E, or F under the IBC, depending on its exact proximity to a fault and the building's specific use.

The latest International Building Code (IBC) and ASCE 7 standard **shall** be used to determine the official Seismic Design Category.

9.5.2 A Step-by-Step Guide to Determining Facility Requirements

Determine if a facility requires seismic-rated equipment racks, cabinets, and other nonstructural component mountings using the following steps:

1. Identify the building's location and risk category. First, the physical address of the building is needed. Next, its Risk Category must be determined, which is defined in Chapter 16 of the IBC. Here is a simplified breakdown:
   - Risk Category I: Buildings with a low hazard to human life in the event of failure (includes agricultural facilities, minor storage facilities).
   - Risk Category II: All buildings not assigned to Risk Categories I, III, or IV. This includes most standard commercial buildings and residential structures.
   - Risk Category III: Buildings with a substantial hazard to human life in the event of failure (includes schools, theaters, and buildings with an occupant load of more than 500).
   - Risk Category IV: Buildings designated as essential facilities (includes hospitals, fire stations, police stations, emergency communication centers, and other facilities required for emergency response).
2. Determine the site's soil classification.
   The soil type at the location plays a significant role in how seismic waves are amplified. A geotechnical engineer can provide a detailed soil report. If a report is unavailable, the IBC allows for a default Site Class D to be used, which assumes a stiff soil profile.
3. Use the ASCE 7 Hazard Tool to find the Seismic Design Category.
   The American Society of Civil Engineers (ASCE) provides a free online tool that simplifies the process of determining the SDC:
   - Go to the ASCE 7 Hazard Tool website ascehazardtool.org.
   - Enter the address of the building.
   - Select the appropriate Risk Category for the building (typically Risk Category IV for mission-critical sites).
   - Enter the Site Soil Class from the site's geotechnical report or use the default Site Soil Class D.
   - Select Seismic under Load Type.
   - Select View Results.

   The tool will generate a report that includes the site-specific seismic parameters, including the crucial Seismic Design Category. The Seismic Design Category for the site can be viewed by selecting Summary.
4. Apply the IBC requirements based on the SDC determined in step 3.
   After the SDC is known, refer to the following subsections to determine the seismic mounting requirements for equipment racks and cabinets.

In seismically active areas, special equipment installation techniques may be required. Typically, this includes areas in IBC Seismic Design Categories C, D, E, and F. These techniques are crucial in ensuring system availability during a seismic event. No requirements are provided in IBC Seismic Design Categories A and B because they present no substantial earthquake risk.

NOTE: Motorola Solutions provides the following general installation requirements for Seismic Design Categories. These guidelines are superseded by a seismic engineer's specific design or requirements from the authority having jurisdiction (AHJ), with whom consultation is recommended.

9.5.3 Seismic Design Categories A and B

There are no special requirements for these seismic design categories. Follow the normal installation requirements in this chapter and the authority having jurisdiction.

9.5.4 Seismic Design Category C

Seismic Design Category C locations are subject to a moderate seismic risk. Racks, cabinets, and other equipment may require additional bracing as determined by the system engineer, customer, and the authority having jurisdiction (AHJ).

The following seismic installation requirements **shall** be followed in SDC C locations:

- Follow all requirements of the authority having jurisdiction.
- Follow all applicable installation requirements in this chapter.
- Follow the installation requirements in “Equipment Securing” on page 9-17.
- Select anchors **that** meet the requirements of “Seismic Anchoring” on page 9-22.
- Anchor equipment according to “Seismic Anchoring” on page 9-22.
- Bolt the racks and/or cabinets using all available mounting holes or as otherwise required by the manufacturer.

Additionally, the following recommendations should be considered in SDC C locations:

- Use seismic-rated equipment racks and cabinets installed according to the manufacturer's instructions.
- Use a specifically engineered rack and/or cabinet mounting solution.
- If a seismic-rated rack or cabinet is not used, use a standard rack or cabinet with appropriate top support, such as listed seismic wire rope or cable, as described in “Semi-rigid Equipment Securing” on page 9-17.
- Use cable tray systems rated for the Seismic Design Category or secured according to the manufacturer's instructions. To meet the seismic requirements, the cable tray may require additional support, such as a seismic wire rope or cable. Consultation with the cable tray manufacturer and/or seismic engineering firm is recommended. See Figure 9-8.

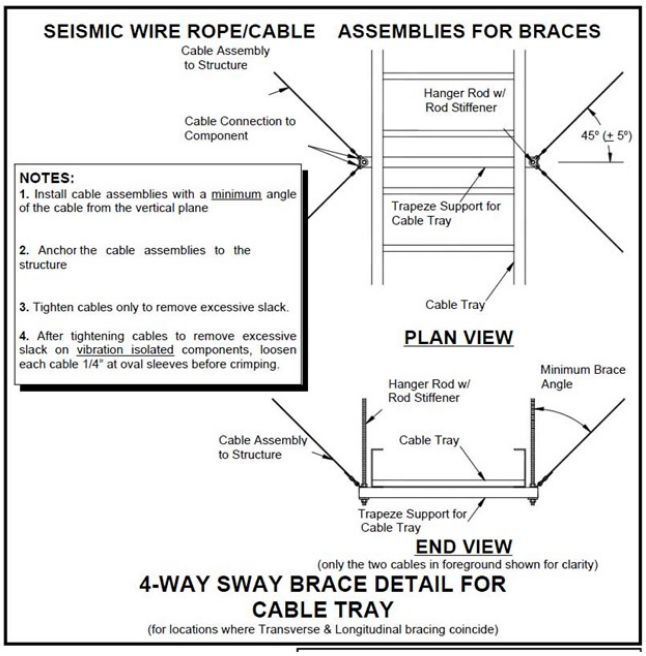


Figure 9-8. Brace Detail for Cable Tray

9.5.5 Seismic Design Category D

Seismic Design Category D locations are subject to a high to very high seismic risk. Racks, cabinets, and other equipment often require extra bracing as specified by the system engineer, customer, and the authority having jurisdiction (AHJ).

The following seismic installation requirements **shall** be followed in SDC D locations, or a specifically engineered rack, cabinet, and cable tray mounting solution **shall** be used:

- Follow all requirements of the authority having jurisdiction.
- Follow all applicable installation requirements in this chapter.
- Follow the installation requirements in “Equipment Securing” on page 9-17.
- Select anchors that meet the requirements of “Seismic Anchoring” on page 9-22.
- Anchor equipment according to “Seismic Anchoring” on page 9-22.
- Bolt the racks and/or cabinets using all available mounting holes or as otherwise required by the manufacturer.
- Use seismic-rated equipment racks and cabinets installed according to the manufacturer's instructions.
- If a seismic-rated rack or cabinet is not used, the rack or cabinet **shall** be secured using appropriate top support, such as listed seismic wire rope or cable, as described in “Semi-rigid Equipment Securing” on page 9-17.
- Use cable tray systems rated for the Seismic Design Category or secured according to the manufacturer's instructions. To meet the seismic requirements, the cable tray may require additional support, such as a listed seismic wire rope or cable. Consultation with the cable tray manufacturer and/or seismic engineering firm is recommended. See Figure 9-8 on page 9-14.

9.5.6 Seismic Design Category E and F

Locations in Seismic Design Categories E and F face a very high seismic risk. Racks, cabinets, and other equipment typically require specific seismic-engineered mounting solutions. Additionally, the requirements of the authority having jurisdiction (AHJ) **shall** be followed.

The following seismic installation requirements **shall** be followed in SDC E and F locations, or a specifically engineered rack, cabinet, and cable tray mounting solution **shall** be used:

- Follow all requirements of the authority having jurisdiction.
- Follow all applicable installation requirements in this chapter.
- Follow the installation requirements in “Equipment Securing” on page 9-17.
- Select anchors that meet the requirements of “Seismic Anchoring” on page 9-22.
- Anchor equipment according to “Seismic Anchoring” on page 9-22.
- Bolt the racks and/or cabinets using all available mounting holes or as otherwise required by the manufacturer.
- Use seismic-rated equipment racks and cabinets installed according to the manufacturer's instructions.
- Use cable tray systems rated for the Seismic Design Category or secured according to the manufacturer's instructions. To meet the seismic requirements, the cable tray may require additional support, such as a seismic wire rope or cable. Consultation with the cable tray manufacturer and/or seismic engineering firm is recommended. See Figure 9-8 on page 9-14.

9.5.7 Seismic Requirements and Recommendations

Refer to the following sections for seismic requirements and recommendations for communication sites.

9.5.7.1 Concrete Anchors

- Concrete anchors **shall** meet the performance requirements of Telcordia NEBS Requirements GR-63-CORE.i05.
- Concrete anchors used to base mount the framework to the floor **shall** be suitable for earthquake (dynamic) applications, as specified by the manufacturer (GR-63-CORE.i05).
- Concrete expansion anchors should use steel construction to minimize creep (GR-63-CORE.i05).

CAUTION: Before drilling into concrete floors, consult the building engineer and/or site owner to identify the type of floor construction (pre-stressed concrete, for example). If no engineering as-built drawings are available for the site, X-rays of the area to be drilled for the anchors are necessary to locate structural components and rebar.

NOTE: Typical concrete anchors are not designed to withstand dynamic loads, such as those caused by earthquakes. The criterion referenced in this section states that the selected anchors should be designed to handle the dynamic loads specified in this document (GR-63-CORE.i05).

9.5.7.2 Other Anchors

- Anchors such as lag bolts used in applications other than concrete, like wood framing, must provide equivalent strength to the concrete anchor. See GR-63-CORE.i05 for more information.
- Fastening systems for wall-mounted equipment **shall** withstand a force equal to three times the weight of the equipment applied in any direction (GR-63-CORE.i05).

NOTE: Wall-mounted equipment listed to the latest edition of IEC 62368-1, Audio/video, information and communication technology equipment - Part 1: Safety requirements, typically conforms to this requirement (GR-63-CORE.i05).

9.5.7.3 Equipment Rack and Cabinet Requirements

- Equipment racks and cabinets **shall** be certified as being compliant with Telcordia GR-63-CORE.i05 (or equivalent) testing requirements.
- Equipment racks and cabinets (framework) should be constructed for base mounting to the floor without the need for auxiliary support or bracing from the building walls or ceilings (see GR-63-CORE.i05 for more information).
- Equipment racks and cabinets (framework) should be of welded construction (GR-63-CORE.i05).

NOTE: Many rack manufacturers only offer “standard” racks and racks rated for “Zone 4" applications. Standard racks require auxiliary support within Seismic Design Categories C and D areas. Standard racks are not permitted in Seismic Design Categories E and F, except under the guidance of a seismic engineer.

- Racks and cabinets **shall not** be loaded beyond the maximum rated capacity of the framework (ATIS-0600336.2020).
- Unless otherwise permitted, racks and cabinets **shall** meet the minimum seismic testing requirements for the Seismic Design Category (SDC) in which they are installed, as defined by GR-63-CORE.i05. For example, a rack installed in an SDC location C or D s**hall** be rated for Zone 3 or Zone 4.
- A specifically engineered rack and/or cabinet mounting solution (from a seismic engineer) may supersede the requirements of this section.

9.5.7.4 General Requirements and Recommendations

9.5.7.4.1 Equipment Securing

- Equipment **shall not** be secured to both the shelter walls and floors, because dissimilar movement between these surfaces is likely during an earthquake, unless connection to the wall is made using a seismic absorbing device.
- Equipment racks and cabinets **shall** be secured to the floor using the manufacturer-recommended number of mounting holes and appropriate anchoring hardware as defined in “Concrete Anchors” on page 9-16, as required by the local building code, or the authority having jurisdiction (AHJ).
- Cabinet designs with wide footprints can help prevent cabinets from tipping over.
- Columns of cabinets stacked and bolted back-to-back present a very stable and wide footprint. The bottom cabinets **shall** be bolted to the floor for complete security.
- Some cabinets can be outfitted with outrigger-type support legs to prevent tip-over. These outriggers alone do not provide adequate earthquake protection, but are typically adequate if the cabinet is bolted to the floor.
- When installing equipment racks or cabinets on a concrete floor, it is important to coordinate the location of anchors with the edge of the concrete and other anchors to ensure that the concrete breakout strength is not compromised. Anchor placements and installations should meet the following requirements (see FEMA 413 “Installing Seismic Restraints for Electrical Equipment” for more information):
  - Do not install an anchor too close to a concrete edge. The anchor distance from the edge should typically be 1½ times the embedment anchor depth.
  - Do not install an anchor too close to another anchor. The minimum spacing between anchors should typically be two times the larger embedment anchor depth.
  - The depth of the concrete base **shall** be at least 2.54 cm (1 in.) greater than the anchor hole. Some undercut anchors may require a deeper concrete base.
  - Drilled holes **shall** be cleaned before inserting the anchor.
  - The anchor manufacturer's installation requirements **shall** be followed.

9.5.7.4.2 Semi-rigid Equipment Securing

- Mounting should allow for some “sway” in the overall equipment supporting framework to absorb the energy of earthquakes. This is usually achieved by rigidly mounting equipment racks or cabinets at the base (as explained in this chapter) while semi-rigidly securing the rack or cabinet at the top. The advantage of this type of installation is that racks or cabinets can sway within limits without falling over. The semi-rigid attachment can be implemented using one of the following methods:
  - Using a listed seismic wire rope or cable.
  - Using a seismic-rated brace designed to absorb shock (installed per manufacturer requirements).
  - Other specifically engineered solutions.

9.5.7.4.3 Anchoring Seismic Wire Rope

On installations utilizing seismic wire rope to semi-rigidly secure the top of equipment racks and cabinets, the wire rope **shall** be attached to the building structure with appropriate anchors. Wire rope and cable anchors should be fastened to ceiling joists, building steel, or other permanent structural elements.

For wire rope anchorages attached to wooden structures, lag bolts are permitted. Utilizing lag bolts for this configuration requires strict coordination of bolt placement relative to the wooden member edges and adjacent fasteners to preserve the wood's structural breakout strength. Anchor placements and installations **shall** comply with the following requirements (see FEMA 413 for more information):

- The distance between the bolt and the non-loaded edge (the edge opposite the direction of the load) of the wood structure should be no less than 1.5 times the bolt diameter (D) or 1.5D. See Figure 9-9.
- The distance between the bolt and the loaded edge (the edge in the direction of the load) of the wood structure should be no less than 4 times the bolt diameter (D) or 4D. See Figure 9-9.
- If a strut is attached to the wood support structure, both edge distances are considered loaded. The distance between the bolt and each edge should be no less than 4 times the bolt diameter (D) or 4D. See Figure 9-9.
- The distance between the bolt and the wood structure end edge should be no less than seven (7) times the bolt diameter (D) or 7D. See Figure 9-9.
- Spacing between bolts should be no less than four (4) times the bolt diameter (D) or 4D. See Figure 9-9.
- Do not anchor to the end grain of wood. See Figure 9-9.

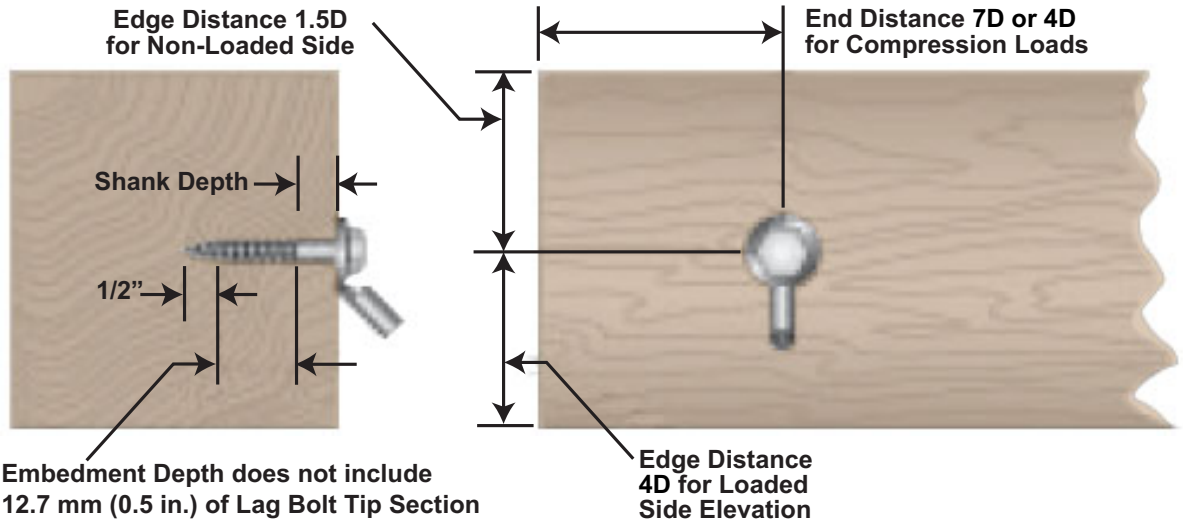


Figure 9-9. Anchoring Seismic Wire Rope

9.5.7.4.4 Computer Floor Applications

- Equipment installed on computer flooring **shall** be anchored to the subfloor as described in “Anchoring Equipment to Raised Floors” on page 9-20. Alternatively, the equipment may be secured as shown in Figure 9-10, Figure 9-11, and Figure 9-12.
- Raised flooring systems appropriate for the Seismic Design Category **shall** be used.
- Raised computer floors may lose structural integrity if panels are removed. This could lead to the collapse of the raised floor during an earthquake. The flooring manufacturer **shall** be consulted if panels are to be permanently removed.

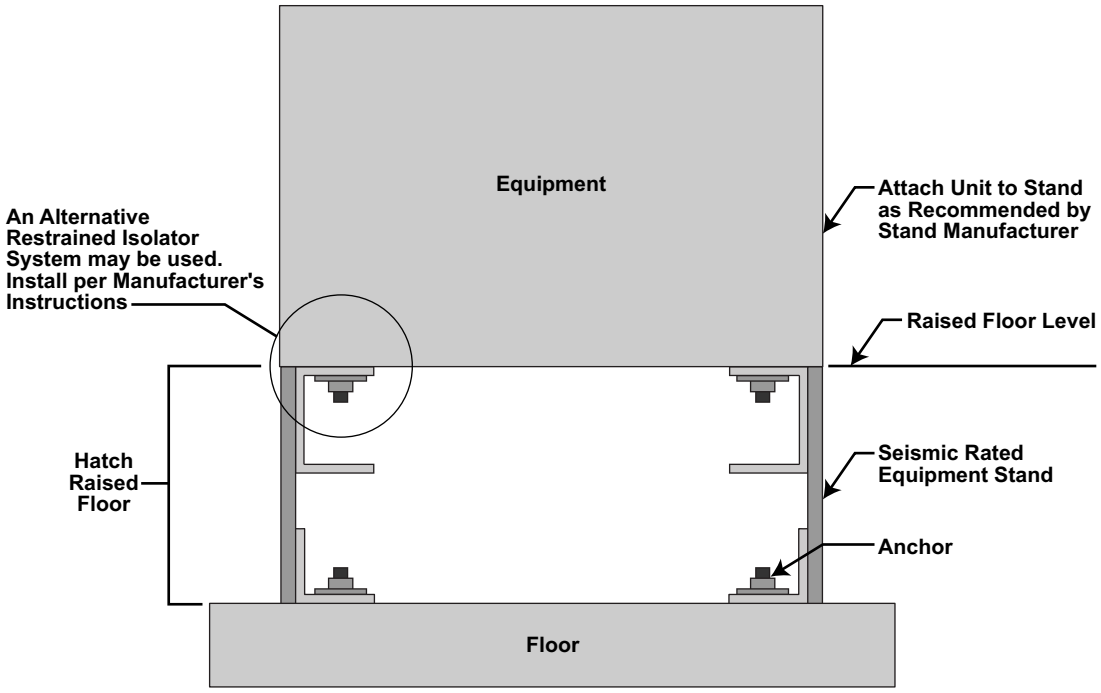


Figure 9-10. Equipment Installed on a Raised Floor: Secured to Seismic-Rated Equipment Stand

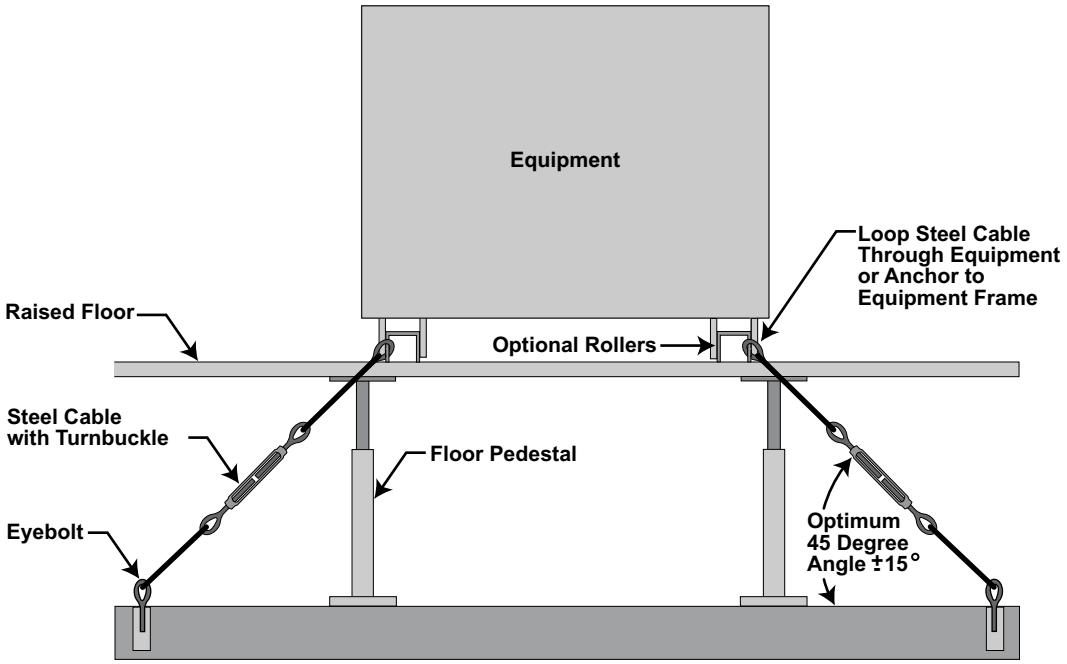


Figure 9-11. Equipment Attached to Cables Beneath a Raised Floor: Secured with Seismic-Rated Cables

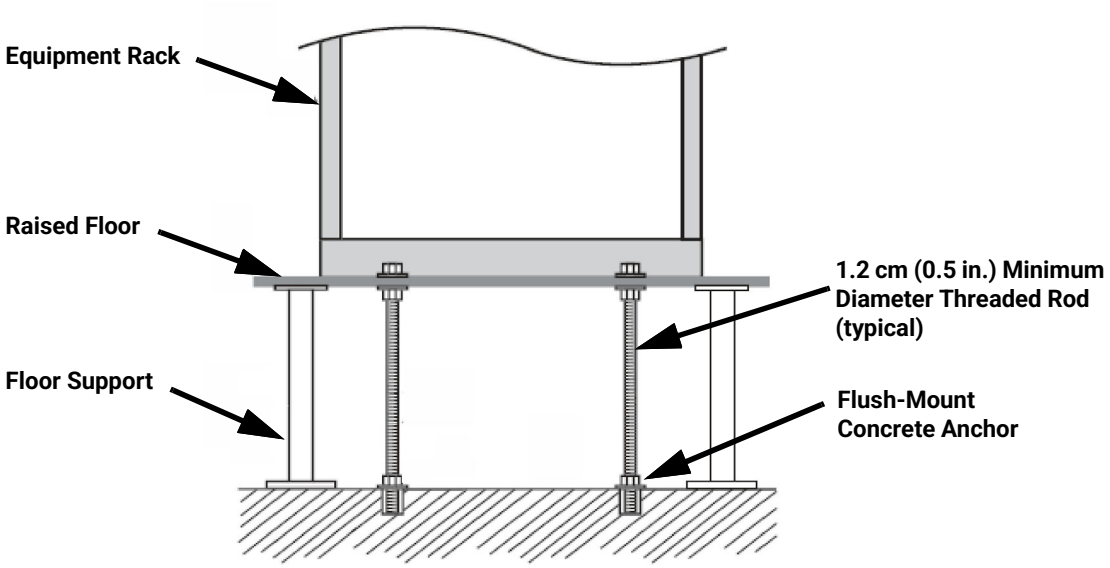


Figure 9-12. Anchoring Equipment to Raised Floors

9.5.7.4.5 Miscellaneous

- Cables and transmission lines **shall** be installed to allow the equipment rack or cabinet to sway. This is especially important for equipment installed on seismic isolation floors that are designed to move independently during a seismic event.
- All ancillary equipment that is not mounted in a rack or cabinet, such as displays or control stations, **shall** be securely fastened to a mounting structure.
- Storage cabinets **shall** be secured to prevent tipping. Storage cabinets **shall** also have closable, secured doors to prevent contents from spilling during an earthquake.
- Ladders and other large objects **shall** be secured or removed from the equipment area when not in use.
- Fluorescent lighting fixtures **shall** have protective lenses or protective plastic sleeves that cover the fluorescent tube, preventing broken glass from falling on occupants.
- Lighting fixtures should be prevented from swaying excessively by adding guy wires.

9.6 Level, Plumb and Squareness

- Equipment **shall** be level and plumb.
- Equipment **shall** be square to the adjacent wall as applicable.
- Equipment level **shall** be tested on a known flat surface in at least two directions to verify accuracy.

9.7 Equipment Anchoring

Anchoring is the mechanical fastening of communications equipment to suitable locations using hardware acceptable for the application. Although every installation is unique, certain methods for anchoring **shall** be adhered to for all installations.

Typically, at least four anchor points **shall** be used on each item of equipment mounted to the floor. The only exception is if the equipment manufacturer supplies more than four mounting points.

NOTE: Where seismic concerns exist (Seismic Design Category D or higher), see “Seismic Considerations” on page 9-10 for additional information and requirements (GR-63-CORE.i05, section 4.4.2).

The requirements for securing racks and cabinets are as follows:

- All racks and cabinets **shall** be anchored in order to prevent movement or tipping. The movement of racks or cabinets can damage equipment and cabling.
- Cabinet columns may be placed on C-channel tracks or wooden pedestals.
- Concrete anchors **shall** meet the performance requirements of Telcordia NEBS Requirements GR-63-CORE.i05.
- Concrete anchors used to base mount the framework to the floor **shall** be suitable for earthquake (dynamic) applications, as specified by the manufacturer (GR-63-CORE.i05).
- In seismic areas, concrete anchors **shall** meet the requirements of “Concrete Anchors” on page 9-16.
- Floor anchors **shall** be secure and **shall not** protrude above the floor level (the part that goes into the hole, not the bolt).
- Floor and wall anchors that comply with the equipment specifications **shall** be used. Types and sizes installed **shall** be in accordance with the support requirements of the intended load.
- Shields and anchors **shall not** be loose or so tight as to prevent expansion. Anchors **shall** be torqued to manufacturer's specifications.
- Unused holes in floors **shall** be filled with an appropriate concrete fill after shields and anchors are removed.

9.7.1 Mounting on Concrete Floors

CAUTION: Before drilling into concrete floors, consult the building engineer and/or site owner to identify the type of floor construction (pre-stressed concrete, for example). If no engineering as-built drawings are available for the site, X-rays of the area to be drilled for the anchors are necessary to locate structural components and rebar.

9.7.1.1 General Requirements

Equipment racks or cabinets should be positioned and securely anchored to the floor using preferred mounting methods. Figure 9-13 illustrates concrete mounting techniques and materials. In general, observe the following:

- An anchor specifically designed for concrete **shall** be used. The preferred method for anchoring racks or other ancillary equipment to concrete floors is to employ flush-mount expansion anchors sized for the application. Flush-mount expansion anchors do not protrude above the floor surface, allowing for easy bolting down. They also provide the necessary pullout and shear strength. If equipment needs to be relocated later, flush-mount expansion anchors do not obstruct movement.
- Unless an isolating mounting system is used (see “Isolated Mounting” on page 9-23), ensure that no anchors contact reinforcing rods or wire mesh buried in the concrete. If preferred or acceptable, wedge-type stud anchors can be used.

- All concrete anchors **shall** be zinc-plated carbon steel for standard applications, galvanized steel for mildly humid or corrosive environments, and yellow zinc or stainless steel for humid, highly corrosive, or acidic environments. Minimum bolt diameter **shall** be 10 mm (0.375 in.) with 12 mm (0.5 in.) preferred. Anchor embedment depth should be at least 76 mm (3 in.) to provide good tensile and shear strength. Follow the manufacturer's instructions for depth reduction when rebar is encountered. A heavy-duty washer should be included in the anchor assembly to ensure the equipment remains secure.

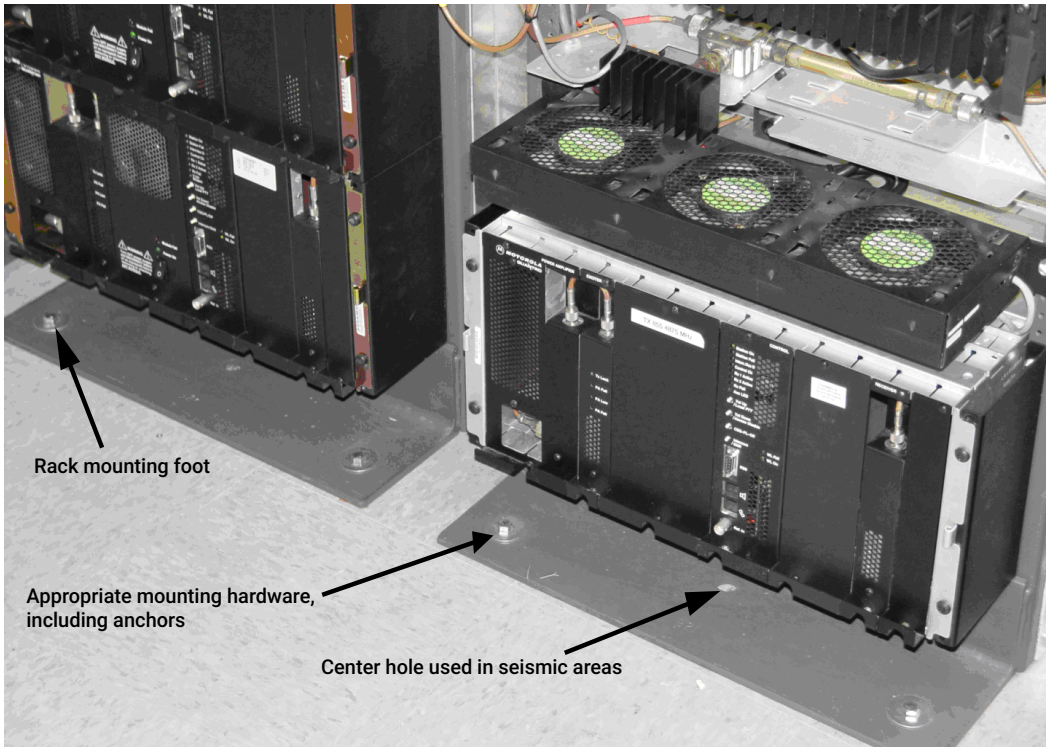


Figure 9-13. Rack Floor Mounting

9.7.1.2 Seismic Anchoring

Seismic anchors are designed, tested, and specified for seismic zones 3 and 4, which correspond with seismic design categories D, E, and F. The use of seismic anchors enhances the stability of equipment due to their special characteristics, which are specifically suited to the dynamic and cyclic loading effects experienced during earthquake events. As such, anchors that are manufactured to specific specifications **shall** be used, ensuring they are the most resistant to dynamic and cyclic loading effects.

Selected anchors **shall** meet the requirements of “Concrete Anchors” on page 9-16.

The following steps describe concrete mounting techniques and materials.

1. Using the appropriate pattern, drill 18mm (11/16 in.) holes. Hole depth **shall** be 102 mm (4 in.) minimum below the floor tile.
2. Vacuum all drilling dust, including the drilled holes, with a 0.3 micron HEPA filter or better. Alternatively, place the vacuum outside and extend only the hose into the shelter. If any existing equipment is in the site, cover it with an anti-static tarp or covering to prevent dust from entering.
3. Insert approved anchors (sleeved concrete anchors as shown in Figure 9-14) into each hole until plate washer is flat against the floor surface.

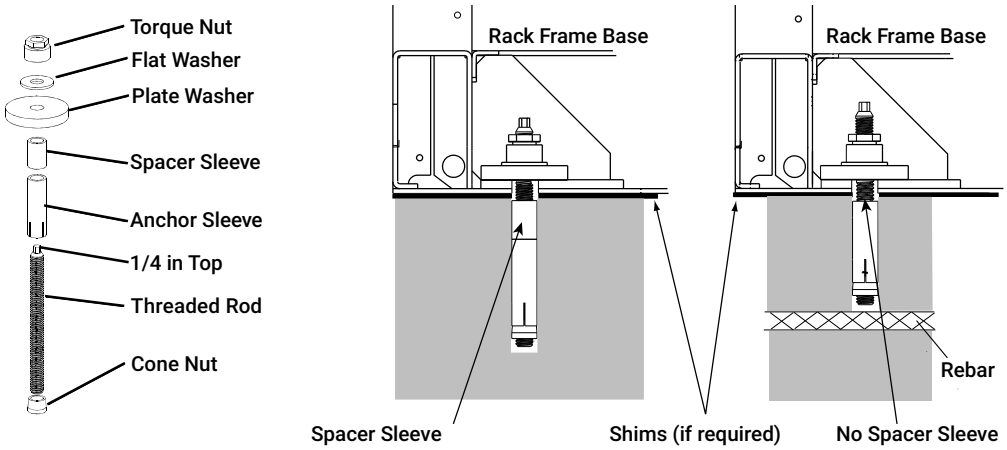


Figure 9-14. Anchor Installation

NOTE: If rebar is encountered with the standard anchor, remove the spacer and install the anchor without it.

4. Tighten anchor nuts to 67.8 N-m (50 ft-lbs).
5. Place the cabinet in position, ensuring that the mounting holes align with those in the floor.
6. Break nuts loose and remove the rods using the 6.35 mm (1/4 in.) drive top.
7. Insert the threaded rods into the anchors and install the nuts loosely to allow leveling and the installation of any shims required.
8. Level the rack and insert shims as required.
9. Using a wrench, tighten the lock nuts until the tops twist off.

9.7.1.3 Isolated Mounting

Isolated mounting is recommended to prevent a secondary path to earth (ground loop and stray current) through the concrete floor and is required for the installation of certain equipment. In these cases, expansion anchors are inserted into the concrete floor. However, isolation of the equipment rack is ensured using an insulating plate and hardware as shown in Figure 9-15. See BICSI N3-20, section 7.7.3, for more information.

If the installation is in an earthquake zone, additional anchors **shall** be used as shown in Figure 9-14.

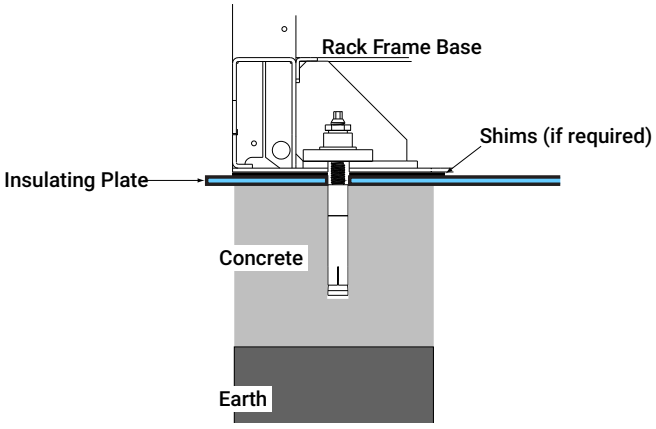


Figure 9-15. Isolated Mounting System

NOTE: The isolation plate should be made of an insulating material such as fiberglass or polypropylene plastic that will not deteriorate in varied temperature ranges.

NOTE: Isolated mounting is recommended when equipment racks are bolted to a concrete floor that is in direct contact with earth. This is to help prevent ground loops and stray currents. If the equipment is placed on vinyl or other non-conductive floor tile, no insulating plate is required; however, insulating washers or sleeves are required.

9.7.2 Mounting on Wood or Similar Surfaces

If equipment is installed in a building with wooden floors, special consideration must be given to provide adequate equipment anchoring. In some applications, an engineering firm may be required to design suitable equipment anchoring. The following paragraphs provide guidance for anchoring equipment to wood floors. Floor loading must also be considered. See “Floor Loading” on page 3-7 for more information.

Appropriately sized anchoring hardware **shall** be used where mounting equipment on wood or similar floors. Additionally, the bolts **shall** pass through the wood and anchor directly into the subfloor support structure. If the underside of the floor is accessible, through-bolting with backing plates should be considered to ensure adequate structural stability.

Minimum lag bolt diameter **shall** be 10 mm (0.375 in.) with 12 mm (0.5 in.) preferred. Lag bolt **shall** penetrate at least 76 mm (3 in.) of wood to provide good tensile and shear strength. A heavy-duty washer should be included in the anchor assembly to ensure the equipment remains secure. If there is not 76 mm (3 in.) of floor structure to penetrate, then an adequate support system **shall** be engineered. This may include a “C-channel” type mounting system or blocking.

It is recommended that base stations and other non-racked ancillary equipment be mounted on a “C-channel” type of mounting track where practicable. This provides for easy cleaning and some isolation in the case of standing water. Another benefit of installing non-rack-mounted equipment off the floor is that the weight is distributed across the floor. In these cases, C-channel type mounting provides multiple floor anchor points, whereas the equipment provides only four to six anchor points.

Table 9-2 lists some of the available types of anchoring hardware.

Table 9-2. Types of Anchoring Hardware

Anchor Type	Minimum Diameter	Minimum Length	Material
Lag Bolts	9.5 mm (3/8 in.)	76 mm (3 in.)	Corrosion-Resistant Steel
Toggle Bolts	9.5 mm (3/8 in.)	Application Specific	Corrosion-Resistant Steel
“C-Channel” Type Mounting Systems	9.5 mm (3/8 in.)	38 mm (1.5 in.)	Corrosion-Resistant Steel
4X4 Beams Anchored to Floor Joists - Equipment Then Anchored to the 4X4s	9.5 mm (3/8 in.)	76 mm (3 in.)	Corrosion-Resistant Steel

9.7.3 Anchoring Equipment to Raised Floors

At least four anchor points **shall** be used on each item of equipment mounted to the floor. See Figure 9-16. The only exception is if the equipment manufacturer supplies fewer than four mounting points. Where mounting racks to raised floors, 13 mm (0.5 in.) minimum diameter threaded rod and flush-mount expansion anchors **shall** be used to anchor the racks to the concrete subfloor. If mounting equipment to a raised floor, 10 mm (0.375 in.) minimum threaded rod and hardware **shall** be used for anchoring. The mounting arrangement **shall** be in accordance with the rack manufacturer's instructions.

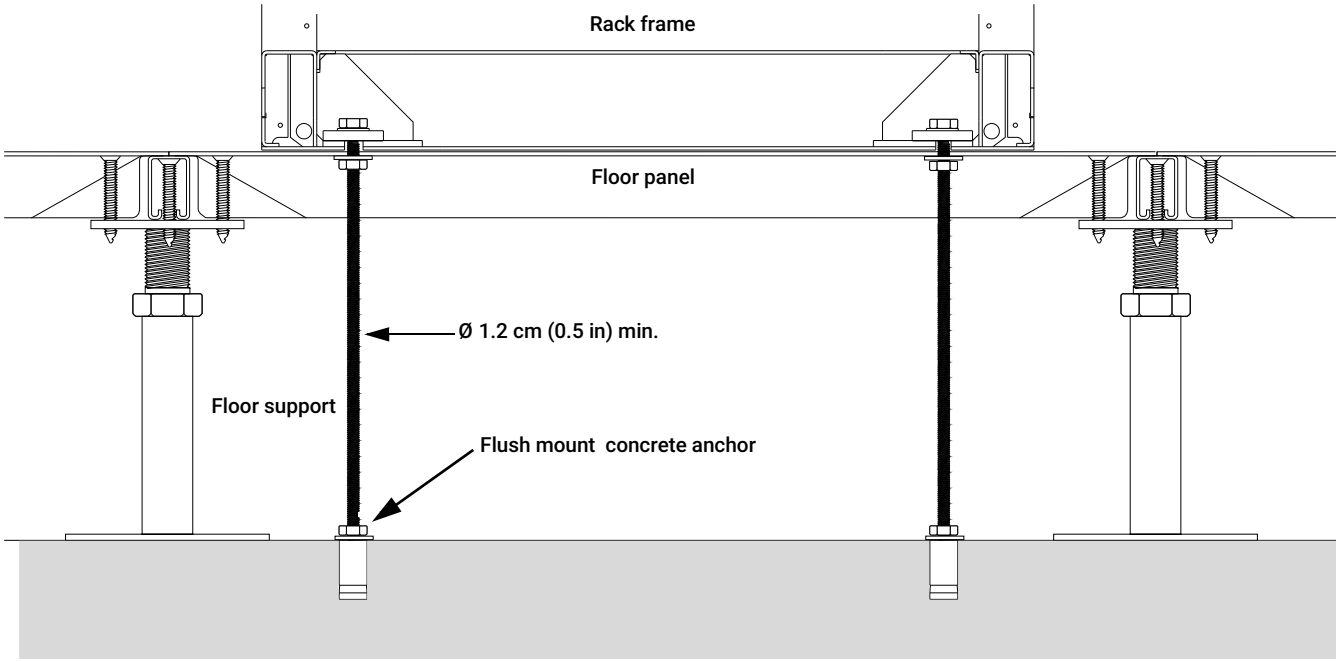


Figure 9-16. Raised Floor Anchoring

9.7.4 Anchoring Overhead and Wall-Mounted Equipment

The anchoring of overhead and wall-mounted devices presents several considerations. Placement is very important. If equipment is bolted to a wall that is on an aisle, the aisle may be unacceptably narrowed, resulting in potential danger of injury to personnel.

Overhead applications generally include coaxial cabling, cable trays, and mounts for earthquake bracing. All overhead applications should consider the loading of overhead surfaces. Care must be exercised when determining the load that the ceiling can support without building foundation support.

Where anchoring cable trays to ceilings or walls, the manufacturer's minimum required support hardware **shall** be used.

Anchors used in overhead applications vary depending on the ceiling structure as follows:

- For concrete and wood ceilings, the principles discussed in "Equipment Anchoring" on page 9-21 apply.
- For an exposed steel I-Beam ceiling, beam clamps for C-channel or threaded drop rods can be used.
- For corrugated steel ceilings, C-channel tracks can be affixed to the ceiling using lag bolts. The C-channel spans the corrugated steel and provides multiple anchor points.

For drywall or plasterboard ceilings, special considerations are required:

- If the drywall is on steel or wooden roof joists, locate and secure it to the roof joists using lag bolts.
- C-channel mounting may be used.

IMPORTANT: Make certain to locate the joists before drilling into drywall. Before drilling, cover any equipment onsite with an anti-static tarp or covering to protect it from drywall dust.

9.7.5 Equipment on Wheels

Equipment, racks and cabinets mounted on wheels **shall** be anchored. The same requirements apply to equipment, cabinets and racks on wheels as apply to non-wheeled items.

9.8 Equipment Installation Within Racks or Cabinets

Most communications equipment is mounted in standard 19-in. EIA racks or enclosed cabinets. Follow the rack and/or equipment manufacturer's instructions when installing equipment into racks or cabinets.

- All supplied bracing hardware **shall** be utilized.
- Suitable hardware **shall** be used to secure equipment.
- Convected heat transfer from one piece of equipment to another **shall** be considered. Heat baffles or fan kits may be required. Do not block fans or ventilation with items placed on top of cabinets or equipment in racks.
- Equipment installed in a rack or cabinet but not bolted in place (for example, computer, computer monitor, and so on) **shall** be secured. See Figure 9-17 for an example.
- In an equipment rack, lighter equipment **shall** be mounted at the top, and heavier equipment **shall** be mounted at the bottom. The weight of the equipment **shall** be evenly distributed from front to back.

See Chapter 5, “Internal Bonding and Grounding (Earthing)”, for equipment bonding and grounding information.



Figure 9-17. Example of Securing Equipment

9.9 Ancillary Equipment Mounting

Any permanent site equipment that is not mounted in a rack or cabinet **shall** be secured or mounted, including items placed on rack-mounted or cabinet-mounted peripheral trays.

9.10 Equipment Cabling

The following subsections describe the recommendations and requirements for cabling within buildings, equipment cabinets, and racks, and requirements for cable runs between equipment cabinets/racks.

9.10.1 Cable Installation Requirements

Requirements for building cabling are as follows.

9.10.1.1 General Cable Installation Requirements

- Communications wires, cables, coaxial cable, and raceways installed in buildings **shall** be listed (NFPA 70-2026, Articles 720.2, 722.2, 722.130, 722.132, 722.160, 722.162, 722.163, 723.2, and 800.2).
- Communications circuits, equipment, and coaxial cables **shall** be installed in a professional and skillful manner (NFPA 70-2026, Articles 110.12, 410.56, 640.6, 640.22, and 720.30).
- Communications cables installed in hazardous areas, as defined in NFPA 70-2026, Article 500, **shall** be installed in accordance with NFPA 70-2026, Article 500, and other applicable electrical and building codes, as well as the authority having jurisdiction (AHJ).
- See the following sections for cable bending radius requirements.

9.10.1.2 Support and Securing

- Communications cables and coaxes **shall not** be attached by any means to the exterior of a conduit or other raceway as a means of support (NFPA 70-2026, Articles 722.134(B), 722.164(C), and 800.48(B)). An example of incorrectly secured cabling is shown in Figure 9-18.

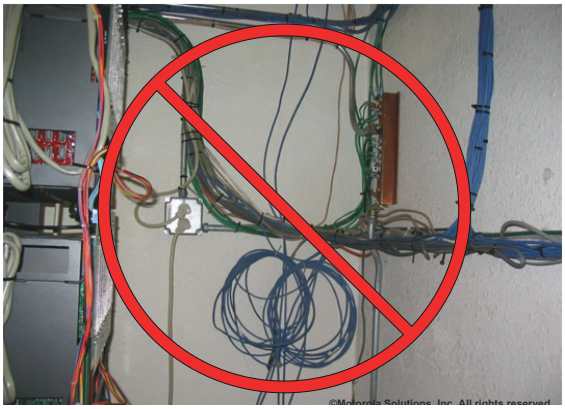


Figure 9-18. Example of Incorrectly Secured Cabling

- Communications cables and coaxes **shall not** be laid directly on the tiles or grid work of a false ceiling (NFPA 70-2026, Article 300.13(B), and TIA-569-E, section 9.5.2.1).
- Communications raceways, cables, and coaxes **shall not** be supported by ceiling-support wires (NFPA 70-2026, Article 300.13(B)(1), and TIA-569-E, section 9.8). Independent wires can be installed to support communications raceways and cables. Where independent support wires are used, they **shall** be secured at both ends (NFPA 70-2026, Article 300.13(B)(2)(1)). See Figure 9-19.

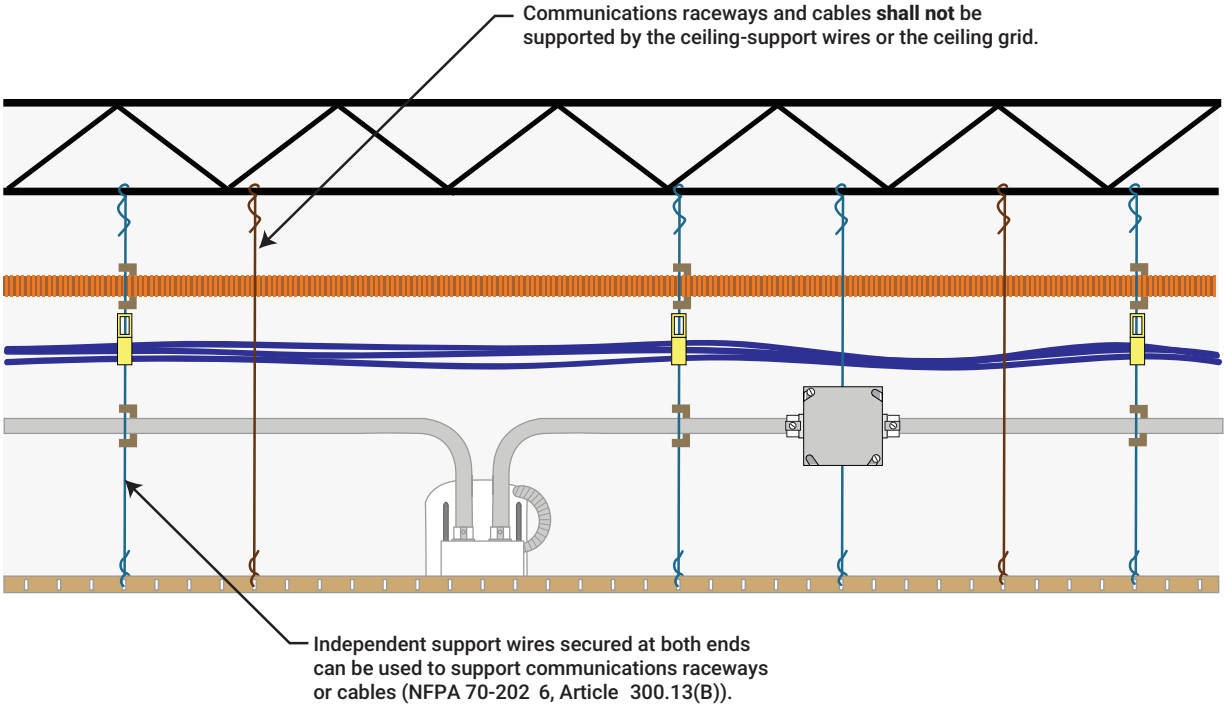


Figure 9-19. Running Cables and Raceways in a Ceiling Space

- Do not over-tighten communications cables with cable ties or other supports. Over-tightening cable ties or other supports can negatively affect the electrical characteristics of the cable and degrade performance. Velcro®-style cable ties (or equivalent) are recommended for computer network and E1/T1 cables. See TIA-568.0-E, section 6.1, and BICSI Information Transport Systems Installation Methods Manual (ITSIMM), 8th Edition, section 3 for additional information.

9.10.1.3 Separation From Noise Sources and Other Cable Groups

- Communications cables **shall** be separated by at least 50.8 mm (2 in.) from conductors of any electric light, power, Class 1, non-power-limited fire alarm, or medium-power network-powered broadband communications circuits (NFPA 70-2026, Article 722.15).
- Balanced twisted-pair cabling should be separated from fluorescent lamps and associated fixtures by a minimum of 125 mm (5 in.) (TIA-569-E, section 9.3.2).
- Avoid routing communications cables near sources of Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI). Routing cables near sources of EMI or RFI can cause data errors and/or degraded system performance. Such noise sources include, but are not limited to, the following: electrical power wiring, electrical transformers, dimmer switches, radio frequency transmitters, motors, generators, and fluorescent lights. See TIA-569-E, Table 6, for more information.
- If routing communications cables near sources of EMI or RFI cannot be avoided, reasonable precautions **shall** be taken to minimize the negative impact of EMI or RFI. Such precautions may include, but are not limited to, the following: increasing the physical distance between the communications cable and the source of the EMI/RFI, installing the communications cable inside a grounded metallic conduit, or using a shielded communications cable. See TIA-568.4-E and 569-E for additional information.

9.10.1.4 Cabling Removal Requirements

Abandoned cables increase the fire loading of a building. The accessible portion of abandoned communications cables (including optical fiber cables) **shall** be removed (NFPA 70-2026, Articles 720.25 and 760.25). The following definitions apply:

- **Abandoned Communications Cable:** An installed communications cable that is not terminated at both ends at a connector or other equipment and not identified for future use with a tag (NFPA 70-2026, Article 100). Also see NFPA 70-2026, Articles 640.6(B), 645.5(G), 720.25, and 760.25.
- **Accessible:** Capable of being removed or exposed without damaging the building structure or finish, or not permanently closed in or blocked by the structure, other electrical equipment, other building systems, or finish of the building. (NFPA 70-2026, Article 100).

The requirements in this section cover the portions of cable installation that are not permanently enclosed by the building structure or finish, or cannot be removed without damaging the building structure or finish. Abandoned cables in a concealed raceway (for example, conduit) are not required to be removed. Abandoned cables under computer floors **shall** be removed.

Unused communications cables labeled for future use are not required to be removed. See Figure 9-20. Cables intended for future use **shall** be identified as such, using a tag of sufficient durability to withstand the environment in which it will be used. See NFPA 70-2026, Articles 720.25 and 760.25.

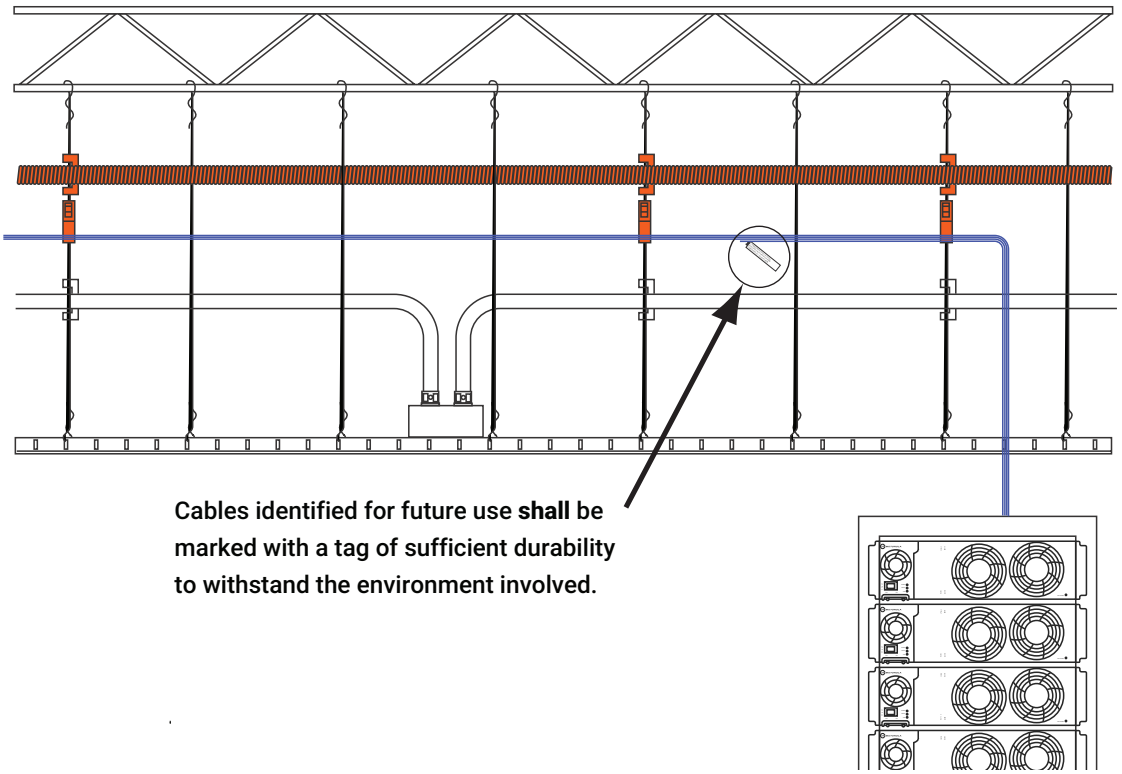


Figure 9-20. Unused Cable ID Tag

9.10.2 Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air

A plenum is a compartment or chamber to which one or more air ducts are connected and forms part of the air distribution system (NFPA 70-2026, Article 100).

“Other spaces used for environmental air” are defined as spaces not specifically fabricated for environmental air-handling purposes but used for air-handling purposes as a plenum (NFPA 70-2026, Article 305.32(C)). This definition does not apply to habitable rooms or areas of buildings, the prime purpose of which is not air handling (NFPA 70-2026, Article 305.32(C)).

The space over a hung ceiling used for environmental air-handling purposes is an example of the type of other space to which this definition applies (NFPA 70-2026, Article 305.32(C) Informational Note 1). See Figure 9-21 and Figure 9-22.

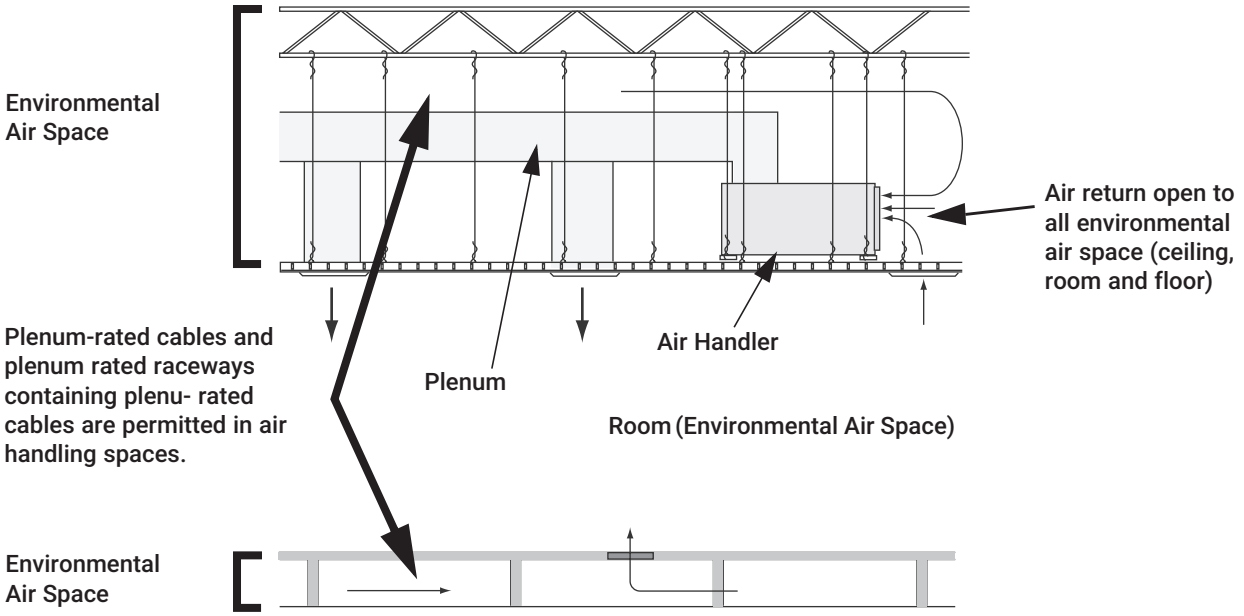


Figure 9-21. Air Handling Spaces - Wiring Restrictions

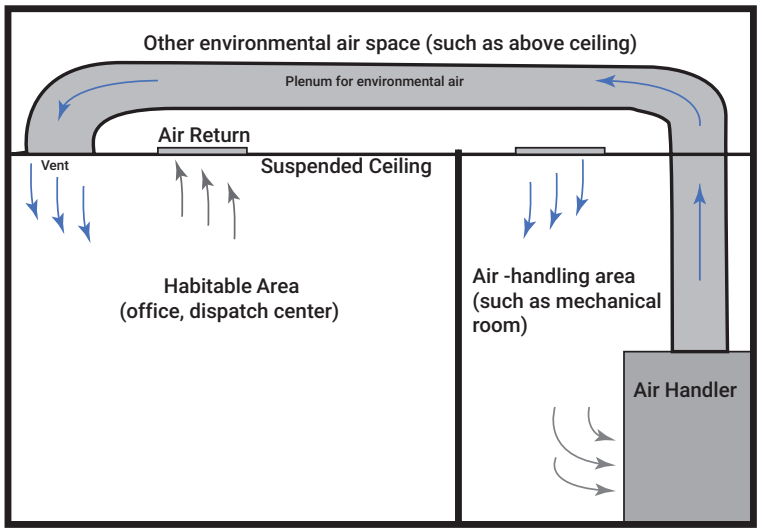


Figure 9-22. Other Air-Handling Spaces

The following requirements specify installation practices that, should a fire occur, help minimize smoke and products of combustion from electrical wiring in areas that handle environmental air:

NOTE: The term “communications cable” is used generically in this section to describe communications cable, coaxial cable, computer network cable, and optical fiber cable.

- No wiring systems of any type **shall** be installed in ducts used to transport dust, loose stock, or flammable vapors (NFPA 70-2026, Article 305.32(A)).
- No wiring system of any type **shall** be installed in any duct, or shaft containing only such ducts, used for vapor removal (NFPA 70-2026, Article 305.32(A)).
- Communications cables **shall not** be installed in a plenum (NFPA 70-2026, Article 305.32(B).
- Communications cables installed in spaces used for air handling (such as for return air) **shall** be plenum-rated (such as type xxP) or specifically listed for use within an air handling space (NFPA 70-2026, Articles 720.22(C)(1) and 722.131 (C)(1)). **Exception**: when the cable is installed in a metallic conduit as permitted by NFPA 70-2026, Articles 720.22(C)(1) and 722.131(C)(1).
- Non-metallic communications raceways installed in other spaces used for air handling **shall** be plenum-rated or specifically listed for use within an air-handling space (NFPA 70-2026, Article 722.131 (C)(1).
- Non-metallic communications raceways installed in other spaces used for environmental air **shall** only contain plenum-rated communications cables specifically listed for use within an air-handling space. The use of plenum-rated non-metallic communications raceway does not negate the requirement to use plenum-rated communications cables. See NFPA 70-2026, Articles 720.22(C)(1) and 722.131 (C)(1).
- A bare grounding conductor may be installed in a plenum area. If a bare conductor is used, it **shall** be secured and protected from making incidental contact with other metallic objects not meant to be bonded. A non-metallic plenum raceway may be used to prevent incidental contact.
- Wire ties, straps, and other non-metallic hardware used to secure communications cables in other spaces used for environmental air **shall** be listed as plenum-rated, and other non-metallic hardware used to secure communications cables in other spaces used for environmental air **shall** be listed as plenum-rated, suitable for use in air handling spaces. See NFPA 70-2026 Article 300.25(C)(1).

IMPORTANT: Non-metallic plenum-rated communications raceways installed in an air-handling space **shall** only contain plenum-rated communications cables. The use of plenum-rated non-metallic communications raceway does not negate the requirement to use plenum-rated communications cables.

IMPORTANT: Communications cables installed in an air-handling space **shall** meet the installation requirements of the AHJ. These requirements may differ from the requirements in this manual.

NOTE: Figure 9-23 shows an example of the space above a suspended ceiling that does not require plenum-rated cables because it is not an environmental air handling space.

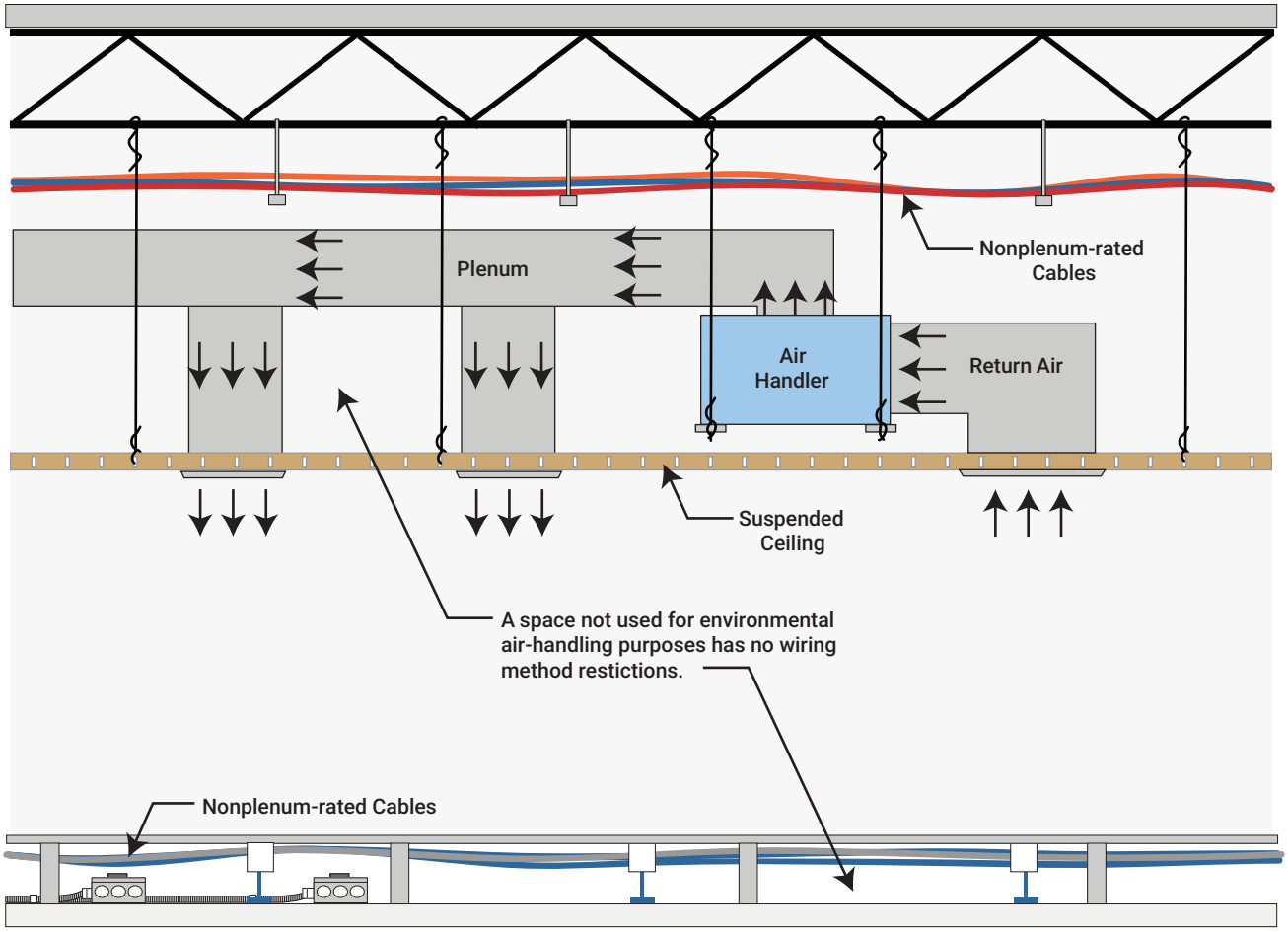


Figure 9-23. Spaces Not Used for Environmental Air – No Wiring Restrictions

9.10.3 Communications Cabling Requirements for Risers

IMPORTANT: Non-metallic riser or plenum-rated communications raceways installed in a riser **shall** only contain riser or plenum-rated communications cables. The use of riser or plenum-rated non-metallic communications raceway does not negate the requirement to use riser or plenum-rated communications cables.

IMPORTANT: Communications cables installed in a riser **shall** meet the installation requirements of the AHJ. These requirements may differ from the requirements in this manual.

NOTE: The term “communications cable” is used generically in this section to describe communications cables, coaxial cables, computer network cables, and optical fiber cables.

The following requirements apply to communications cabling installed in a riser (vertical run):

- Communications cables penetrating one or more floors and cables installed in vertical runs in a shaft **shall** be riser or plenum rated (such as type xxR or xxP) (NFPA 70-2026, Articles 760.53(B)(3), 722.131(D), 722.161(D), and 722.163).
  - Riser or plenum-rated cable is not required if the cable is installed in a metal raceway and the metal raceway has approved fire stops at each floor (NFPA 70-2026, Articles 722.131(E) and 722.161(E)).
  - Riser or plenum-rated cable is not required if the cable is installed in a fireproof riser shaft and the shaft has approved fire stops at each floor (NFPA 70-2026, Articles 722.131(F) and 722.161(F)).
- Non-metallic communications raceways installed in a riser **shall** be riser or plenum-rated (NFPA 70-2026, Articles 722.131(D) and 722.163).
- A bare grounding conductor may be installed in a riser. If a bare conductor is used, it **shall** be secured and protected from making incidental contact with other metallic objects not meant to be bonded to the grounding conductor. Non-metallic riser-rated or plenum-rated raceway may be used to prevent incidental contact.

9.10.4 Fire Stopping Requirements

Electrical installations in hollow spaces, vertical shafts, and ventilation or air-handling ducts **shall** be installed in a manner such that the possible spread of fire or products of combustion will not be substantially increased. Openings around electrical penetrations into or through fire-resistance-rated walls, partitions, floors, or ceilings **shall** be fire-stopped using approved methods to maintain the fire resistance rating. See NFPA 70-2026, Articles 300.23, 305.31, 368.234(B), 369.110, 720.21, 760.4(A), and 720.21; TIA-569-E; and BICSI N1-2019, section 8, for additional information.

Approved fire-stopping products may include the following (BICSI N1-2019, section 8):

- Mechanical systems
- Mortar compounds
- Collar devices
- Blankets
- Caulks or sealants
- Putty
- Wrap strips
- Pillows or bags
- Sprays

The fire-stopping product used **shall** be approved by the AHJ and **shall** be installed in accordance with the manufacturer's instructions.

CAUTION: Openings around electrical penetrations into or through fire rated walls, floors, and ceilings SHALL be fire-stopped using products and methods approved by the AHJ. See Figure 9-24.

IMPORTANT: Check with the AHJ to determine requirements for fire-stopping, permitting, and inspection requirements.

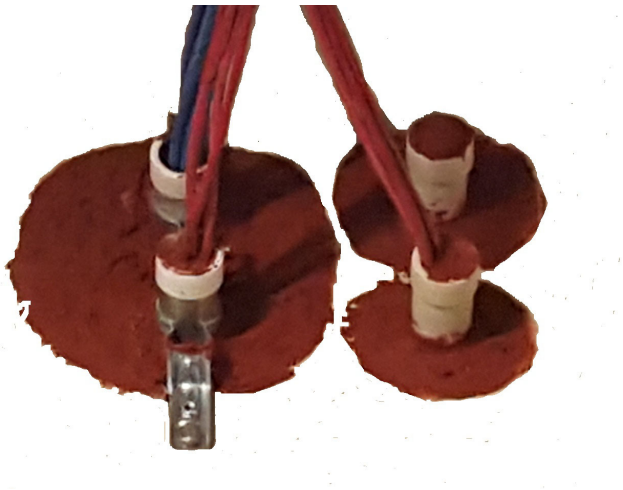


Figure 9-24. Fire-Stopping Electrical Openings

9.10.5 Cabling Requirements For Cable Trays or Ladders

The following subsections identify the installation requirements for cabling in cable trays or ladders.

9.10.5.1 Cable Installation Within Cable Trays or Ladders

- Cables that span a horizontal gap greater than 610 mm (2 ft) **shall** be supported.
- Cables installed within a cable tray system **shall** be fastened securely to transverse members in all horizontal and vertical runs every 914 mm (36 in.).
- The most desirable method for cable to exit the cable runway is to drop out the bottom (versus over the side) into a rack/cabinet or a vertical support, such that physical separation is maintained.
- When installing cables into a cable tray system, cables **shall not** be pulled with such force that the conductor insulation or cable jacket integrity is destroyed or that the cable is deformed.
- Minimum bending radii for transmission lines **shall** be considered when placing these cables within the cable tray. Adhere to manufacturers' specifications.
- Cable trays **shall** be planned for an initial maximum calculated fill of 25%. The maximum fill of any cable tray **shall** be 50%. The maximum fill depth of any cable tray **shall** be 150 mm (6 in.). See TIA-569-E 9.7.1.1 for more information.
- AC power cables **shall not** be run within a cable runway system unless they are enclosed within an approved conduit or raceway or are otherwise approved for installation in cable trays (see NFPA 70-2026, Article 392).
- Cables run in a cable tray **shall** adhere to the requirements set forth in NFPA 70-2026 (see NFPA 70-2026, Articles 336 and 392).
- For DC Power Cabling requirements, see “DC Power Cabling” on page 9-40.

NOTE: Raceways or conduits installed below or alongside cable runways may not be supported by the cable runways unless the cable runway system is designed to provide such support and such installation is approved by the authority having jurisdiction. Raceways or conduits may be supported by the same supporting hardware as the cable runway system. See NFPA 70-2026, Articles 314.1 and 392.18(G).

9.10.5.2 Cable Separation and Grouping Within Cable Trays and Ladders

- Cable groups **shall** be separated a minimum of 50.8 mm (2 in.) from other cable groups. See TIA-569-E, section 9.3; NFPA 70-2026 Articles 722.15 and 830.133; and Figure 9-25 for additional information.

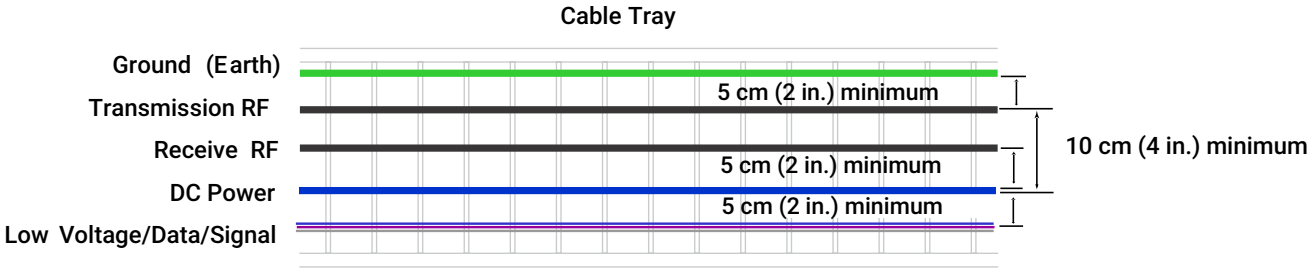


Figure 9-25. Minimum Cable Group Separation In Cable Tray

- Groups are defined as:
  - AC power
  - DC Power
  - Grounding/bonding conductor
  - RF transmission cabling
  - Data, control, signal, and timing reference cabling and telephone cabling
- Transmission lines (coax) for transmitting stations **shall** be separated a minimum of 101 mm (4 in.) from electric light, power, and signaling circuits (NFPA 70-2026, Article 810.70).
- At a minimum the group separation described in this section **shall** be maintained. However, logical sub-groups are permitted with adequate cable tray space, such as bundles of DC cabling or bundles of RF cabling.
- AC power cables **shall not** be run in the same cable tray as network or communications cables unless separated by a barrier as defined by NFPA 70-2026 (such as Electrical Metallic Tubing). See “Computer Network Cabling” on page 9-41.

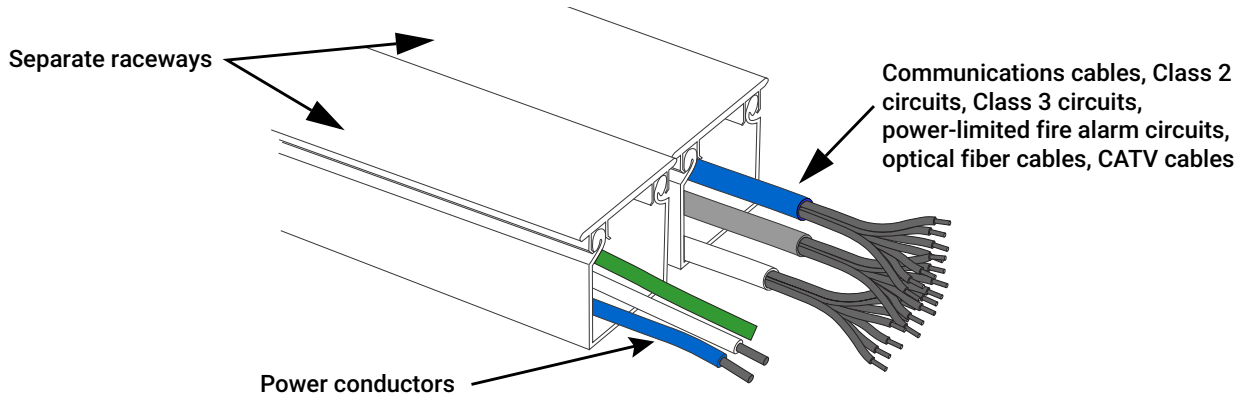


Figure 9-26. Use of Raceways for Cables

9.10.5.3 Securing Cables Within Cable Trays and Ladders

- Cables and conductors **shall** be secured at intervals of no more than 914 mm (36 in.).
- Cable fasteners, ties and securing devices **shall** be non-metallic.
- Cable securing **shall** be tight enough to secure the cables without crushing, deforming, or pinching them.
- Waveguides and other RF transmission lines can be secured with metallic fasteners specifically designed for this purpose.
- Cables running vertically on a cable ladder **shall** be secured at a minimum of 914 mm (36 in.). It is recommended that the cables be secured at every rung.
- Where cables span a gap (such as between a cable tray and a ladder) in excess of 610 mm (24 in.), the cables **shall** be supported.
- Cables **shall** be sized to length, including a sufficient service loop. Excess cable **shall not** be coiled on top of cabinets or cable trays.
- Certain telephony requirements may exist for cables to be laced. See “Cabling in Telephone Wiring Environments” on page 9-64 for additional information.



Figure 9-27. Securing Cables in Cable Tray

9.10.5.4 Cable Bending Radius Within Cable Trays and Ladders

- The minimum inside bend radius for twisted-pair cables **shall** be four times the cable diameter, or as otherwise specified by the cable manufacturer (see TIA-568.2-E-2024, section 5.3.6, for additional information).
- The minimum inside bend radius for a patch cord **shall** be four times the cable diameter (TIA-568-E).
- The minimum inside bend radius for shielded twisted-pair cables **shall** be eight times the cable diameter, or as otherwise specified by the cable manufacturer (see TIA-568.2-E-2024, section 5.3.6, for additional information).
- See “Network Cable Bending Radius” on page 9-51 for computer network cable bending radius requirements.
- See “Optical Fiber Cabling Bending Radius” on page 9-56 for optical fiber bending radius requirements.
- The minimum inside bending radius of E1/T1 cables **shall** follow the requirements for computer network cables described in “Network Cable Bending Radius” on page 9-51 or as required by the cable manufacturer.
- All other cables **shall not** have sharp bends, which will damage or degrade the performance of the cable. The cable manufacturer's specifications **shall** be followed.
- Grounding conductors of all sizes **shall** maintain a minimum bending radius of 203 mm (8 in.) as described in Chapter 5, “Internal Bonding and Grounding (Earthing)”.

NOTE: A patch cord is a length of cable terminated with a plug or connector on both ends, used to establish a flexible connection for telecommunications circuits and data links. It is used to connect, or "patch," various points within a structured cabling system, such as linking equipment to a telecommunications outlet or interconnecting components like patch panels and network hardware. See TIA-942-C, TIA-568.0-E, TIA-568.2-E, TIA-569-E, BICSI ITSIMM, 8th Edition, and BICSI-N1-2019.

9.10.6 Cabling Requirements for Equipment in Racks and Cabinets

All cables **shall** be installed and routed so that personal safety and equipment functionality are not compromised, and that all equipment is accessible for servicing and maintenance. The following requirements apply to cabling installed in racks or cabinets:

9.10.6.1 Routing Cables Within Racks and Cabinets

- Consideration should be given to using some method of cable management within the rack. See Figure 9-28 for an example.

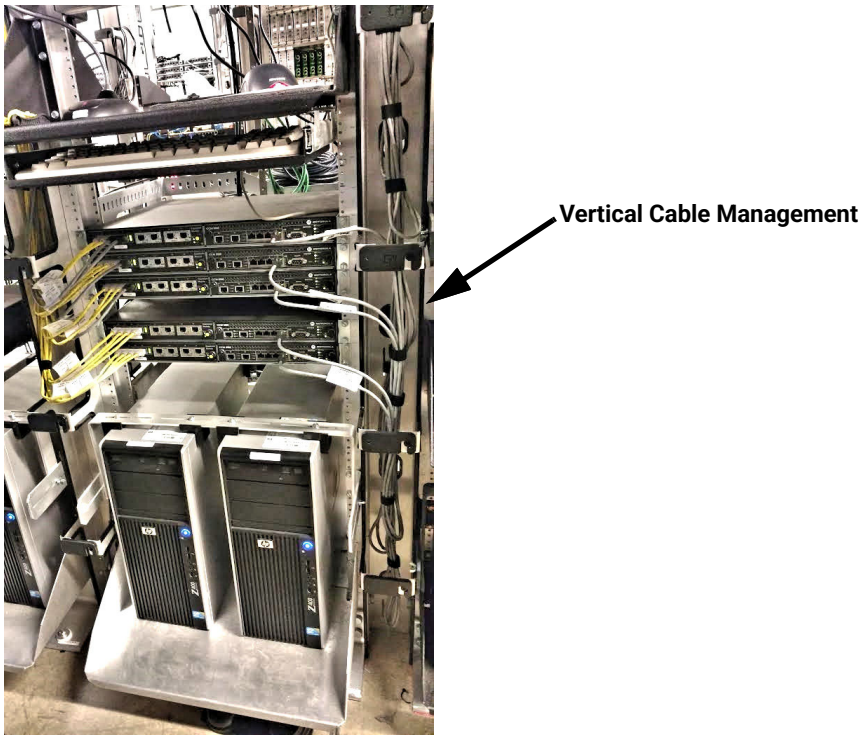


Figure 9-28. Cable Management System Example

- Cables in racks or cabinets **shall** be installed and routed in a neat and workmanlike manner.
- Cables in racks or cabinets **shall** be sized to length.
- AC power cords should be sized according to the length needed. AC power cords longer than necessary may be looped down and back up a rack or cabinet. Excess lengths of AC power cord **shall not** be coiled on top of racks or cabinets.
- Grounding conductors within racks or cabinets **shall** be installed and as described in Chapter 5, "Internal Bonding and Grounding (Earthing)".

9.10.6.2 Securing Cables Within Racks or Cabinets

- To help prevent damage or accidental disconnection, cables and conductors **shall** be secured at intervals of no more than 914 mm (36 in.). Attachment **shall** be accomplished in a manner that does not restrict access to the equipment in the rack or cabinet.
- Insulated standoffs can be used in racks or cabinets as a means of cable management. The standoffs should be of sufficient length to maintain adequate cable separation.
- Cable fasteners, ties and securing devices **shall** be non-metallic.
- Cable securing **shall** be tight enough to secure the cables without crushing, deforming or pinching them.
- Waveguide and other RF transmission lines may be secured with metallic fasteners designed for the purpose.
- Nonmetallic cable ties **shall** be cut flush directly adjacent to the locking tab to prevent sharp protrusions.

9.10.6.3 Protecting Cables Within Racks and Cabinets

- Where cables or conductors are routed through holes in metallic surfaces or near sharp edges, the sharp surfaces **shall** be suitably protected with a grommet or similar material to help protect the cable or conductor from damage caused by sharp edges.
- Ensure cables are not crimped or bent when cabinet doors are opened or closed.

9.10.6.4 Cable Bending Radius Within Racks and Cabinets

- The minimum inside bend radius for twisted-pair cables **shall** be four times the cable diameter, or as otherwise specified by the cable manufacturer (see TIA-568.2-E-2024, section 5.3.6, for additional information).
- The minimum inside bend radius for shielded twisted-pair cables **shall** be eight times the cable diameter, or as otherwise specified by the cable manufacturer (see TIA-568.2-E-2024, section 5.3.6, for additional information).
- The minimum inside bend radius for a patch cord **shall** be four times the diameter of the cable.
- See “Network Cable Bending Radius” on page 9-51 for computer network cable bending radius requirements.
- See “Optical Fiber Cabling Bending Radius” on page 9-56 for optical fiber bending radius requirements.
- The minimum inside bending radius of E1/T1 cables **shall** follow the requirements for computer network cables described in “Network Cable Bending Radius” on page 9-51 or as required by the cable manufacturer.
- All other cables **shall not** have sharp bends, which can damage or degrade the performance of the cable. The cable manufacturer's specifications **shall** be followed.
- Grounding conductors of all sizes **shall** maintain a minimum bending radius of 203 mm (8 in.) as described in Chapter 5, “Internal Bonding and Grounding (Earthing)”.
- The inside bend radius for RF cables **shall** be as specified by the cable manufacturer. See “RF Cabling” on page 9-57.
- The minimum inside bend radius for equipment power cords **shall** be adequate to prevent damage to the cord. Power cords **shall** be installed in a manner that prevents kinking and/or pinching.

9.10.6.5 Cable Separation and Grouping Within Racks and Cabinets

- Cabling in racks or cabinets **shall** be grouped according to function. Groups are defined as:
  - AC power cords
  - DC power cables
  - Grounding conductors
  - RF transmission cabling
  - Data, control, signal, and timing reference cabling, and telephone cabling

- Where practicable, cable groups **shall** be separated by 50.8 mm (2 in.) or cross at a 90-degree angle. See TIA-569-E, section 9.3.1.1.
- Where practicable, cable groups of different types should maintain 50.8 mm (2 in.) separation where passing through a cabinet housing. Where the 50.8 mm (2 in.) separation cannot be maintained through the cabinet housing penetration, separation **shall** be maintained before and after the penetration point. See Figure 9-29 for an example. The right half of the figure illustrates cables of different groups passing through a penetration in the top of the cabinet and shows separation of cable groups before and after the penetration.

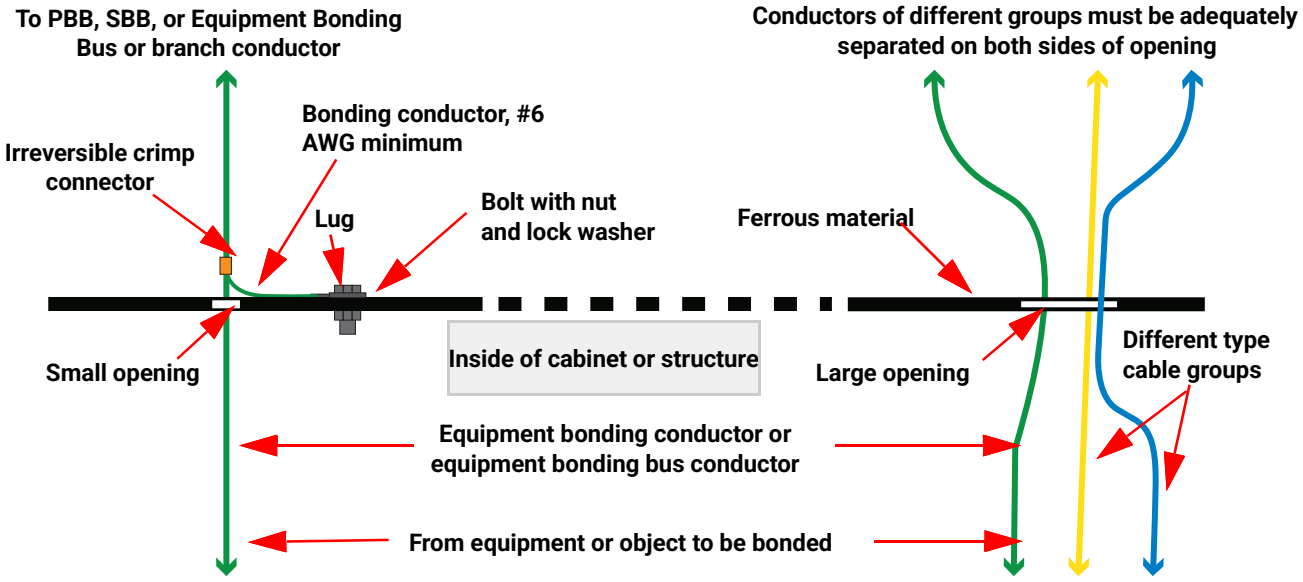


Figure 9-29. Conductor Routing Through Holes or Openings in Metallic Surfaces

9.10.7 AC Power Cabling

Facility AC wiring within junction boxes, receptacles and switches **shall** be performed by a qualified, licensed and bonded electrical contractor. Personnel safety and liability hazards can result from AC wiring performed by installation personnel other than an electrical contractor.

When an open equipment rack is used, hard wiring of power is not always practicable. Mounting a dedicated simplex receptacle or receptacle assembly on the rack may be the most convenient method of supplying power, especially if multiple pieces of equipment are mounted in the rack. See Figure 9-30 for an example.

These receptacle assemblies can be manufactured in advance and mounted to the top face of an equipment rack. Mounting can also use a fabricated power pole mounted between racks.

Consumer-grade power outlet strips **shall not** be used in any installation under any circumstances. Extension cords of any type **shall not** be used for connecting line power to communications equipment.

CAUTION: Do not plug ancillary items into receptacles supporting communications equipment. Examples of ancillary equipment include space heaters, microwave ovens, televisions, and similar devices.

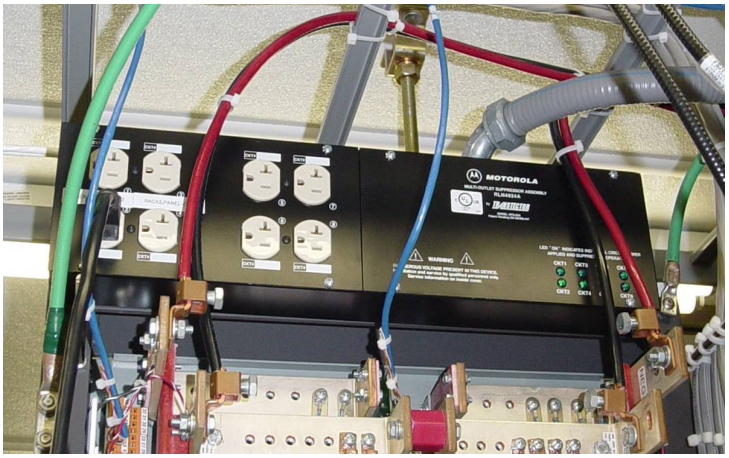


Figure 9-30. Example of Rack-Mounted Receptacle Assembly

9.10.8 DC Power Cabling

In telecommunications environments, common DC systems are as follows:

- +12 volt systems
- +24 volt systems
- -24 volt systems
- -48 volt systems

Traditional wireline telephone offices most often use -48V, sometimes referred to as -BATT voltage, whereas many cellular, PCS, and other radio systems utilize +24 to 27V. There are also instances of -24V systems. In U.S. installations, the most common practice is to use red cabling for the sourcing, fused, ungrounded or “hot” terminal. Black cabling is used for the return, unfused, grounded terminal. European installation practice uses blue insulation for the “hot” lead. The manual for the equipment being installed also specifies the required cabling size. Careful consideration must be given to cable size and length. See Chapter 6, “Power Sources”, which discusses power cabling sizing and other installation concerns.

9.10.8.1 Cable Tray Installation Requirements

Requirements for installing DC power conductors and/or cables in a cable tray are as follows:

- Individual conductors **shall not** be installed directly in a cable tray. **Exception:** In industrial establishments, as determined by the authority having jurisdiction (AHJ), single-conductor cables can be supported in a cable tray if they are 1/0 AWG or larger and marked on the outer surface for use in a cable tray (NFPA 70-2026, Article 392).
- DC power **cables** can be supported on the cable tray without additional protection if they are Tray Cable (TC) rated. TC-rated cables are defined under NFPA 70-2026, Article 100, as “A factory assembly of two or more insulated conductors, with or without associated bare or covered grounding conductors, under a nonmetallic jacket.” See Figure 9-31.
- DC power **conductors** can be supported by a cable tray if they are installed in an approved raceway under the conditions described in their respective articles and sections. Approved raceways may include, but are not limited to, the following:
  - Rigid Polyvinyl Chloride Conduit: Type PVC (NFPA 70-2026, Article 352).

- Liquid-tight Flexible Nonmetallic Conduit: Type LFNC (NFPA 70-2026, Article 356) for lengths not longer than 1.8 m (6 ft) or as otherwise allowed by the AHJ.
- Nonmetallic Tubing: Type ENT (NFPA 70-2026, Article 362). See Figure 9-32.
- Electrical Metallic Tubing: Type EMT (NFPA 70-2026, Article 358).

NOTE: DC conductors **shall not** be spliced.



Figure 9-31. Examples of TC Rated DC Cabling

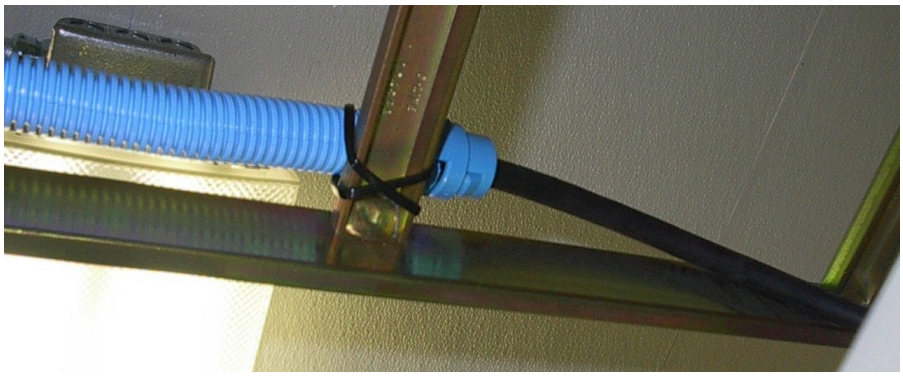


Figure 9-32. DC Power Cable Routed in Electrical Nonmetallic Tubing

9.10.9 Computer Network Cabling

Computer network cabling typically consists of Category 5e (CAT 5e), Category 6 (CAT 6), Category 6a (CAT 6A), or Category 8 cabling, terminated with 8-pin modular connectors.

Properly installed computer network cabling is critical to the safe and reliable operation of the computer network. It is recommended that standards developed by the Telecommunications Industry Association (TIA) or equivalent be followed. Applicable NFPA codes, local electrical codes, local building codes, and other standards in this manual **shall** also be followed when installing computer network cabling.

NOTE: It is recommended that computer network cable installations be performed by a specialist with the necessary expertise, knowledge of applicable local codes, and the required test equipment.

9.10.9.1 Computer Network Cable Types

Category 5e (CAT 5e), Category 6 (CAT 6), Category 6a (CAT 6A), and Category 8 unshielded twisted pair (UTP), 100-ohm cables are the recommended cable types for computer network cabling and will be assumed throughout this section. See TIA-568-E for additional information.

Horizontal cabling is defined as that portion of the cabling system that extends from the work area outlet, through the cabling in the wall/ceiling/floor, and then to the patch panel in the telecommunications room (see BICSI ITSIMM 8th Edition).

Cable requirements are as follows:

- Horizontal cabling **shall** have solid conductors (TIA-568.2-E, section 5.3).
- Cables used for constructing work area cords, equipment cords, and patch cords should have stranded conductors to ensure greater flexibility and durability, especially at movable operator positions. (TIA-568.2-E, TIA-568.5-E, and BICSI ITSIMM, 8th Edition).
- Shielded (screened) cables may be used in applications that require additional shielding. Where shielded cables are used, the shield **shall** be connected at both ends to ensure continuity for the entire channel (TIA-568.2-E).

CAUTION: Installing a shielded cable between different buildings (inter-building) may create a dangerous ground loop condition and should be avoided where practicable. This is due to the use of different electrical services and different grounding electrode systems. Interrupting the cable shield at one end (see “Telecommunication Cable Metallic Shields” on page 5-127) or in the middle within a handhole is recommended. Consultation with Motorola Solutions Engineering or other engineering firm is recommended in these applications.

9.10.9.2 Connecting Hardware

Unshielded twisted pair (UTP) cables **shall** be terminated with connecting hardware of the same category rating or higher. This includes all connectors, punch blocks, cross-connect jumpers, and patch cords. It is recommended that hardware used to terminate cables be of the insulation displacement (IDC) type.

Modular connectors **shall** be appropriate for the cable used; connectors for solid conductor cable may be different than for stranded cable. See TIA-568.2-E for additional information.

If connecting hardware has markings to designate transmission performance, install so the markings are visible after installation, if possible. Such markings typically consist of the following:

- “cat 3” or for category 3 components
- “cat 5e” or  for category 5e components.
- “cat 6” or for category 6 components.
- “cat 6A” or  for category 6A components.
- “cat 8” or  for category 8 components

NOTE: Performance markings are supplementary and do not replace markings required by listing agencies or markings needed to comply with electrical or local building codes.

9.10.9.3 Cable and Connector Wiring

Use standard color-coding and jack pair assignments when wiring modular jacks, connectors, and cables. Maintain a consistent wiring standard throughout the cabling system. Recommended standards are TIA-568A and TIA-568B. Figure 9-33 illustrates the color coding and end view of an 8-pin modular female jack for both standards, with the pairs and colors labeled. Refer to TIA-568.0-E and TIA-568.2-E for more details.

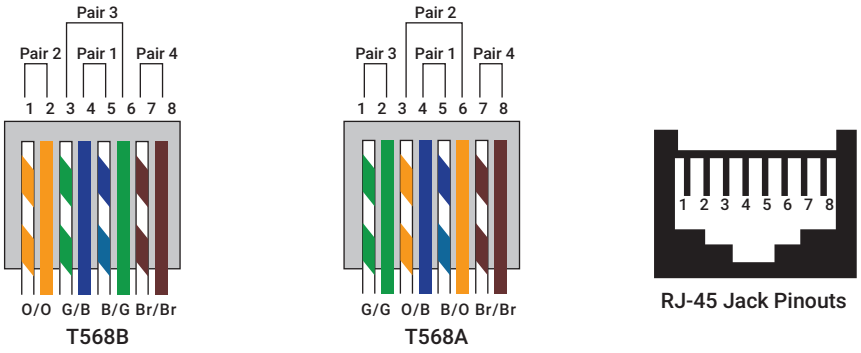


Figure 9-33. RJ-45 Color Coding

NOTE: A cross-over cable has one end wired as T568B and the other end wired as T568A.

9.10.9.4 Network Cable Connector Installation Overview

This section outlines the procedural steps to be followed for a single connector manufacturer. The procedure for each brand of connector may vary, but the results should be the same. The connectors and tools used in this example are specifically designed for the EZ-RJ45 connector; other brands of connectors follow a similar installation process.

IMPORTANT: Shielded connectors **shall** be used on shielded cables.

NOTE: The example photos show the EZ-RJ45 connector. Motorola Solutions recommends the EZ-RJ45 connectors for use only in indoor, air-conditioned environments.

Using the correct tools for the job is critical to the integrity of the finished product. Figure 9-34 shows the tools and components required for this procedure:

- The connector manufacturer-specified **ratcheting crimper** for the connector being used
- Wire stripper for removing the outer cable jacket
- Flush cut wire cutter
- Screwdriver for straightening the wires
- Connectors
- Connector boots



Figure 9-34. Tools for Network Cable Connector Installation

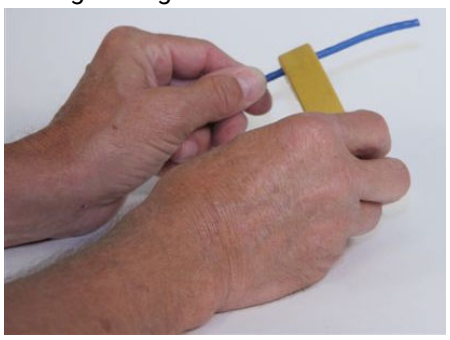
IMPORTANT: Ratcheting crimpers recommended by the connector manufacturer **shall** be used.

IMPORTANT: Do not crimp the connector beyond the tool ratcheting point. Over-crimping beyond this point may result in a poor connection.

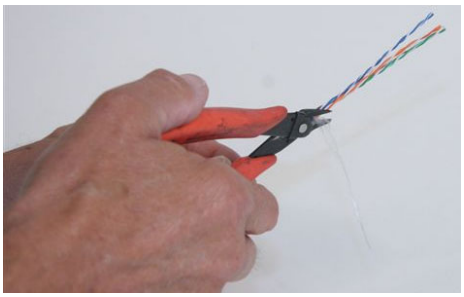
1. Install the boot on the cable.



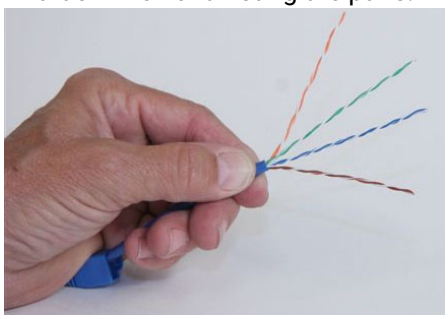
2. Strip the cable to the appropriate length for the connector being used. Using a cable stripper helps prevent wire damage and gives a clean cut.



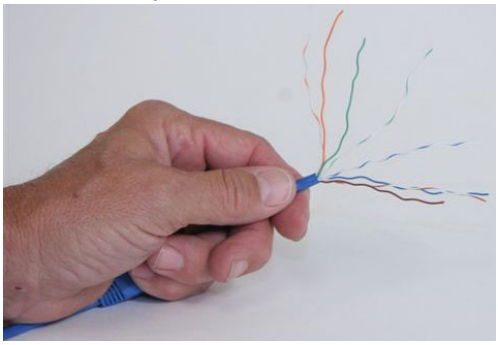
3. Cut the cellophane filler strip flush with the cable jacket.



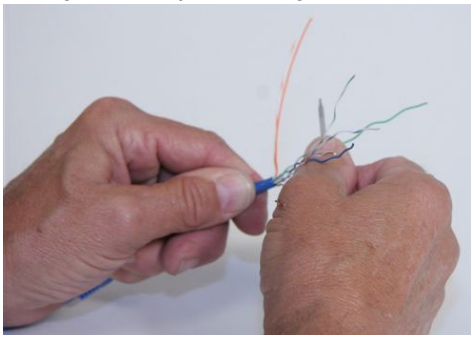
4. Separate the wire pairs in the following order: orange, green, blue, brown. This makes it easier to keep the wires in order when untwisting the pairs.



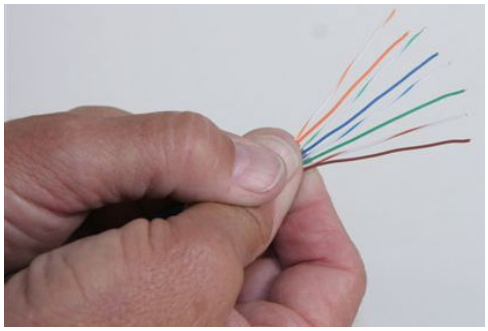
5. Untwist each pair.



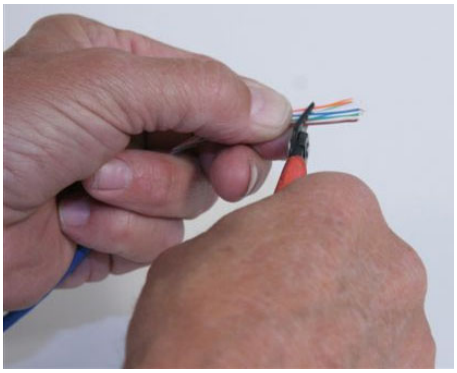
6. Straighten the pairs using a screwdriver or similar tool.

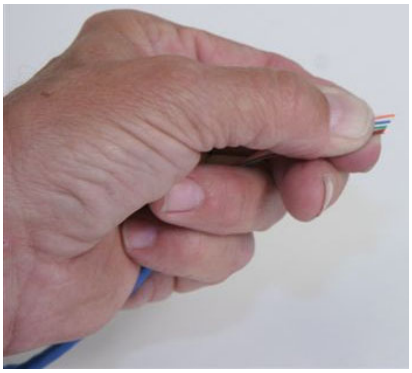


7. Position the wires in the following order:

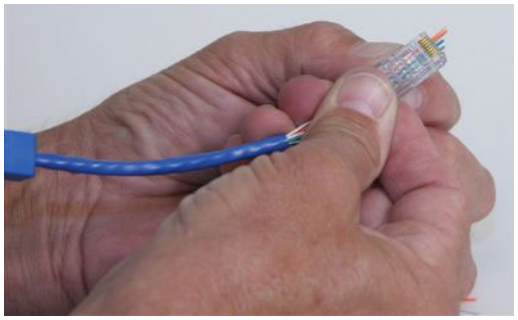
Order	TIA568B	TIA568A	TIA568B Example
1	White/Orange	White/Green	
2	Orange	Green	
3	White/Green	White/Orange	
4	Blue	Blue	
5	White/Blue	White/Blue	
6	Green	Orange	
7	White/Brown	White/Brown	
8	Brown	Brown	

8. Cut the ends of the separated wires at an angle, which simplifies insertion of the wires into the EZ-RJ45® connector. Other connector styles may require a variation of this method.

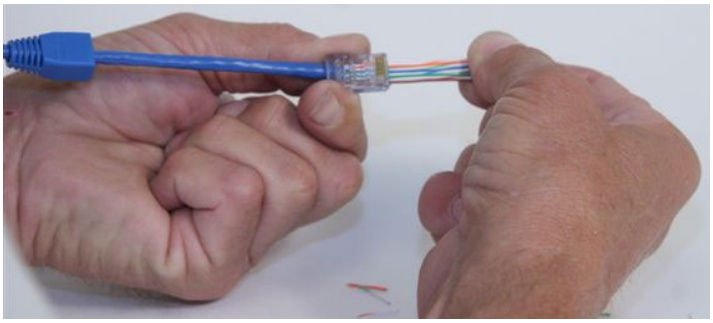


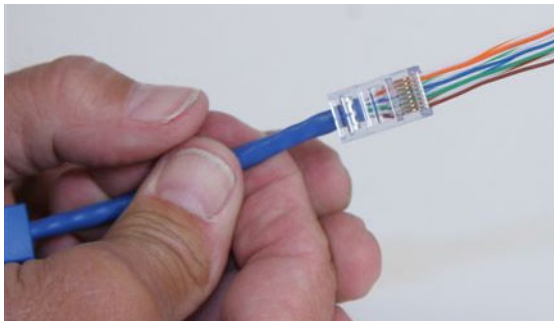


9. Insert the wires in the connector and confirm the wires are in the correct order.

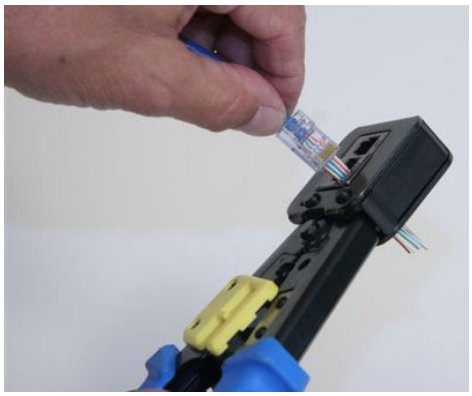


10. Pull wires securely into the connector. The cable jacket should be visible well inside the base of the connector.

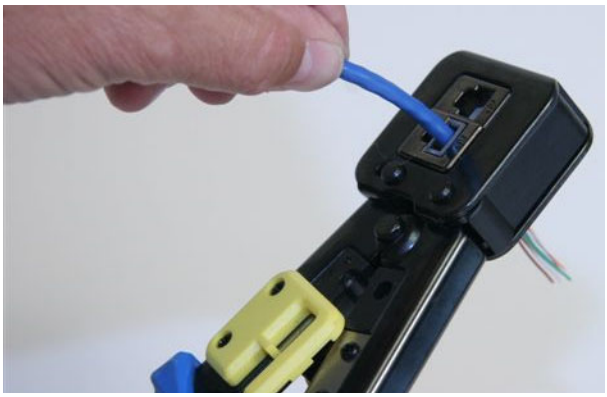




11. After reconfirming the wires are in correctly, insert the connector into the crimp tool.



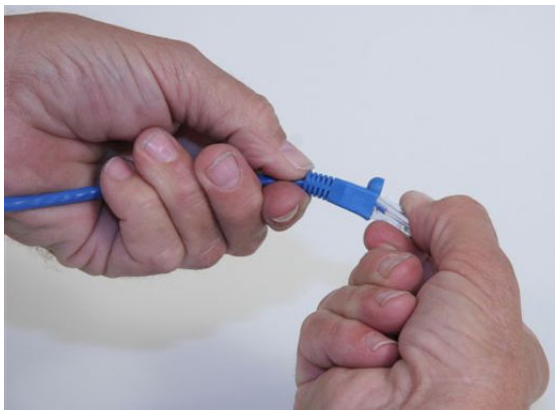
12. With the connector firmly seated in the tool, crimp the connector in place. The tool should cut the wires flush with the connector.

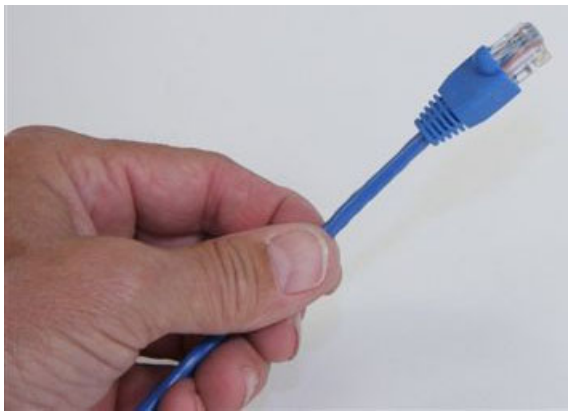


13. Remove connector and inspect it.



14. Slide the boot into place.





9.10.9.5 Network Cable Installation and Routing

Observe the following installation and routing requirements for computer network cabling in addition to the general requirements throughout the rest of this manual:

- Network cabling **shall** be installed in a neat and workmanlike manner. See BICSI ITSIMM, 8th Edition, and BICSI N3-2020.

- Consider using some method of cable management and containment for network cables. Such methods include dedicated cable runs, lay-in wire-ways, cable trays, and conduits. See TIA-569-E for additional information. See Figure 9-35 for an example.
- Network cables **shall not** be installed in the same conduit, cable tray, outlet box, or similar device with AC power cables, unless they are separated by a permanent barrier (such as a metallic conduit) or a listed divider. Doing so can be unsafe and is likely to cause EMI on the network cable, resulting in network errors. See NFPA 70-2026, Article 722.133(A)(3) and TIA-568.0-E. See Figure 9-36 for an example.

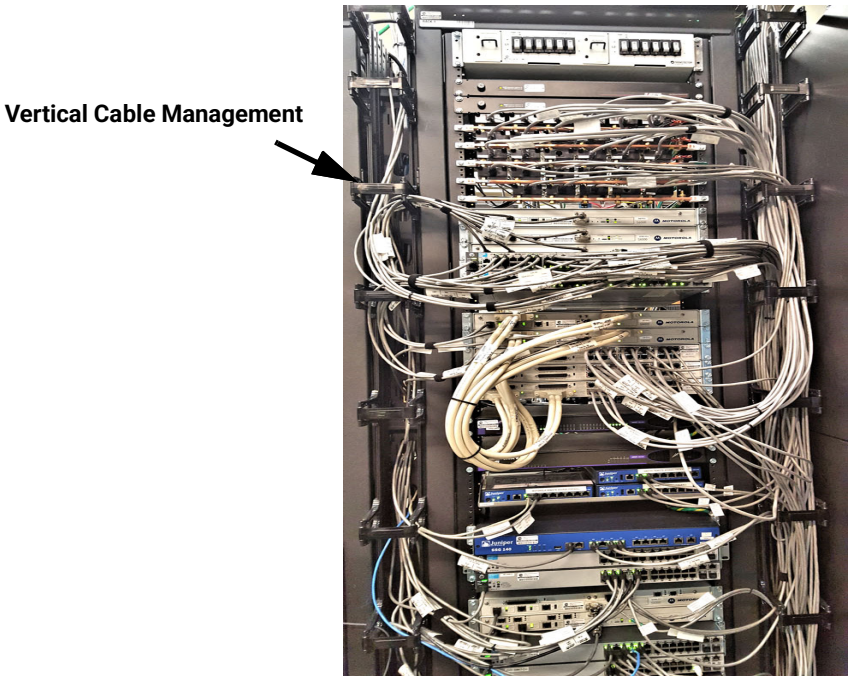


Figure 9-35. Cable Management System

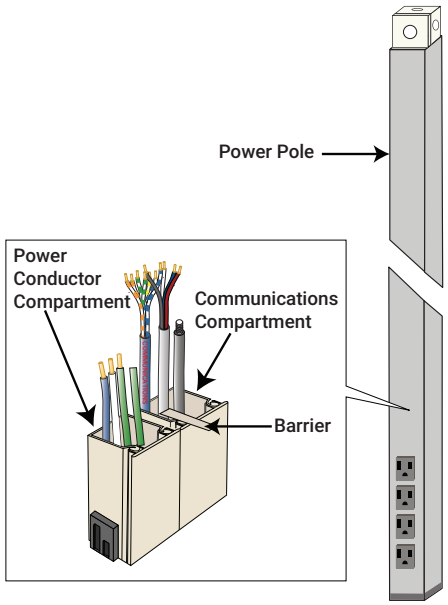


Figure 9-36. Cables in Conduit with Barrier

- Network cables **shall not** be laid directly on the tiles of a false ceiling. See Figure 9-37 for an example of routing cables in a suspended ceiling. See TIA-569-E and NFPA 70-2026, Article 720.30(B), for additional information.
- Network cables **shall not** be supported by ceiling-support wires (NFPA 70-2026, Article 300.13(B)(1), 720.30(B), and TIA-569-E, section 9.8). Independent support wires can be installed to support communications raceways and cables. Where independent support wires are used, they **shall** be secured at both ends (NFPA 70-2026, Article 300.13(B)(2)(1)).

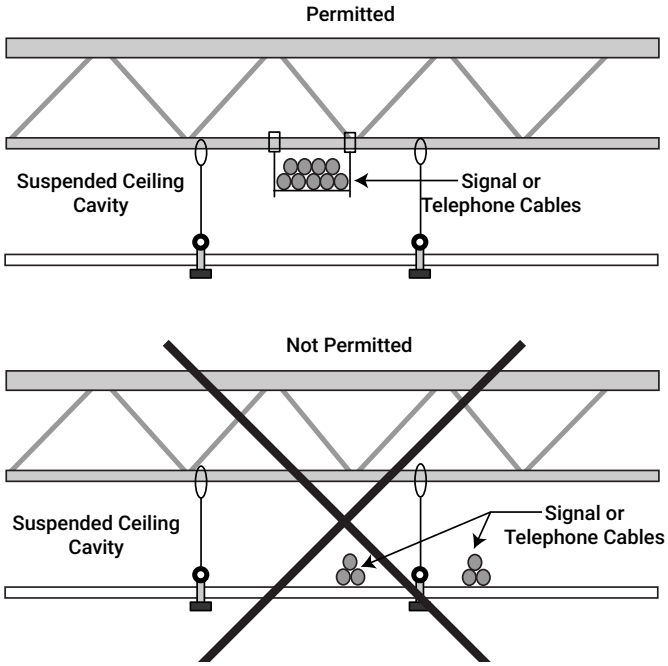


Figure 9-37. Routing Cables in a Suspended Ceiling

- Avoid routing network cables near sources of Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI). Routing cables near sources of EMI or RFI can cause data errors and degraded system performance. Such noise sources include, but are not limited to, the following: electrical power wiring, electrical transformers, dimmer switches, radio frequency transmitters, motors, generators, and fluorescent lights.
- Balanced twisted-pair cabling should be separated from fluorescent lamps and associated fixtures by a minimum of 125 mm (5 in.) (TIA-569-E, section 9.3.2).
- If routing network cables near sources of EMI or RFI cannot be avoided, reasonable precautions **shall** be taken to minimize the negative impact of EMI or RFI. Such precautions may include the following: increasing the physical distance between the network cable and the source of the EMI/RFI, installing a CAT6A or higher instead of a CAT5e, installing the network cable inside a grounded metallic conduit, or use of a shielded network cable (screened twisted pair cable). See TIA-568.0-E and TIA-569-E for additional information.
- Avoid parallel paths between power and telecommunications cables (TIA-569-E, section B.5).
- See Table 9-3 on page 9-49 for the minimum separation distance between computer network cabling (UTP/STP) and power cables.
- Network cables running from one building to another **shall** be grounded in accordance with Chapter 4, “External Grounding (Earthing) and Bonding” and **shall** have adequate surge suppression as described in Chapter 7, “Surge Protective Devices”.
- Network cabling entering and/or leaving a building **shall** be grounded and protected from surges as required elsewhere in this manual. Consultation with Motorola Solutions Engineering is recommended in these applications. See Chapter 7, “Surge Protective Devices”.

CAUTION: Installing a shielded cable between different buildings (inter-building) may create a dangerous ground loop condition and should be avoided where practicable. This is due to different electrical services and different grounding electrode systems. Interrupting the cable shield at one end (see "Telecommunication Cable Metallic Shields" on page 5-127). or in the middle within a handhole is recommended. Consultation with Motorola Solutions Engineering or another engineering firm is recommended in these applications.

Table 9-3. Minimum Separation Distance Between Computer Network Cabling (UTP/STP) and Power Cables

Power Circuit Type (50/60 Hz) or Electric Device	Minimum Required Separation[2]	Notes
120/240 VAC, 20 A 1ϕ		Based on all circuit conductors routed together and enclosed in a grounded, metallic conduit.
Up to 30 circuits	50 mm (2 in.)	
31 to 60 circuits	100 mm (4 in.)	
61 to 90 circuits	150 mm (6 in.)	
91 or more circuits	300 mm (12 in.)	
120/240 VAC, 32 A 1ϕ		Based on all circuit conductors routed together and enclosed in a grounded, metallic conduit.
Up to 9 circuits	50 mm (2 in.)	
10 to 19 circuits	100 mm (4 in.)	
20 to 28 circuits	150 mm (6 in.)	
29 or more circuits	300 mm (12 in.)	
120/240 VAC, 63 A 1ϕ		Based on all circuit conductors routed together and enclosed in a grounded, metallic conduit.
Up to 3 circuits	50 mm (2 in.)	
4 to 8 circuits	100 mm (4 in.)	
9 to 14 circuits	150 mm (6 in.)	
15 or more circuits	300 mm (12 in.)	
480 VAC, 100 A 3ϕ		Based on all circuit conductors routed together and enclosed in a grounded, metallic conduit.
1 circuit	300 mm (12 in.)	
2 or more circuits	600 mm (24 in.	
Fluorescent Lighting	125 mm (5 in.)	See TIA-569-E, section 9.3.2.
Electric Motors	122 cm (48 in.)	Suggested best practice.
Transformers	122 cm (48 in.)	Suggested best practice.

NOTES:

1. Chart based on NFPA 70-2026 (various articles) and TIA-569-E, Table 6
2. Separation distance may be cut in half if the UTP/STP cable is installed in a separate, grounded conduit.
3. Avoid parallel paths between power and telecommunications cables (TIA-569-E, section B.5).

9.10.9.6 Installation In Plenums, Air Handling Spaces and Risers

The following **shall** be followed when installing computer network cabling in plenums, air handling spaces and risers:

- See “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30 for cable installation requirements in these spaces.
- See “Communications Cabling Requirements for Risers” on page 9-32 for cable installation requirements in these spaces.

9.10.9.7 Network Cable Installation Practices

Observe the following installation practices for computer network cabling in addition to other requirements throughout this chapter:

- Avoid unnecessary junction points and cross-connects. Every additional junction point and cross-connect can decrease the network's performance.
- Multiple appearances of the same cable at different locations, referred to as bridge taps, **shall** be avoided (see Figure 9-38). Each cable segment **shall** have only one source and one destination.
- Never untwist the twisted pairs of a network cable beyond 12.7 mm (0.5 in.) from the point of termination. Untwisting the wires can decrease the cable's category performance rating and degrade system performance. See TIA-568.0-E for additional information.
- Do not pull a network cable using a force greater than 110 Newtons (25 lb-force) or as recommended by the cable manufacturer (see TIA-569-E). Pulling a cable with excessive force can negatively impact its electrical characteristics and degrade its performance. See TIA-568.0-E for additional information.
- Do not over-tighten network cables with cable ties or other supports. Over-tightening cable ties or other supports can negatively impact the electrical characteristics of the cable, degrading system performance. Hook-and-loop (Velcro®) style cable ties are recommended. See BICSI ITSIMM 8th Edition for additional information.
- Due to performance and testing requirements, it is recommended that modular cords be factory-manufactured (TIA-568.0-E).

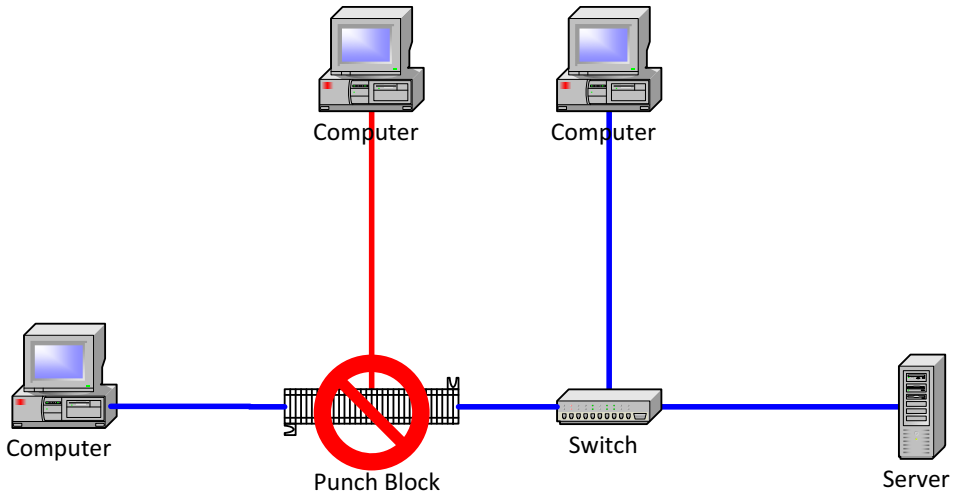


Figure 9-38. Disallowed Bridge-Tap Connection

IMPORTANT: Velcro®-style cable ties are recommended for securing computer network and E1/T1 cables. Velcro®-style cable ties prevent cable damage that could occur from over-tightening a standard cable tie.

9.10.9.8 Network Cable Bending Radius

Sharp bends **shall** be avoided on computer network cables. Sharp bends negatively impact the electrical characteristics of the cable and degrade system performance. SeeTIA-568.2-E and TIA-569-E for additional information. Observe the following computer network cable bending radius requirements:

- The minimum inside bend radius for a network cable **shall** be four times the cable diameter.
- The minimum inside bend radius for a shielded (screened) network cable **shall** be eight times the cable diameter.
- The minimum inside bend radius for a patch cord **shall** be equal to four times the diameter of the cable.

9.10.9.9 Computer Network Topology

Computer network cabling **shall** utilize a “Star” topology, unless the specific design of the network calls for a different topology. Figure 9-39 shows a star topology example. See TIA-568.0-E and TIA-568.1-E for additional information.

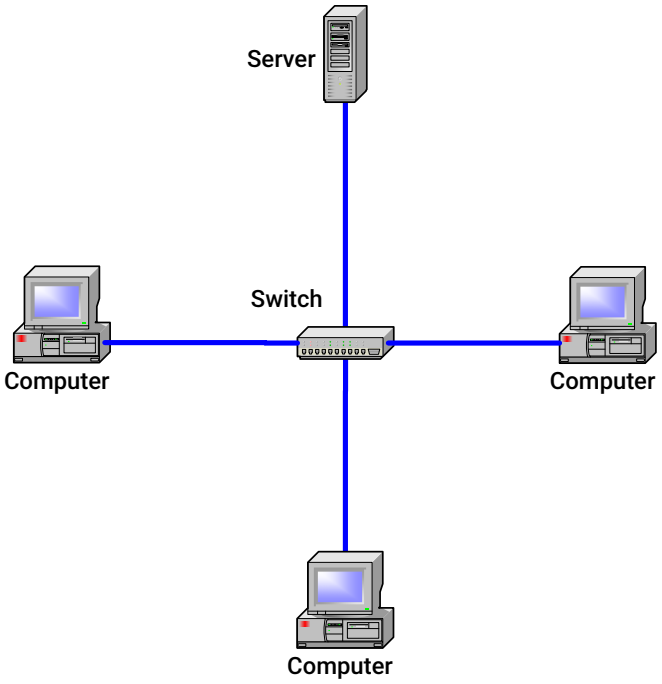


Figure 9-39. Star Network Topology

Computer network cable segment lengths **shall not** exceed 100 m (328 ft). This includes 90 m (295 ft) of building cabling and up to 10 m (32.8 ft) of equipment cords, cross-connects, and patch cords. Of the 10 m (32.8 ft) allowed for equipment cords, cross-connects, and patch cords, a maximum of 5 m (16 ft) should be used from the computer workstation to the information outlet. See TIA-568.0-E and TIA-568.1-E for more information. Figure 9-40 shows the maximum cabling lengths between various network elements.

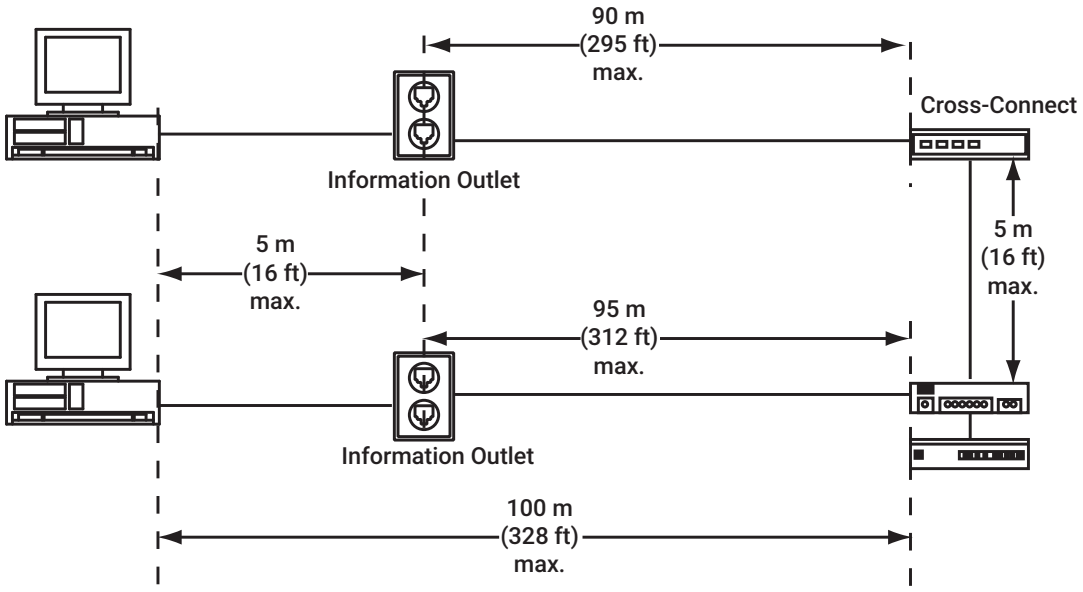


Figure 9-40. Network Segment Length Limits

For simplifying installation and reducing cable runs, a single computer network cable may be run from the equipment room switch to an additional switch in the computer workstation area for distribution to the individual computers (if approved by the system engineer). This can reduce the number of cables required between the equipment room and the individual computers. Figure 9-41 shows an example of a single cable run. Figure 9-42 shows an example with an intermediate switch. See TIA-568.0-E and TIA-568.1-E for additional information.

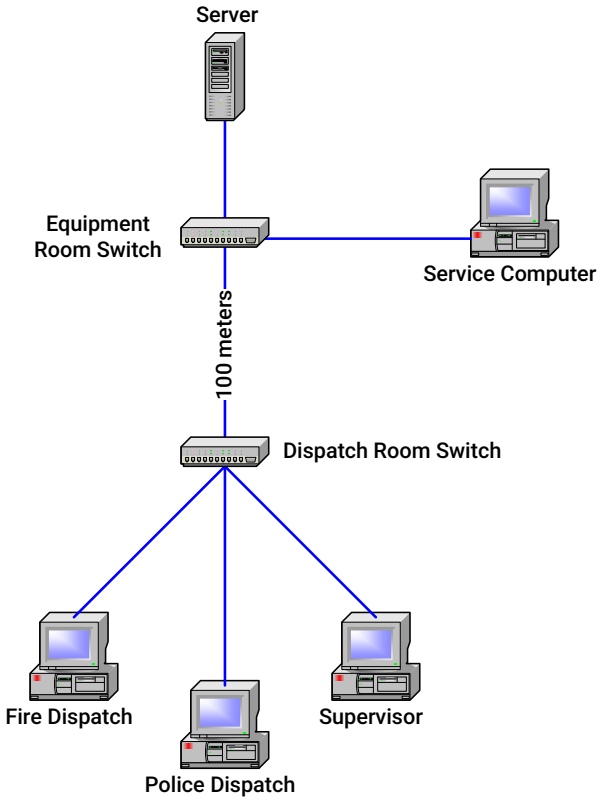


Figure 9-41. Switch-Connected Network Segments

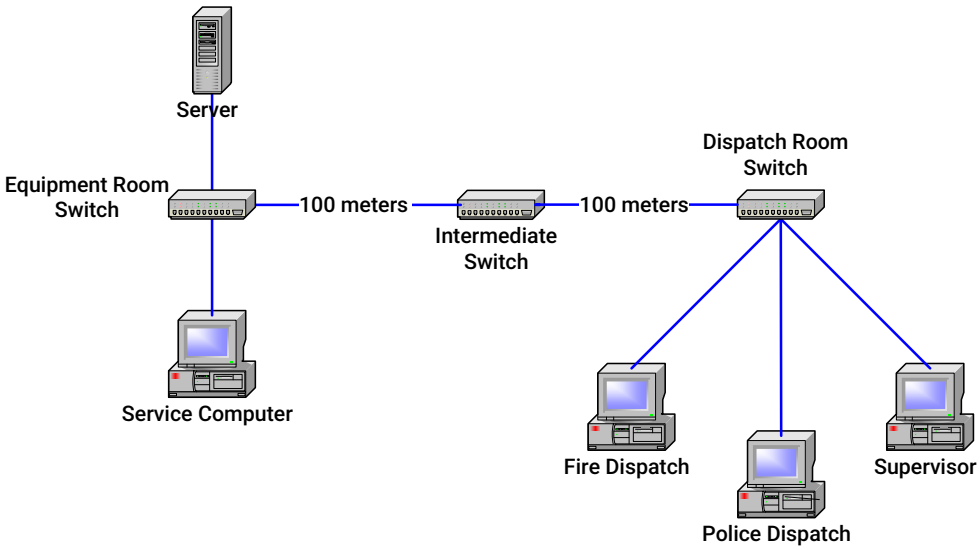


Figure 9-42. Additional Switch Used for Distances Greater Than 100 m

IMPORTANT: The use of additional intermediate switches **shall** be approved by the system engineer.

9.10.9.10 Bonding and Grounding

- Bonding and grounding of network devices **shall** comply with Chapter 5, "Internal Bonding and Grounding (Earthing)".
- The shields of shielded 8-position modular connectors (plugs and jacks) **shall** be designed to ensure shield continuity when mated (TIA-568.5).
- Shielded computer network cables **shall** utilize an appropriate shielded connector on both ends of the cable so the shield is continuous for the complete channel (see TIA-568.2-E).

9.10.9.11 Labeling

Cables **shall** be labeled at both ends and at any pull boxes or junctions as described in "Interior Cable Labeling" on page 9-66.

See TIA-606-D for detailed labeling guidelines.

9.10.9.12 Network Cabling Testing and Certification

Every effort should be made to ensure a quality installation of the computer network cabling system, but even the best installation effort cannot guarantee a working system. Therefore, computer network cabling must be tested.

Certification is the process of comparing the transmission performance of an installed cabling system to a standard, using a method defined by the standard to measure performance. Certification of the cabling system demonstrates the quality of the components and the workmanship of the installation. The network cable testing requirements are documented in TIA-568.0-E, TIA-568.2, and ISO/IEC 11801:2017 and **shall** be used as the basis for this testing. A cable tester designed for TIA-568.2 or ISO/IEC 11801 certification **shall** be used. A cable tester that features automated certification tests and provides a pass/fail indication is recommended. See Figure 9-43 for an example.



Figure 9-43. Network Cable Testing Example

Typical TIA-568.2-E and ISO/IEC 11801 test parameters that **shall** be performed to assure system performance are as follows:

- Wire Map
- Resistance
- Length
- Propagation Delay
- Delay Skew
- Insertion Loss (IL)
- Return Loss (RL)
- Near End Crosstalk (NEXT)
- Attenuation to Crosstalk Ratio
- Alien Crosstalk

9.10.10 Optical Fiber Cabling

WARNING: Never look into an optical fiber cable. Optical fiber cables use invisible laser light that is dangerous and can cause damage to the eye.

There are four general categories of optical fiber cables as described in the following subsections (see NFPA 70-2026, Article 100, for additional information):

- **Non-conductive:** These cables contain no conductive materials.
- **Conductive:** These cables contain non-current-carrying conductive members, such as metallic strength members, metallic vapor barriers, and metallic armor or sheath.
- **Composite:** These cables contain optical fibers and current-carrying electrical conductors. These cables may also contain non-current-carrying conductive members, such as metallic strength members and metallic vapor barriers.

- **Protected:** Optical fiber cable protected from releasing optical radiation into the atmosphere during normal operating conditions and foreseeable malfunctions by additional armoring, conduit, cable tray, or raceway.

9.10.10.1 Optical Fiber Cabling General Requirements

Observe the following general requirements for the installation of optical fiber cabling:

- Optical fiber cables **shall** be installed in a professional and skillful manner (BICSI N1-2019, NFPA 70-2026, Article 110.12).
- Optical fiber cable installations **shall** conform to TIA-568.3-E.
- Optical fiber cable manufacturer requirements **shall** be followed.
- Optical fiber cables **shall** be permitted to be installed in raceways, listed optical fiber raceways, and listed communications raceways. See NFPA 70-2026, Article 722.13, for more information.
- Optical fiber cables **shall** be permitted in the same cable tray, enclosure, or raceway, with conductor of any of the following (NFPA 70-2026, Article 722.13):
  - Communications circuits in compliance with Parts I and IV of NFPA 70-2026, Article 722.13.
  - Community antenna television and radio distribution systems in compliance with Parts I and IV of NFPA 70-2026, Article 722.13.
  - Low-power network-powered broadband communications circuits in compliance with Parts I and IV of NFPA 70- 2026, Article 722.13.
  - Class 2 and Class 3 remote-control, signaling, and power-limited circuits in compliance with Parts I and II of NFPA 70-2026, Article 722.13.
  - Power-limited fire alarm systems in compliance with NFPA 70-2026, Article 722.13.
- Optical fiber cables **shall** be supported so that the cable will not be damaged by normal use of the building (NFPA 70-2026, Article 720.30).
- Where optical fiber cabling is used, the cable **shall** be labeled to distinguish it from electrical signal cabling (see Figure 9-44).
- Cables, raceways, and equipment installed behind panels designed to allow access, including suspended ceiling panels, **shall** be arranged and secured to allow the removal of panels and access to the equipment. NFPA 70-2026, Articles 300.26 and 720.23. See Figure 9-45 on page 9-56 for an example.
- Other applicable requirements of this chapter **shall** be observed.



Colored Armor



Label

Figure 9-44. Fiber-Optic Cable Identification

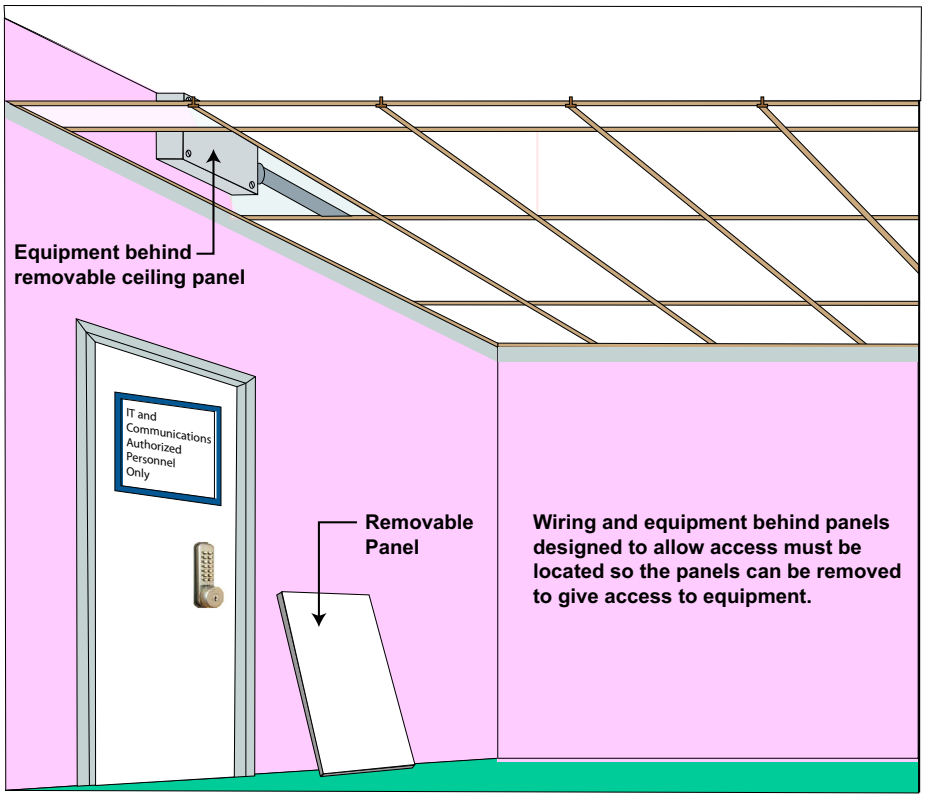


Figure 9-45. Cable Access Panel Example

9.10.10.2 Optical Fiber Cabling Bending Radius

Sharp bends **shall** be avoided on optical fiber cables. Sharp bends can negatively impact the optical characteristics of the cable, degrading system performance. The minimum inside bending radius for an optical fiber cable **shall** be 10 times the outside diameter of the optical fiber cable or as otherwise required by the cable manufacturer (TIA-568.3-E).

9.10.10.3 Optical Fiber Cable Installation In Plenums, Air Handling Spaces and Risers

The following **shall** be adhered to when installing optical fiber cabling in plenums, air handling spaces and risers.

- See “Communications Cabling Requirements for Plenums and Other Spaces Used for Environmental Air” on page 9-30 for cable installation requirements in these spaces.
- See “Communications Cabling Requirements for Risers” on page 9-32 for cable installation requirements in these spaces.

9.10.10.4 Conductive Optical Fiber Cabling Requirements

The following requirements apply specifically to conductive optical fiber cabling. These requirements are in addition to other requirements in this section.

- The non-current-carrying metallic members of optical fiber cables entering buildings **shall** be grounded as close to the point of entrance as practicable or **shall** be interrupted as close to the point of entrance as practicable by an insulating joint or equivalent device (NFPA 70-2026, Articles 270.4(A), 750.48(A)(1), and 750.112(A)). See “External Ground Busbar” on page 4-46.

- Conductive optical fiber cables without an armored or metal-clad-type sheath **shall not** be permitted to occupy the same cable tray or raceway with conductors for electric light, power, Class 1, non-power-limited fire alarm, Type ITC, or medium-power network-powered broadband communications circuits, unless all of the conductors of electric light, power, Class 1, non-power-limited fire alarm, and medium-power network-powered broadband communications circuits are separated from all of the optical fiber cables by a permanent barrier or listed divider. (NFPA 70-2026, Article 722.164(A)).

9.10.10.5 Non-Conductive Optical Fiber Cabling Requirements

The following requirements apply specifically to non-conductive optical fiber cabling. These requirements are in addition to other requirements in this section.

- Non-conductive optical fiber cable **shall** be permitted to occupy the same cable runway or raceway with conductors for electric light, power, Class 1, non-power-limited fire alarm, Type ITC, or medium power network-powered broadband communications circuits operating at 1000 volts or less (NFPA 70-2026, Article 722.164).
- Non-conductive optical fiber cables **shall not** occupy the same cabinet, outlet box, panel, or similar enclosure housing the electrical terminations of an electric light, power, Class 1, non-power-limited fire alarm, or medium power network-powered broadband communications circuit (NFPA 70-2026, Article 722.164) unless one or more of the following exceptions apply:
  - The optical fiber cable is functionally associated with the other circuits.
  - The conductors for electric light, power, Class 1, non-power-limited fire alarm, Type ITC, or medium-power network-powered broadband communications circuits operate at 1000 volts or less.
  - Where the optical fiber cable is installed in factory- or field-assembled control centers.
  - In industrial establishments (see NFPA 70-2026, Article 722.164 for more details).
- Optical fiber cables **shall not** be strapped, taped, or attached by any means to the exterior of any conduit or raceway as a means of support (NFPA 70-2026, Article 722.164).

9.10.10.6 Hybrid Optical Fiber Cabling Requirements

Optical fibers in hybrid optical fiber cables containing only current-carrying conductors for electric light, power, Class 1 circuits rated 1000 volts or less **shall** be permitted to occupy the same cabinet, cable tray, outlet box, panel, raceway or other termination enclosure with conductors for electric light, power or Class 1 circuits operating at 1000 volts or less (NFPA 70- 2026, Article 722.164(B)).

9.10.11 RF Cabling

RF cabling installed inside a building typically consists of 6.35 mm (0.25 in.) or 12.5 mm (0.5 in.) coaxial cables made of foam-filled or highly flexible construction.

The minimum inside bend radius for coaxial cable **shall not** be less than that recommended by the manufacturer. If no recommendation is provided, the minimum inside bend radius **shall** be ten times the cable outside diameter under no-load conditions and 20 times the cable outside diameter when the cable is under a tensile load. See ANSI/TIA-568.0-E, section 6.4.1.



CAUTION: Sharp bends can damage or negatively affect the impedance characteristics of a cable.

9.10.11.1 Securing RF Cables to Tower and Cable/Ice Bridge

Hangers are the hardware devices required to secure a cable to the tower. When installing coaxial cables, hangers designed for the specific type and size of cable **shall** be used.

- The number and spacing of hangers for RF cabling **shall** conform to the manufacturer's specifications.
- Only hangers designed for the specific purpose **shall** be used. An insufficient number of hangers can result in cable damage.
- Appropriate hanger hardware **shall** be used.
- The hanger **shall** be designed for use as a cable hanger.
- The hanger **shall** be approved by the cable manufacturer.
- Tie wraps **shall not** be used.
- The correct size hanger **shall** be used. Too small can damage the cable; too large may not provide adequate support.

Hanger spacing is the maximum distance between hangers. Hanger spacing is specified by the cable/hanger manufacturer, and is calculated based on wind speed and ice conditions, as well as cable and hanger types.

- Hanger spacing should be based on TIA-222 guidelines.
- Cables installed outdoors **shall** be rated for outdoor use.

See “Grounding and Bonding of RF Transmission Lines and Communications Cables” on page 4-104 for RF cable grounding and bonding requirements.

9.10.11.2 RF Connectors

RF connector installation issues are responsible for the majority of antenna system installation problems. Improperly installed connectors can cause return loss/VSWR issues and/or Passive Intermodulation (PIM) problems. RF connector installation requirements are as follows:

- Installers **shall** be trained.
- Installers **shall** be certified by the cable/connector manufacturer.
- Connectors designed for the specific cable **shall** be used.

IMPORTANT: Foreign debris in connectors and/or cable dielectric can cause degraded return loss and/or PIM performance.

NOTE: The connector and/or cable manufacturer's cleaning instructions may supersede the instructions given in this section.

- Before connecting the assembly to the cable or coupling connectors, the inside of the assembly connector and the cable connector and dielectric **shall** be cleaned, dried, and inspected as follows (see Figure 9-46):
  - Inspect under magnification for foreign debris.
  - Clean with a lint-free, self-saturating, foam-tipped alcohol swab (isopropyl 91% minimum) or a soft, non-metallic brush as appropriate (see Figure 9-47).
  - Dry using inert, compressed gas.
  - Repeat inspection and cleaning as needed to remove all foreign debris.



Figure 9-46. Connector Cleaning



Figure 9-47. Examples of Connector Cleaning Supplies

9.10.11.3 Torque

Where specified by the manufacturer, connectors being assembled **shall** be tightened with a torque wrench.

Connectors coupled together (e.g., jumper to feedline) **shall** be tightened with the appropriate torque wrenches. See Table 9-4 for common connector coupling torque values. Coupling connectors to specific equipment, such as a combiner or multi-coupler, may require less torque than that shown in Table 9-4. Consult the manufacturer's instructions.

NOTE: Specific connector torque wrenches are available from the connector manufacturers (see Figure 9-48 on page 9-60).

Table 9-4. Common Connector Coupling Torque Values

Connector Type	Torque Value	
	ft-lb	N-m
N	4	5.4
7-16 DIN	18	24.4
4.3-10	6	8.1
NOTE: Check with the connector manufacturer for specific torque requirements.		



Figure 9-48. Example of Connector Manufacturer Torque Wrench

IMPORTANT: Incorrect connector torque can cause reduced return loss and/or PIM performance.

9.10.11.4 Tools

Connectors **shall** be installed using the tools and methods specified by the manufacturer.

- The cable/connector manufacturer's cable preparation tool **shall** be used.
- The cable preparation tool **shall** be in good condition, clean, and have sharp cutting surfaces (see Figure 9-49).



© Courtesy of Eupen Cable USA

Figure 9-49. Example of Cable Preparation Tool Kits

IMPORTANT: The cable and connector manufacturer preparation tool **shall** be used for installing connectors. The preparation tool **shall** have sharp cutting blades. Do not attempt to install the connector without the preparation tool.

9.10.12 Antenna System Commissioning

Antenna systems are essential components of communication systems. A damaged or incorrectly installed antenna system can reduce communication capabilities and potentially damage other system components. To ensure installation and component integrity, antenna systems **shall** be tested and verified using a Frequency Domain Reflectometer (FDR) or Vector Network Analyzer (VNA) during installation, a process known as antenna system commissioning (ASC). Antenna system commissioning should also be performed when connecting new equipment to an existing antenna system.

NOTE: Antenna system commissioning **shall** be performed by trained and certified personnel.

9.10.12.1 Technician Training and Certification

Technicians performing antenna system commissioning **shall** be trained and certified through an accredited organization, such as ETA International. Certification should include antenna system commissioning and wireless communications.

9.10.12.2 Analyzer and Test Equipment Requirements

The requirements for the analyzer and antenna system test equipment are as follows:

- The analyzer and precision load **shall** be in good working order and serviced at the factory as recommended by the manufacturer.
- The analyzer **shall** be operated in accordance with the manufacturer's requirements.
- The analyzer **shall** be user-calibrated at the time of testing according to the manufacturer's instructions. It is not recommended to recall saved calibrations.
- The analyzer's calibration status **shall** indicate a valid calibration and **shall** be verified before each measurement.
- Adapters **shall** be avoided whenever practicable. If adapters are necessary, only precision adapters **shall** be used.
- If a precision adapter is used, it **shall** only be placed in a location that can be calibrated out during the normal FDR/VNA user calibration. This means the adapter remains in place after the user calibration.
- When using a load, only a precision load **shall** be used.

CAUTION: To prevent damage to the precision load caused by dropping or impact, handle the precision load with care. It is very delicate.

- Only a phase-stable cable **shall** be used as a test port extension cable.
- At a minimum, Motorola Solutions recommends the antenna system commissioning tests listed in Table 9-5.

9.10.12.3 Recommended Analyzer Configuration

Motorola Solutions recommends the following general FDR/VNA test configuration settings for typical LMR applications. Some settings may require adjustment for particular tests or types of test equipment.

- **Mode**: VNA Field
- **Start Frequency:** 100 MHz
- **Stop Frequency:** 1100 MHz
- **Windowing:** Nominal
- **Units:** Feet or meters as appropriate
- **Start Distance:** 0 m (ft)
- **Stop Distance:** System-specific as needed to see the entire antenna system during a distance-to-fault test.
- **Scale Top:** 0 dB
- **Scale Bottom:** -50 dB
- **Data Points:** 2001
- **Smoothing:** 0%

- **Output Power:** High
- **RF Immunity:** Low
- **IFBW:** 1 kHz
- **Interpolation:** On
- **Measurement Type:** Specific to the test

9.10.12.4 Recommended Antenna Commissioning System Tests for LMR Systems

Motorola Solutions recommends the tests outlined in Table 9-5 for typical mission-critical LMR systems. These tests assume a demarcation point at the building entry and do not include the surge protective device (SPD) and the bottom jumpers. The SPD and bottom jumpers **shall** be tested during the RF site optimization and commissioning.

All sweeps (raw data files) **shall** be saved in the site's documentation for future comparison and troubleshooting purposes.

IMPORTANT: For all distance-to-fault (DTF) measurements, select the correct cable type in the FDR/VNA. For system DTF measurements, choose the longest cable, usually the feedline.

NOTE: The tests in Table 9-5 are a general recommendation. Some systems may require additional or different tests depending on system design and specific customer requirements. Some tests might need interpretation from an RF engineer or an ASC subject matter expert.

Table 9-5. Recommended Antenna System Commissioning Tests for Land Mobile Radio Systems

Test Number	Test Name	Description	Frequency Range	Measurement Type	Termination Device
1	Antenna	Measure the antenna's return loss across the specified bandwidth before it is installed on the tower. Verify the antenna return loss meets specifications across the entire specified frequency band.	100 - 1100 MHz See Note below.	Return Loss	Antenna
2	Jumper Length	Measure the jumper's length using distance-to-fault (DTF). This value is required for calculating the expected Cable Loss value.	100 - 1100 MHz	Distance-to-Fault	Precision Open or Precision Short
3	Jumper Cable Loss	Measure the jumper's cable loss across the antenna passband. Modern instruments will directly display this value without requiring technician interpretation. Verify the cable loss value meets the manufacturer's specifications for the given length of cable. This information is required for system optimization, such as setting effective radiated power (ERP) or configuring Tower Top Amplifier systems.	Antenna Passband	Cable Loss	Precision Open or Precision Short
NOTE: After the initial 100–1100 MHz test verifies proper antenna operation, the frequency span can be narrowed—typically to 100 MHz above and below the operating band. This narrower span provides higher resolution for the targeted antenna sweep. Both sweeps should be saved.					

Table 9-5. Recommended Antenna System Commissioning Tests for Land Mobile Radio Systems (continued)

Test Number	Test Name	Description	Frequency Range	Measurement Type	Termination Device
4	Jumper Distance-to-Fault (DTF)	Perform a DTF return loss measurement of the jumper. Verify that there are no faults and that the DTF value is passing along the entire length of the cable, as defined by the manufacturer's specifications. Also, verify a passing DTF return loss of each connector, as defined by the manufacturer.	100 - 1100 MHz	Distance-to-Fault	Precision Load
5	Jumper Return Loss	Measure the jumper's return loss and verify that the worst-case return loss meets the manufacturer's specifications.	100 - 1100 MHz	Return Loss	Precision Load
6	Feedline Length	Measure the feedline's length using distance-to-fault (DTF). This value is required for calculating the expected Cable Loss value.	100 - 1100 MHz	Distance-to-Fault	Precision Open or Precision Short
7	Feedline Cable Loss	Measure the feedline's cable loss across the antenna passband. Modern instruments will directly display this value without requiring technician interpretation. Verify the cable loss value meets the manufacturer's specifications for the given length of cable. This information is required for system optimization, such as setting effective radiated power (ERP) or configuring Tower Top Amplifier systems.	Antenna Passband	Cable Loss	Precision Open or Precision Short
8	Feedline Distance- to-Fault (DTF)	Perform a DTF return loss measurement of the feedline. Verify that there are no cable faults and that the DTF value is passing along the entire length of the cable, as defined by the manufacturer's specifications. Also, verify a passing DTF return loss of each connector, as defined by the manufacturer.	100 - 1100 MHz	Distance-to-Fault	Precision Load
9	Feedline Return Loss	Measure the feedline's return loss and verify that the worst-case return loss meets the manufacturer's specifications.	100 - 1100 MHz	Return Loss	Precision Load
10	Antenna System Distance- to-Fault	Measure the system's DTF return loss to establish a baseline signature. Verify no anomalies.	Antenna Passband	Distance-to-Fault	Top Jumper and Antenna
11	Antenna System Return Loss	Measure the system's return loss to establish a baseline signature. Verify a passing system return loss value using an RF calculator tool, such as the RF Path Calculator tool from Andrew® or a calculation from an RF engineer or ASC subject matter expert.	Antenna Passband	Return Loss	Top Jumper and Antenna

NOTE: After the initial 100–1100 MHz test verifies proper antenna operation, the frequency span can be narrowed—typically to 100 MHz above and below the operating band. This narrower span provides higher resolution for the targeted antenna sweep. Both sweeps should be saved.

9.10.13 Reuse of Existing RF Transmission Line

Under engineering guidance, RF transmission lines can be reused when replacing transmitters, receivers, and transceivers. However, if the RF transmission line is near or beyond the manufacturer's recommended lifespan for the cable type, it should be replaced. All tests outlined in Table 9-5 should be conducted on all reused RF transmission lines.

9.10.14 GPS Antenna Installation

IMPORTANT: Redundant GPS antennas should be physically separated as much as practicable to help prevent any signal obstructions from affecting both antennas at the same time, and reduces the risk of damage to both antennas from a falling tree limb or other physical hazard.

The GPS antenna **shall** be mounted with an unobstructed view of the sky. A clear 360 degrees is preferred; however, blockage from buildings, trees or other objects should be less than 50%. Typically, the GPS antenna is mounted low and close to the roof of the equipment shelter or adjacent tower. This will help prevent the GPS antenna from sustaining a direct lightning hit. GPS antennas may be mounted on PVC masts.

A Surge Protective Device (SPD) **shall** be installed on the GPS antenna lead and any associated control or data cables within 61 cm (24 in.) of the entrance to the equipment room. If practicable, the GPS antenna should be located at least 13.7 m (45 ft) from towers, lightning rods or any other objects that are susceptible to lightning. The GPS antenna should be installed lower than any object susceptible to a lightning strike.

9.10.15 Cabling in Telephone Wiring Environments

The following considerations apply only at sites that must meet specifications provided by a telephone service provider. If no special requirements are stated by the telephone service provider, best commercial practices, such as Telcordia specifications, may be used for telephony cabling within the communication site.

When installing cabling that connects with telephone company assets or a demarcation point, inquire about any lacing requirements before work is performed. Special cabling methods, such as cable lacing, may be required when installing a system for a telephone service provider or possibly other utility companies. Observe the following considerations for cable lacing:

- Horizontal cables in cable trays should have lacing every 914 mm (3 ft). See Figure 9-50 for an example.
- Vertical cables on a cable ladder should be laced at every ladder rung. Any cable hanging between horizontal/vertical runways and racks cannot be unsupported for more than 610 mm (24 in.).



Figure 9-50. Example of Cable Lacing for a Utility

9.10.16 Distribution Frame Configurations

A distribution frame provides a centralized cross-connection point for audio, data, and alarm and control wiring between different pieces of equipment at a site and between the site and external lines. See Figure 9-51 for examples. Distribution frames **shall** be implemented using one of the following methods:

- Distribution punch blocks affixed to a plywood panel that is mounted on a wall or a rack.
- Distribution punch blocks mounted on open-rack frames. These frames can be anchored to the floor.
- Typically, a distributed (as opposed to centralized) method is used. Pre-wired cross-connect panels (each one rack unit in height) distribute connections on a rack-by-rack basis.
- Cable management systems should be used.



Figure 9-51. Examples of Typical Distribution Frames

9.10.16.1 Distribution Frame Cross-Connect Wiring

- Distribution frame cross-connect wiring **shall** be performed in a professional and skillful manner (NFPA 70-2026, Article 110.12).
- Cross-connect wires for 66-blocks and 110-blocks **shall** be AWG #22 - #24 (0.644 mm - 0.511 mm) plastic-insulated solid copper wire.
- Individual wires for punch blocks **shall** enter the punch terminal from the top, ensuring the wire tail points downward after punch-down.
- CAT 3, 4, 5, 6, or 8 data wiring **shall** enter punch terminals from the middle such that one wire points up while the other points down. In this manner, the cable twist that maintains the cable impedance stays intact. See Figure 9-52 for an example.
- The wiring **shall** dress down the source block column, across the bottom of the frame, and up the destination block column. Approximately 50.8 mm (2 in.) of service loop is allowed.
- Wiring **shall** be secured using industry-standard methods as described in this chapter. Cable management systems are recommended.

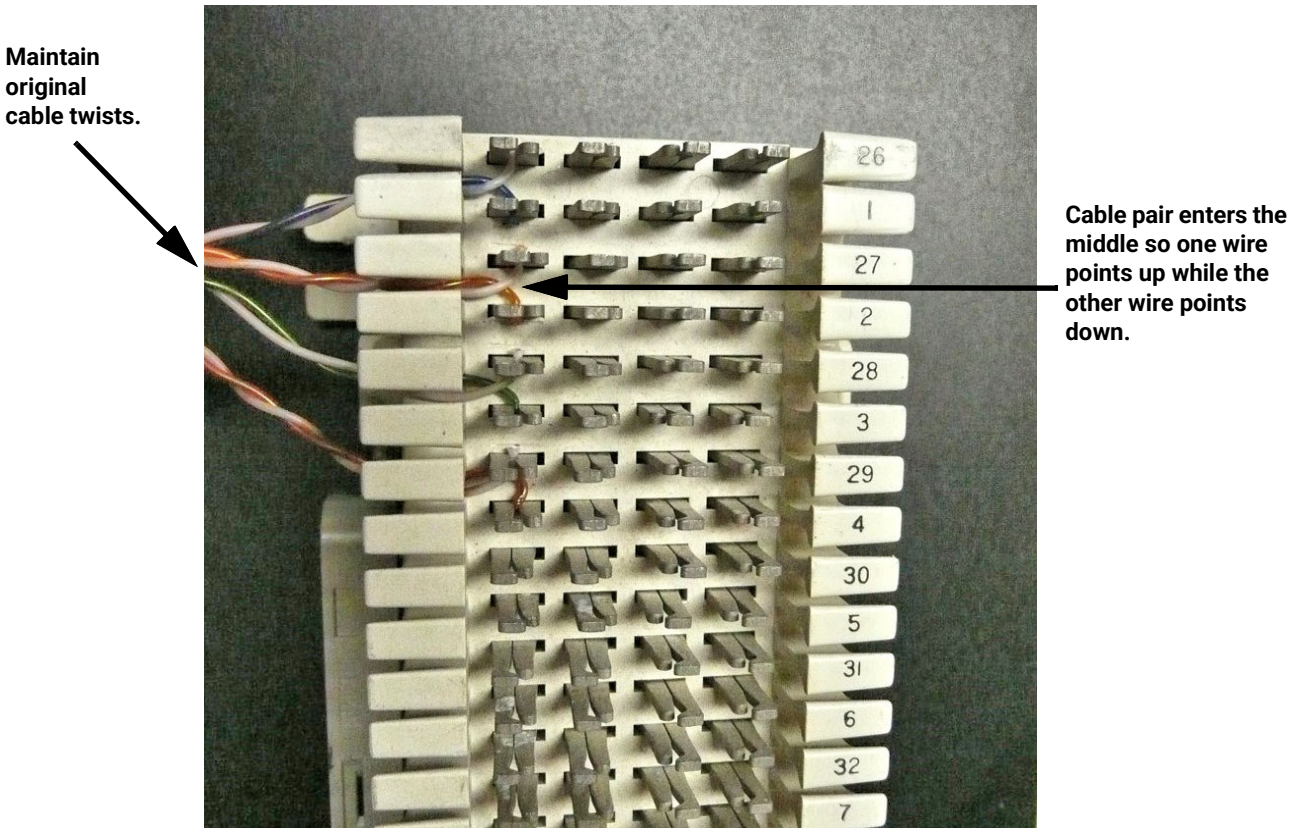


Figure 9-52. Example of Punch Blocks Used for Data

9.10.17 Interior Cable Labeling

Cabling within the site building or shelter **shall** be identified with a standardized, double-ended system to facilitate cable and equipment connection identification. See Figure 9-53 and TIA-606-D for additional information. Observe the following when devising a cable labeling system:

- Labeling **shall** identify the direction along the cable where terminating equipment is located.
- Labeling **shall** indicate the destination ends of the cable, including equipment name and connector reference designator or name. This applies to connectorized, lugged, or punched-down cable terminations, regardless of the application (RF, audio or control).
- Labeling **shall** be imprinted on white opaque material (preferably plastic or plasticized paper) using indelible black ink.
- Label placement **shall** be between 101 and 152 mm (4 to 6 in.) from each end of the cable, or at the most logical point that allows the label to be easily read).
- Labeling should wrap entirely around the cable. It should be secure enough to assure label retention if cable is to be pulled through conduit.
- Information printed on each label should be concise yet clearly understandable. Use industry-standard abbreviations, initials and acronyms to conserve label space. See Figure 9-53.
- Interior RF cables **shall** be labeled in the same manner as described previously.



Figure 9-53. Examples of Cable Labeling

9.10.18 Exterior Cable Labeling

Exterior cables (such as RF and data) **shall** have permanent identification, such as stamped brass tags or phenolic tags. Colored tape or tape bands may be used temporarily during installation, but are not considered permanent and therefore do not meet the labeling requirements. See Figure 9-54 for examples.

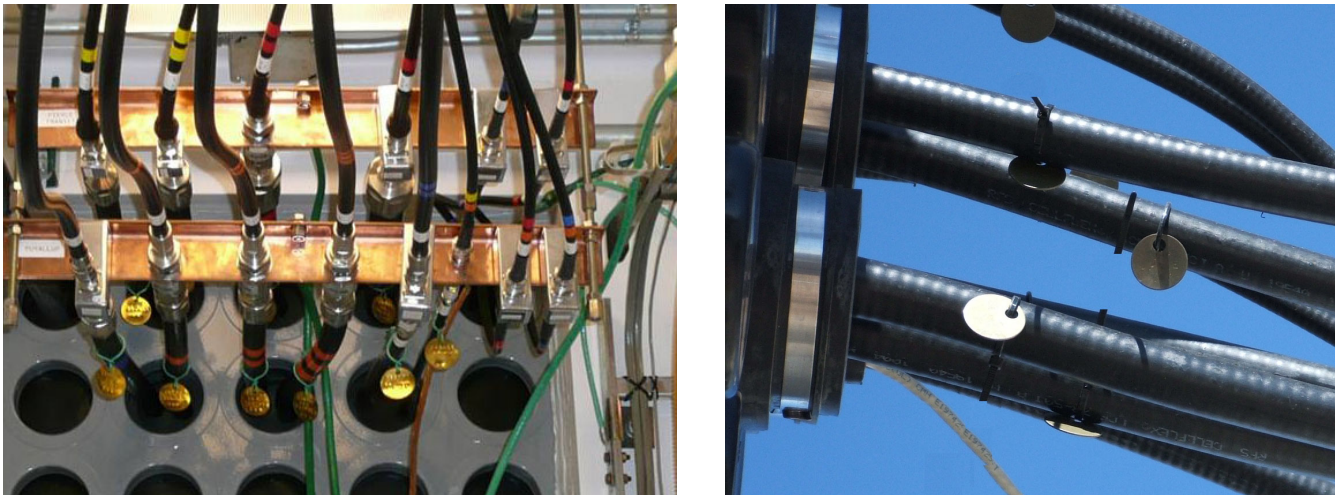


Figure 9-54. Examples of Interior and Exterior Cable Labeling

9.10.19 Outdoor Equipment/Cable Installation

9.10.19.1 Outdoor Equipment Cabinets

Equipment installed in an outdoor equipment cabinet (or similar) **shall** comply with all applicable requirements in this manual, including but not limited to the requirements described in:

- Chapter 4, “External Grounding (Earthing) and Bonding”
- Chapter 5, “Internal Bonding and Grounding (Earthing)”
- Chapter 7, “Surge Protective Devices”
- Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”

9.10.19.2 Outdoor Cable Installation

The following outdoor cable installation requirements **shall** be observed:

- The antennas or lead-in conductors **shall not** be attached to the electric service mast. They **shall not** be attached to poles or similar structures carrying open electric light or power wires or trolley wires of over 250 volts between conductors. See Figure 9-55, Figure 9-56 and Figure 9-57 for examples.
- Outdoor antennas and lead-in conductors from an antenna to a building **shall not** cross over open conductors of electric light or power circuits and **shall** be kept well away from all such circuits to avoid the possibility of accidental contact.
- Where proximity to open electric light or power service conductors of less than 250 volts between conductors cannot be avoided, the installation **shall** be such as to provide a clearance of at least 600 mm (2 ft).
- Where practicable, antenna conductors **shall** be installed so they do not cross under open electric light or power conductors. See NFPA 70-2026, Article 810.13.
- See “RF Cabling” on page 9-57.

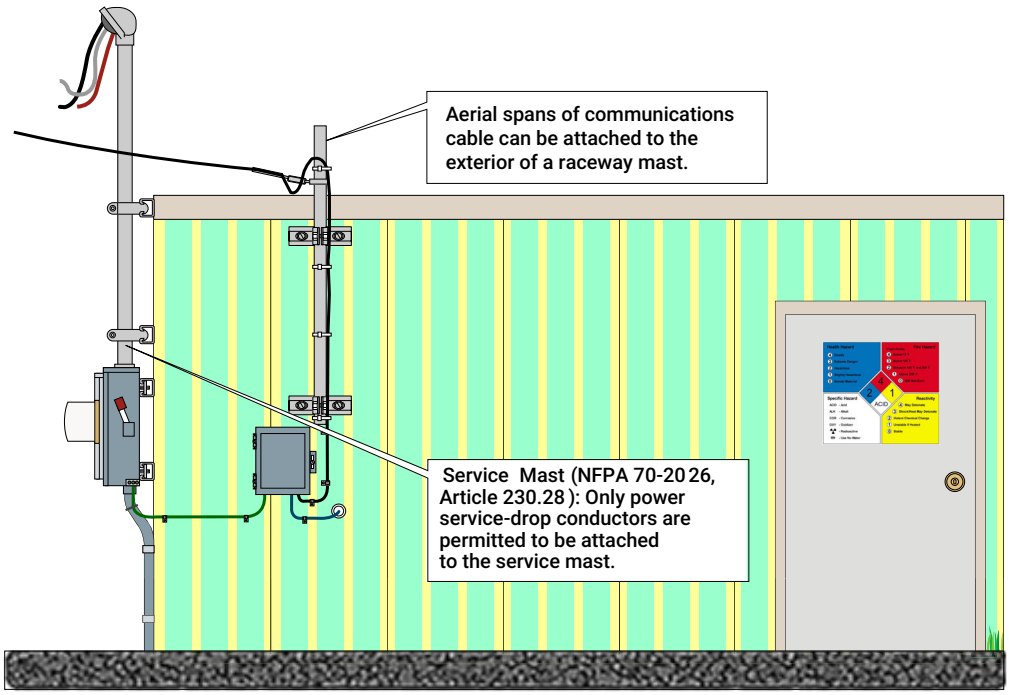


Figure 9-55. Example of Correct Installation of Outdoor Cables

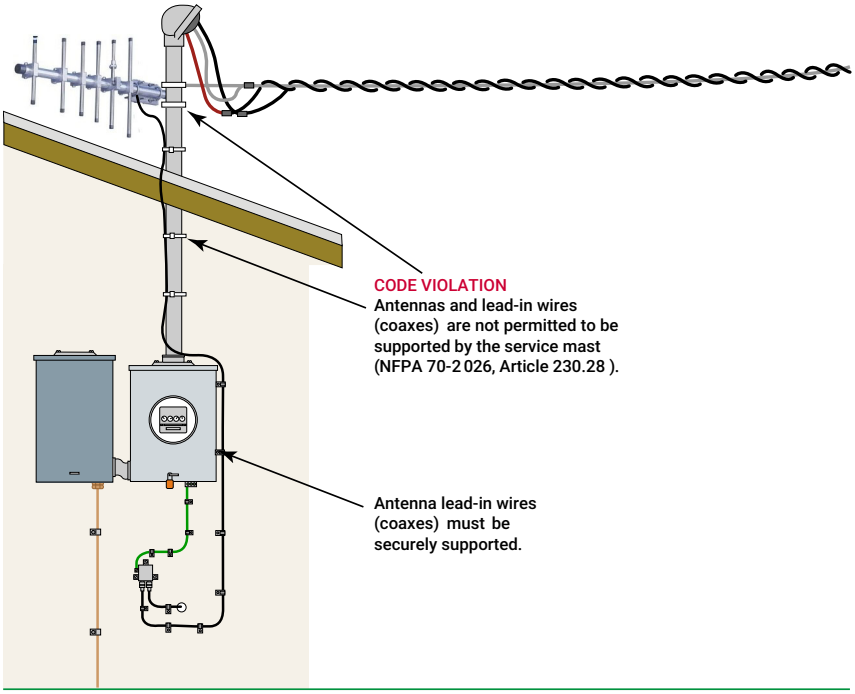


Figure 9-56. Example of Incorrect Installation of Outdoor Cables

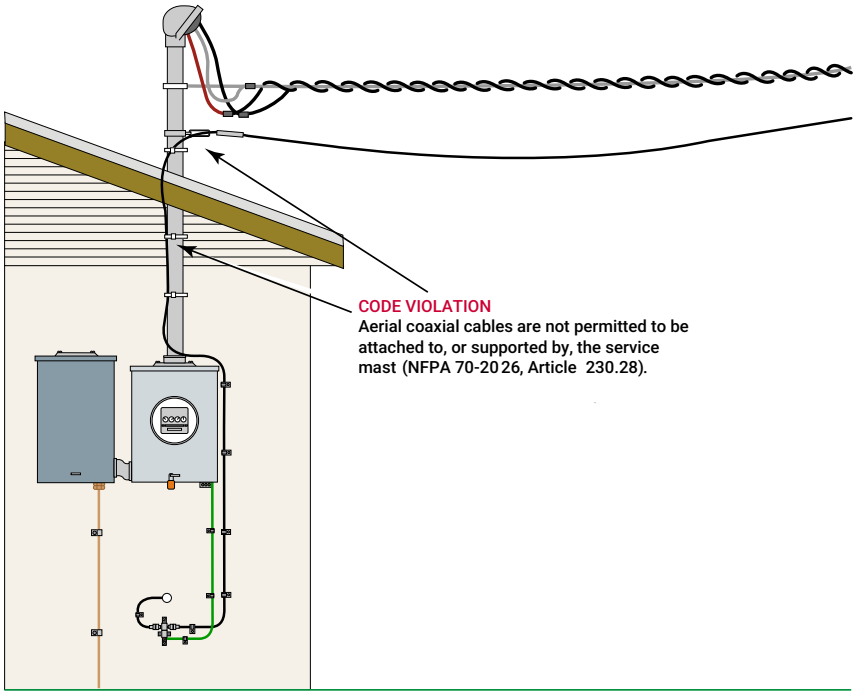


Figure 9-57. Example of Incorrect Installation of Outdoor Cables

9.10.19.3 Broadband Point-to-Point and Multi-point Wireless Links

See “Broadband Point-to-Point and Multi-point Wireless Links” on page 7-50 for information regarding these types of installations.

9.11 Tower Lighting Systems

The installation of tower lighting systems **shall** comply with the manufacturer's instructions. The following **shall** be observed:

- External control boxes **shall** be bonded to the grounding electrode system as described in Chapter 4, "External Grounding (Earthing) and Bonding".
- Internal control boxes **shall** be bonded as described in Chapter 5, "Internal Bonding and Grounding (Earthing)".
- All conductors entering or exiting the shelter **shall** have appropriate surge protective devices as described in Chapter 7, "Surge Protective Devices".
- Cables installed on the tower **shall** be secured to the tower and cable/ice bridge using manufacturer-approved hardware at the recommended intervals. See "RF Cabling" on page 9-57.
- Power cables from the control box to the light **shall** be shielded unless otherwise specified by the manufacturer.
- Power cables for LED tower lights **shall** be separated from RF cables by a minimum of 5 cm (2 in.).
- Power cables for strobe lights **shall** be separated from RF cables as much as practicable. Typical manufacturer's instructions specify that the strobe cable should be secured to the inside of a tower leg.

9.12 Equipment Removal

This section provides workmanship requirements for equipment removal. The requirements in this section are general guidelines and are not all inclusive. See Telcordia GR-1275-COREi12, section 20, for more information.

9.12.1 Equipment Removal Requirements

An inspection of the facility and equipment **shall** be conducted by a trained and certified site auditor, the project manager, and/or site owner prior to the start of the removal activity. The purpose of the joint inspection is to disclose any potential hazards that may jeopardize personnel safety and/or equipment operation and maintenance. Additionally, this inspection **shall** identify any unusual work conditions, additional work effort, and/or unique material items that may need to be addressed due to existing facility conditions.

Personnel safety and equipment protection are crucial when work is performed on live power equipment and circuits.

- All equipment removal **shall** be performed by qualified personnel.
- See "Safety for Equipment Installation" on page 9-1.
- See "Installation Practices" on page 9-3.

NOTE: Equipment removal should not begin unless a minimum of two people are present. An exception is the removal of small, lightweight equipment. This is a safety precaution to ensure a timely response in the event of an accident.

- Adequate protection and insulation **shall** be placed on tools, busbars, framework, etc., when working on live equipment to prevent accidental short circuits.
- Conduits, outlet boxes, and panels remaining in the removal area **shall** be supported and securely fastened.
- Open knockouts in AC service cabinets, conduit junction boxes, and so on **shall** be closed using approved caps.
- Open breaker locations in AC service cabinets **shall** be covered using approved caps.
- Conduit junction boxes and fittings remaining in the removal area **shall** be equipped with covers.

- Any AC conductors remaining after equipment removal (such as pig tails) **shall** be terminated in an enclosed location, such as a conduit junction box.
- All applicable safety precautions **shall** be adhered to during cable removal. Sharp objects **shall not** be used to separate cable bundles.
- All exposed floor obstructions or protrusions (for example, floor anchors, bolts, and so on) resulting from a removal **shall** be removed or cut flush with the floor covering.
- Holes in the floor due to the removal of equipment **shall** be filled and sealed.
- Building penetrations through floors and walls that are no longer used for cable, conduit, etc., **shall** be permanently sealed.

9.12.1.1 Equipment Protection During Removal

Removal personnel **shall** provide adequate protection for working equipment in the area of the removal activity. At the completion of the removal activity, all associated equipment protection **shall** be removed.

9.12.1.2 Grounding

After equipment removal, all remaining equipment, cabling, racks, cabinets, and ancillary equipment **shall** be grounded and bonded as specified in this manual. See “External Grounding (Earthing) and Bonding” on page 4-1 and “Internal Bonding and Grounding (Earthing)” on page 5-1.

9.13 Site Security Surveillance Systems

Site security surveillance systems at remote RF communications sites typically contain infrared motion detectors, cameras and recording devices. The video is typically streamed over a microwave or fiber link to a central monitoring and dispatch center. See Figure 9-58 for an example of this type surveillance system at a remote RF site.

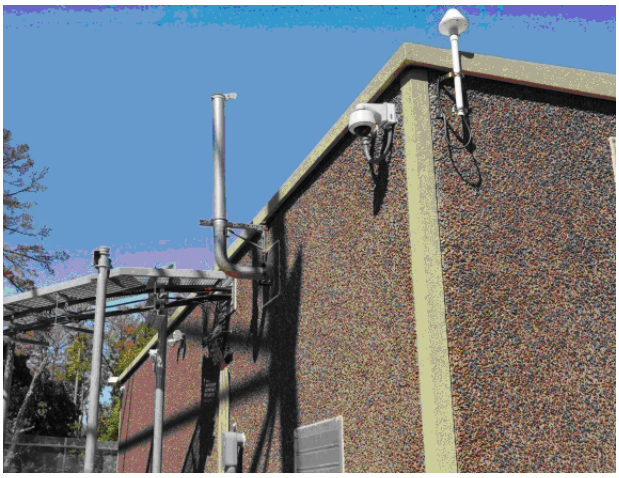




Figure 9-58. Remote Site Security Surveillance System Examples

Where a video surveillance system is installed at a communications site, the following installation requirements **shall** be met:

- All cabling penetrations into the building **shall** be sealed to prevent moisture and insect intrusion.
- Exterior routed cabling **shall** be securely attached to the structure and protected from damage (Figure 9-59).
- All cabling **shall** meet the minimum 51 mm (2 in.) cable group separation requirements throughout the cable routing path to the interior equipment.
- All exterior routed sensor, video and power cabling **shall** be protected as specified in Chapter 7, “Surge Protective Devices”.
- All interior routed cabling **shall** be protected as specified in Chapter 7, “Surge Protective Devices”.



Figure 9-59. Securing and Protecting Surveillance Equipment Cabling

9.14 Utility Pole-Mounted Equipment Installation and Clearances

The following sections describe clearance requirements for utility pole-mounted access points, wireless routers, point-to-point links, external Surge Protective Devices (SPDs) associated with the electronic equipment, and similar devices. Written approval **shall** be obtained from the utility and/or AHJ before beginning work on a utility pole.

WARNING: Installations on utility poles SHALL meet all installation and clearance requirements of the National Electrical Safety Code® (or equivalent), the electric utility (or utility that owns the pole) or other AHJ.

WARNING: High voltage hazards may exist with utility pole installations. Only trained and qualified personnel SHALL perform communications equipment installations and maintenance on utility poles and SHALL follow applicable OSHA regulations (or equivalent). Qualification and training SHALL be determined by the utility and/or AHJ.

NOTE: This section provides general guidance only. Consultation with the National Electrical Safety Code® (NESC®), the utility pole owner, and the AHJ is required for all installations.

9.14.1 Utility Pole Required Clearances

Installations on utility poles require careful coordination with the utility to ensure safe installations. Any communications equipment installed on a utility pole **shall** maintain clearances as required by the *National Electrical Safety Code®* (or equivalent), the utility owning the pole, or other AHJ.

In general, the following clearances **shall** be observed (*National Electrical Safety Code®*):

- Not less than 102 cm (40 in.) of vertical clearance between 7.2 kV phase-to-ground supply circuit equipment and the communications equipment (Figure 9-60). See NESC® Rules 235C, 238B, and 238E.

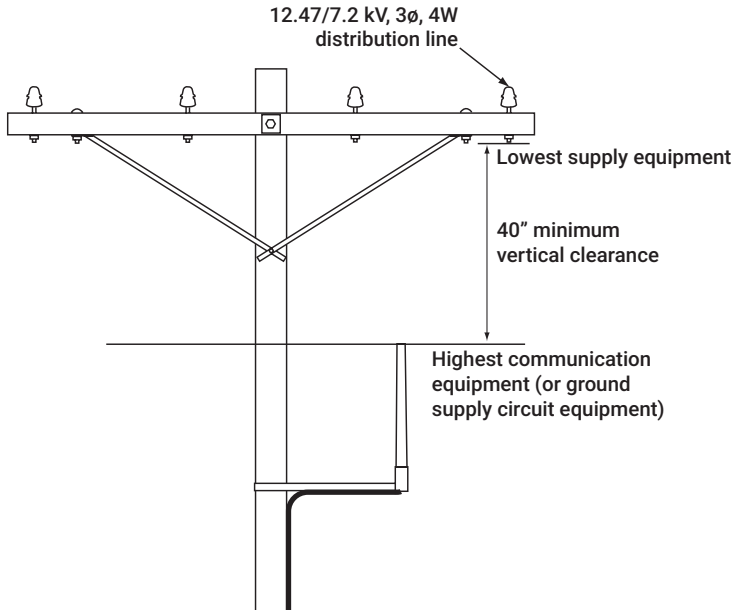


Figure 9-60. Supply to Communication Equipment Clearance - 7.2 kV Supply

- Not less than 109 cm (43 in.) of vertical clearance between 14.4 kV phase-to-ground supply circuit equipment and the communications equipment (Figure 9-61). See NESC® Rules 235C, 238B, and 238E.

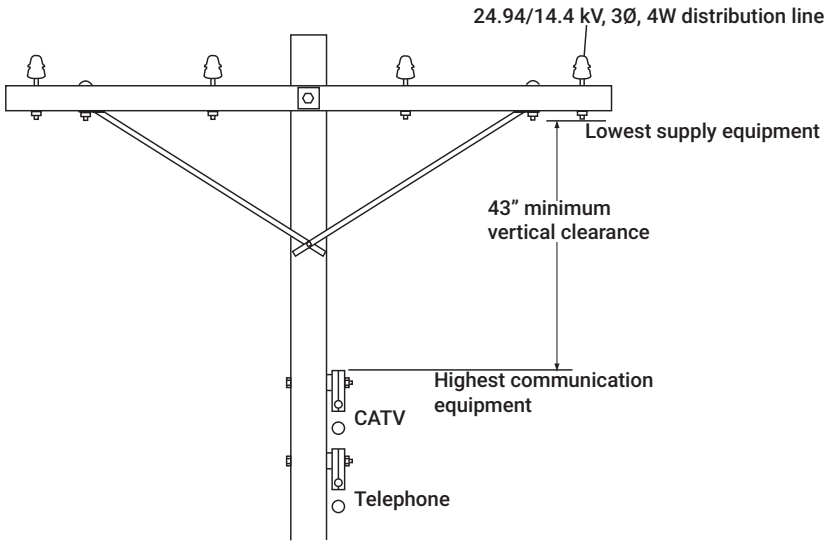


Figure 9-61. Supply to Communication Equipment Clearance - 14.4 kV Supply

- Not less than 762 mm (30 in.) of vertical clearance between the effectively grounded neutral hardware and the communications equipment (Figure 9-62). See NESC® Rules 235C, 238B, and 238E.

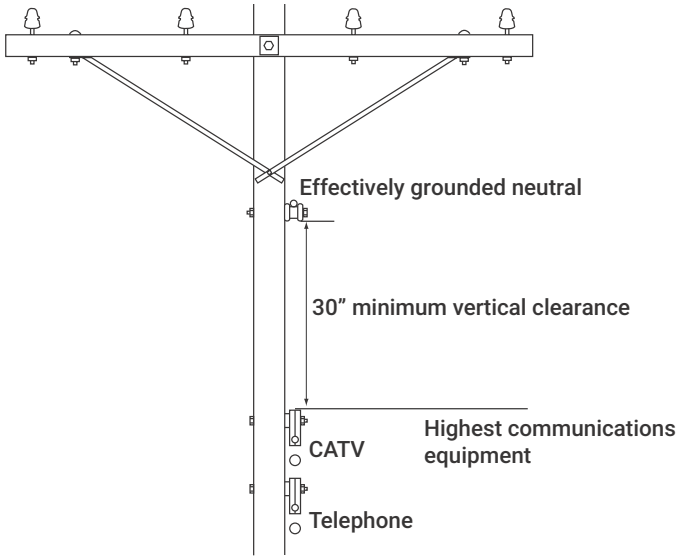


Figure 9-62. Vertical Clearance Between Grounded Neutral and Communication Equipment

- Not less than 762 mm (30 in.) of vertical clearance between non-current-carrying parts of effectively grounded supply equipment (for example, the transformer case) and the communications equipment (Figure 9-63). See NESC® Rules 235C, 238B, and 238E.

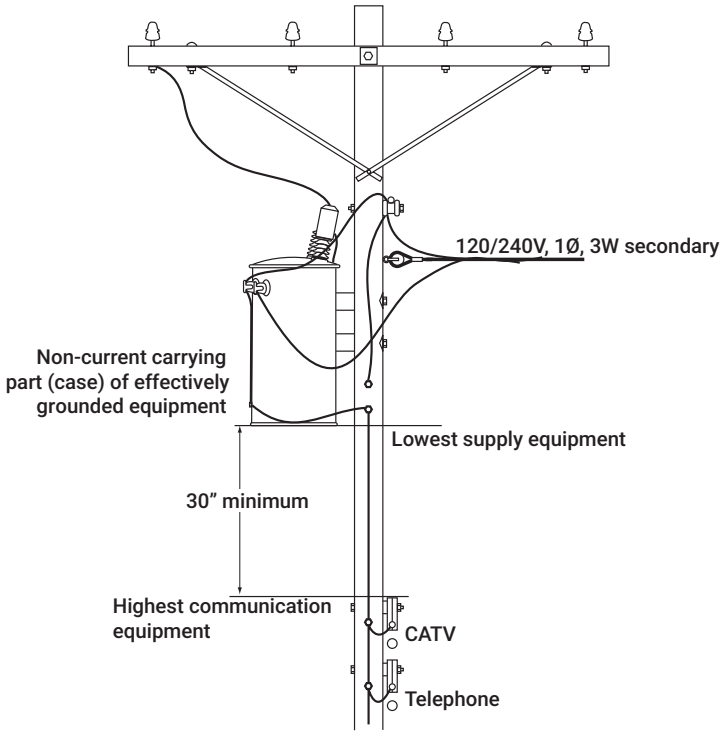


Figure 9-63. Vertical Clearance Between Communication Equipment And Non-Current-Carrying Parts (Secondary Above Bottom)

NOTE: The non-current carrying parts of supply equipment must be consistently grounded throughout a well-defined area, and the neutral associated with the supply equipment must be bonded to the communications equipment.

- Not less than 102 cm (40 in.) of vertical clearance between a 120/240 V, 1θ, 3W secondary triplex (see NESC® Rule 230C3) and the communications equipment (Figure 9-64). See NESC® Rules 235C, 238B, and 238E.
- Not less than 10.1 cm (4 in.) of vertical clearance between a luminaire bracket and the communications equipment (Figure 9-65). See NESC® Rules 238C and 238D.
- Not less than 305 mm (12 in.) of vertical clearance between a luminaire supply conductor drip loop and the communications equipment (Figure 9-65).
- All clearances **shall** meet the requirements of the utility and/or the AHJ. The requirements of the AHJ **shall** take precedence over the requirements listed in this section.

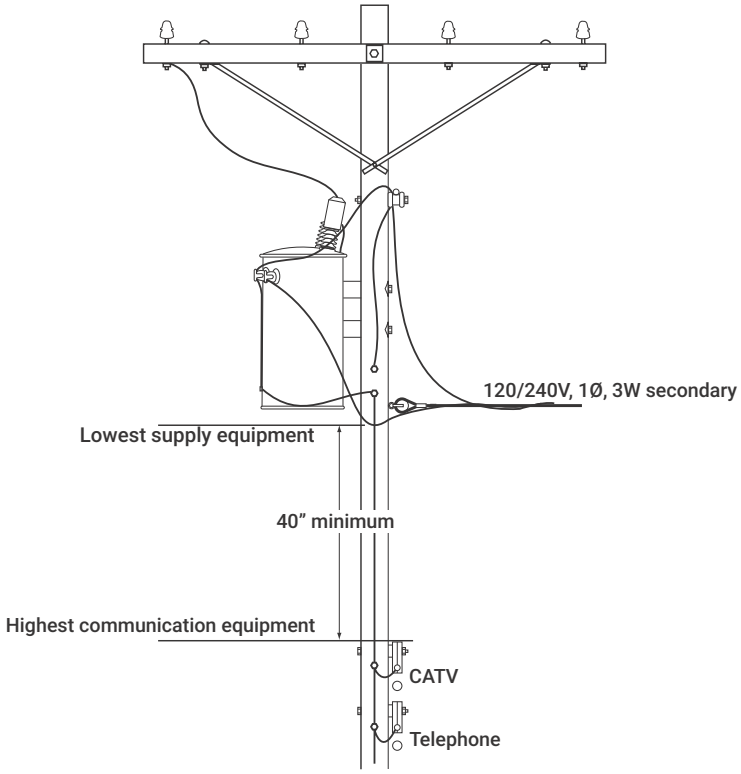


Figure 9-64. Vertical Clearance Between Communication Equipment and Non-Current-Carrying Parts (Secondary Below Bottom of Grounded Case)

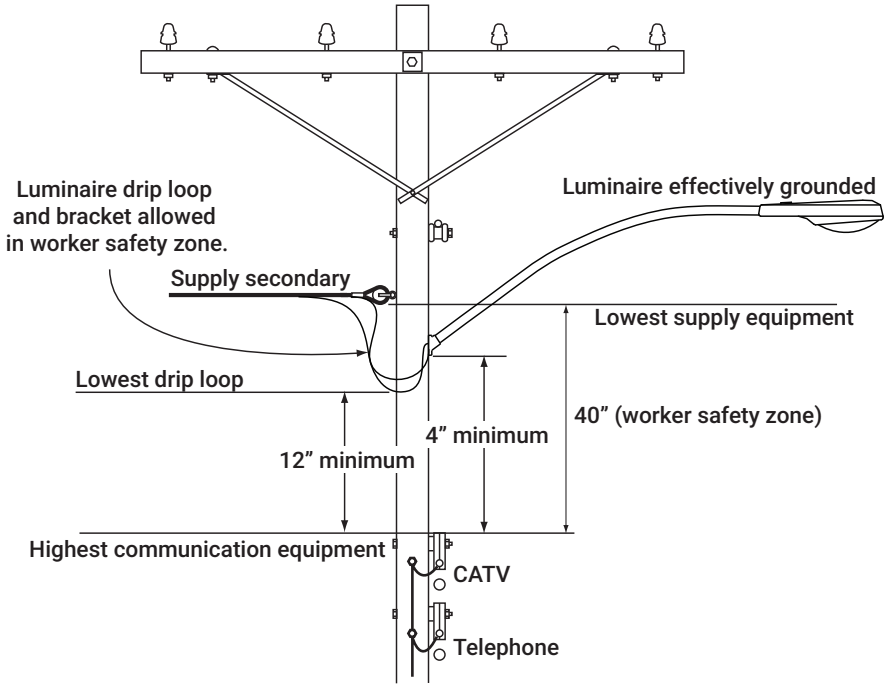


Figure 9-65. Luminaire Bracket and Drip Loop Clearances

9.15 Electrostatic Discharge Considerations

CAUTION: Do not handle ESD-sensitive equipment without taking appropriate precautions.

Electronic equipment is vulnerable to damage caused by Electrostatic Discharge (ESD). Although newer equipment is becoming more susceptible to ESD damage, older equipment can also be easily harmed by ESD. See Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”, for more details.

The following electrostatic discharge prevention practices **shall** be observed whenever installing or servicing electronic equipment:

- ESD wrist straps **shall** be available at the site.
- An ESD wrist strap **shall** be worn when handling ESD-sensitive modules. ESD wrist straps should fit snugly, ensuring firm contact with the user's skin.
- ESD-rated protective wrapping **shall** remain on the equipment until it is placed near its final location.
- ESD rated packaging **shall** be available at the site for storing and transporting static-sensitive components.
- All equipment-specific precautions on **shall** be followed according to the relevant documentation.
- See Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers”; and Telcordia GR-1275-CORE.i12, section 9.3.
- See Appendix C, “Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers” for more details.

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APPENDIX

A

Electromagnetic Energy Information

This appendix includes the following topics:

- “Environmental Evaluation” on page A-2
- “Engineering Considerations” on page A-11
- “Work Practices” on page A-16
- “Signage” on page A-19
- “Personal Protective Equipment (PPE)” on page A-22
- “EME Action Thresholds Summary” on page A-23

IMPORTANT: This appendix provides supplementary information based on FCC guidelines in the United States. Entities such as the Occupational Safety and Health Administration (OSHA), and/or state or local authorities, may offer additional guidance on Electromagnetic Energy (EME) and safety best practices. International regulatory bodies, including ISED Canada, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), the United Kingdom Health Security Agency, and EUR-Lex (European Union), may impose guidelines that differ from those presented in this appendix. The requirements and training mandated by the authority having jurisdiction (AHJ) in the site’s specific country or region **shall** be complied with.

A.1 Introduction

Motorola Solutions provides the information in Appendix A to users to help them understand various concepts necessary to satisfy their obligations to comply with the Federal Communications Commission (FCC) guidelines regarding human exposure to Electromagnetic Energy (EME) at antenna sites. Motorola Solutions does not intend for this information to replace a structured training program. Rather, it is meant to provide the user basic knowledge and methodology to assist the user develop its Electromagnetic Energy compliance program. The methods outlined in this appendix may represent one approach to meeting FCC requirements. However, other methods may also satisfy FCC guidelines. The user should independently determine what compliance program is appropriate for their situation.

In 1996, the FCC adopted guidelines for evaluating the environmental effects of Radio Frequency (RF) energy from transmitters on wireless communication sites. Although there is no established scientific evidence that RF emissions from these sites operating within established safety guidelines pose a health risk, the fields near antennas at transmitter sites must be understood, and care must be taken to ensure safe operation during operation and maintenance. The guidelines set by the FCC provide substantial margins of protection against any established health risks, such as excessive RF-induced heating.

This appendix presents several issues related to analyzing and understanding the Electromagnetic Energy (EME) environment that may exist at a complex communications site. A complex site is defined as any location with more than one RF transmitter or antenna.

Modern communication sites usually host multiple transmitters providing various functions or services, such as cellular, Personal Communications Services (PCS), Enhanced Specialized Mobile Radio (ESMR), paging, basic two-way radio, commercial broadcasting, and more. Given that each of these services requires separate transmitters, historically, each service tended to develop its own sites and operate independently. However, the continued growth of these services has increased transmitter co-location (the grouping of transmitters for different communications services at a single site). This co-location naturally leads to increased RF exposure levels in and around the site.

The drive for co-location stems from the need for more sites to meet commercial, public, and first responders' demand for wireless communication services, along with public expectations regarding the proliferation and placement of those sites. This results in more complex communication sites. To accommodate this growth, more sites are expected to host multiple RF transmitters and antennas.

Co-location presents challenges to the companies providing these services. As more transmitters are added to a site, the intensity of RF signals increases. For example, hilltops near large metropolitan areas are likely to have a high density of broadcast and communications sites. Because these are usually located on a shared ridge or peak, the relative RF exposure levels may, in close proximity to transmit antennas, approach or exceed recognized exposure limits.

This appendix also discusses issues important for managing complex communications sites and crucial to ensuring that best practices are employed to meet recognized exposure limits. Following best practices by adhering to FCC guidelines can help ensure the occupational and general public exposure levels remain within statutory limits.

A.2 Environmental Evaluation

The potential health effects linked to EME exposure have been investigated for over 75 years. Scientists have recognized and studied the exposure threshold at which RF energy begins to pose adverse behavioral or biological effects. The only confirmed adverse effect of RF energy, in the frequency ranges above 10 MHz used in mobile communications, is related to excessive tissue heating, which can in extreme cases lead to severe burns. Consequently, standard setting organizations have established recommended exposure limits that are at least an order of magnitude lower than the established effects thresholds. This substantial built-in margin of protection underpins reliable science-based guidelines for safe human exposure. Globally, EME exposure standards are available in numerous countries and regulatory bodies. In the United States, a recognized standard comes from the IEEE International Committee on Electromagnetic Safety (ICES), formerly ANSI C95, established in the 1950s.

In 1988, the Institute of Electrical and Electronics Engineers (IEEE) became the sole sponsor of the C95 Committee, which was then renamed the IEEE Standards Coordinating Committee (SCC), SCC28. In 1991, IEEE adopted the ANSI C95 standards as IEEE C95-1991. These standards were later acknowledged by ANSI in 1992 as the ANSI/IEEE C95-1992 standard for safety levels of RF exposure. The exposure limits in the ANSI standard share many similarities with those established by the National Council on Radiation Protection and Measurements (NCRP), an independent organization chartered by the U.S. Congress. The latest revision of IEEE Std C95.1 (2019) incorporates up-to-date knowledge on potential effects of RF exposure for workers as well as the general population.

The Federal Communication Commission (FCC) adopted guidelines that generally align with recommendations from expert health and safety agencies such as the EPA, FDA, OSHA, NIOSH, and others. These guidelines establish field and power density limits as suggested by the NCRP Report No. 86, and the SAR limits from IEEE C95.1-1992. For additional information, refer to the FCC Report and Order (FCC 96-326) and the Second Memorandum and Order (FCC 97-303), both of which are available on the FCC Office of Engineering and Technology website: https://www.fcc.gov/general/radio-frequency-safety-0.

NOTE: As of the publication of this manual, IEEE C95.1 was updated in 2019 (IEEE C95.1-2019) and is titled IEEE Standards for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.

A.2.1 Exposure Standards and Limits

With the publication of the SCC28 standard as ANSI/IEEE C95.1-1992, a number of elements were added to prior ANSI standards. These changes included modification of the exposure limits and the classification of exposure environments as Occupational/Controlled and General Population/Uncontrolled. Exposure limits in the guidelines were adopted by the FCC in the Code of Federal Regulations (47 CFR § 1.1310 Radiofrequency radiation exposure limits). The guidelines are published in further detail in the Office of Engineering Technology (OET) bulletin 65 and are specified in terms of Maximum Permissible Exposure (MPE) as a function of frequency; MPEs are given in units of electric and magnetic field strength and power densities. Table A-1 (General Population) and Table A-2 (Occupational) show a portion of the MPE outlined in the FCC rules and the exposure averaging time, indicating that the exposure level may be briefly exceeded so long as the time-averaged exposure still remains compliant.

Table A-1 limits apply to individuals who are presumed to have no awareness of or control over potential RF exposure.

Table A-1. Maximum Permissible Exposure: General Population

Frequency Range (MHz)	Power Density	Average Time
30 – 300	0.2 mW/cm^2	< 30 minutes
300 – 1,500	f/1500 mW/cm^2	< 30 minutes
1,500 – 100,000	1.0 mW/cm^2	< 30 minutes

Table A-2 limits are for individuals who are aware of potential RF exposure due to their employment, operating in areas exceeding General Population limits, and are trained to control such an exposure. Examples include maintenance technicians working on transmitters and able to control exposure by establishing minimum distances from transmitting antennas. Their exposures are evaluated against Occupational/Controlled limits due to this knowledge.

Table A-2. Maximum Permissible Exposure: Occupational

Frequency Range (MHz)	Power Density	Average Time
30 – 300	1.0 mW/cm^2	< 6 minutes
300 – 1,500	f/300 mW/cm^2	< 6 minutes
1,500 – 100,000	5.0 mW/cm^2	< 6 minutes

Understanding and taking simple precautions can help ensure RF levels near antenna sites remain within permitted exposure limits. Notably, MPE exposure levels for the General Population/Uncontrolled environment are five times lower than those for Occupational/Controlled environments. See Figure A-1 for a graphical representation of these limits. In the previous example, the technician could be exposed to a power density of up to 3 mW/cm^2 from a 900 MHz transmitter, while a bystander could only be exposed to 600 $\mu W/cm^2$.

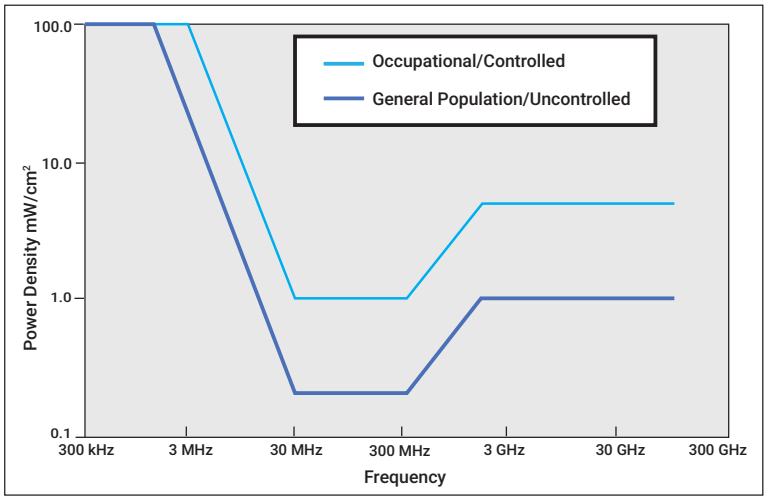


Figure A-1. FCC Adopted Maximum Permissible Exposure Limits

Where exposed to multiple RF emitters operating across different frequencies, the sum of the ratios of the measured or predicted squared-field strengths (or power densities) at each frequency to the respective MPE limit for that frequency must not exceed 1.0, or equivalently, or the sum of the percentages of the MPE produced by each frequency must not exceed 100%. As an example, the RF fields at a specific location comprise four (4) different frequencies and their measured field strengths represent a percentage of the applicable MPE for Occupational/Controlled environments (see Table A-2) shown in the following Table A-3; the resulting exposure can be expressed as 85% of the allowable Occupational/Controlled environment MPE and continuous exposure would be in compliance with the FCC limits.

Table A-3. Example of Maximum Permissible Exposure Conformity Evaluation

Frequency (MHz)	Measured Power Density	MPE (%)
155.025	0.25 mW/cm^2	25%
465.0125	0.54 mW/cm^2	35%
955.0125	0.48 mW/cm^2	15%
851.0125	0.28 mW/cm^2	10%
	Total Exposure:	85%

A.2.2 Compliance Analysis

A.2.2.1 Spatial-peak

The Whole-Body Peak (WBP) serves as a crucial metric in RF safety evaluations, representing the absolute maximum level of RF energy present across the vertical extent of a human body. This measurement is designed to identify the point of highest potential RF exposure within a defined area. This peak exposure value must be taken into consideration when evaluating and determining the overall risk associated with RF fields. If a comprehensive evaluation of an area reveals that no WBP measurements surpass the applicable Maximum Permissible Exposure (MPE) limit (as defined by the FCC in 47 CFR § 1.1310) for the relevant classification level (Controlled or Uncontrolled environment), then the area is below the defined limits and no further, more granular investigation or mitigation strategies are necessary. This approach streamlines the safety assessment process by providing a clear and decisive criterion for determining the RF exposure compliance of an environment.

A.2.2.2 Spatial-averaging

When evaluating an area for potential exposure, if it is determined that there are locations where the WBP exceeds the applicable MPE limit, then spatial-averaging of the MPE levels is performed. Spatial-averaging considers the whole height of the human body in the evaluation of exposure. Measurements are made between ground or floor level and 1.8 m (6 ft) in height and then averaged. If spatially-averaged RF energy levels are still above the applicable MPE, access at these locations must be restricted.

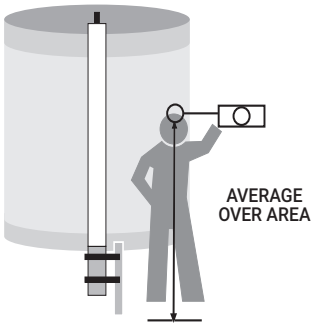


Figure A-2. MPE Spatial Averaging

A.2.2.3 Time Averaging

MPE guidelines (FCC § 1.1310) are expressed in terms of a time-averaged exposure over a rolling temporal window, (6 minutes for Occupational/Controlled environments and 30 minutes for General Population/ Uncontrolled environments).

It is therefore permissible to exceed the numerical value of the applicable MPE for brief durations as long as the average exposure, over all the relevant rolling time windows, does not exceed such MPE limit value.

Time averaging, while sometimes acceptable for managing high exposure levels, demands careful attention due to the potential for error or misunderstanding, making its sole use generally inadvisable. Where spatial-averaging limits are exceeded, alternative exposure reduction methods **shall** be utilized. However, time averaging can be a viable control method in specific scenarios, such as tower climbing. During ascent, climbers moving through high-exposure fields can maintain guideline limits if a steady rate of movement ensures the time-averaged exposure remains within permissible levels.

A.2.3 Exposure Evaluation

RF exposure levels can be evaluated through theoretical modeling and physical testing. Site modeling helps testers identify potential high-exposure areas requiring close physical examination and testing.

FCC limits mandate a maximum exposure of 100% of the MPE, averaged over time and body height. To ensure compliance and provide a suitable margin, an action threshold of 50% (3 dB reduction) of the applicable MPE should be used. Any exposure levels exceeding 50% of the applicable MPE **shall** trigger predefined action procedures to restore such margin.

A.2.3.1 RF Modeling

RF Modeling is a theoretical (mathematical or computer-based) calculation that estimates RF energy or field strength levels with sufficient site-related information in lieu of or preceding actual testing. This process relies on understanding an antenna radiation pattern in free space and the potential impact of reflecting objects on the RF energy distribution around the antennas. Antenna emissions resemble ripples from a pebble dropped in water. Close to the antenna, the wavefront is highly curved; farther away, the curvature diminishes, and the wavefront appears planar, exhibiting plane-wave characteristics within observable limits. See Figure A-3.

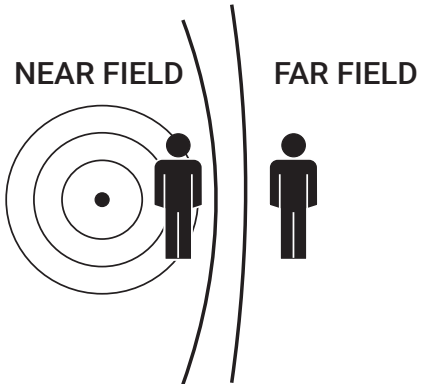


Figure A-3. RF Modeling

The region close to an antenna is known as the **near field**, where RF fields exhibit a complex spatial distribution. In this region, the spatially averaged RF power density decreases inversely with the distance (D) from the antenna. This is referred to as the 1/D region. The **far field** region is located farther from the antenna where the beam is fully formed and propagates more predictably. In this region, the power density diminishes proportionally to the inverse square of the distance from the antenna (**$1/D^2$**). The characteristics of far field RF signals are commonly used in coverage predictions and in estimating signal strength for mobile and/or portable receivers. From the standpoint of anticipating the power density to which a person will be exposed from an antenna, both the near and far fields must be understood. If RF levels are predicted very near an antenna based on the square of the distance using the far field formula shown later (spherical model, where the antenna is deemed a point source), the calculated levels increase faster than what really occurs near the antenna because its physical dimensions are neglected. There is a point called the crossover point where the two fields meet. Before this point the power density drops off with the inverse of the distance and after this point it follows an inverse squared relationship.

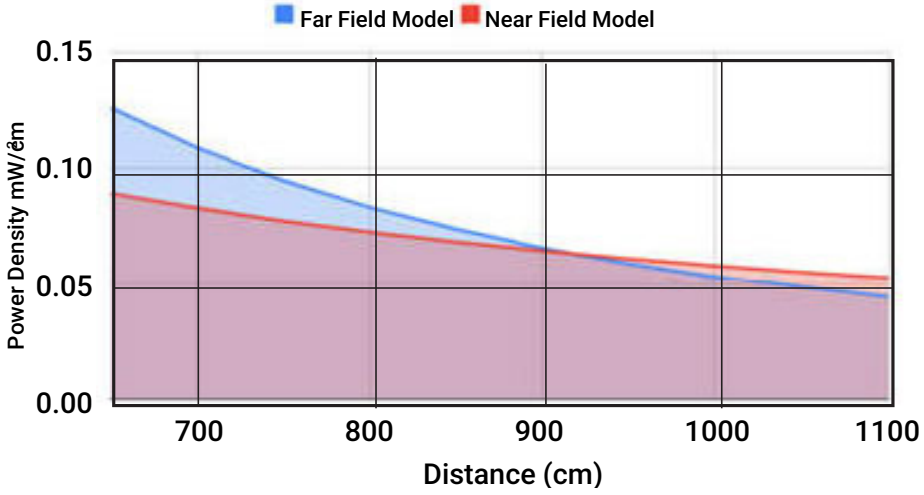
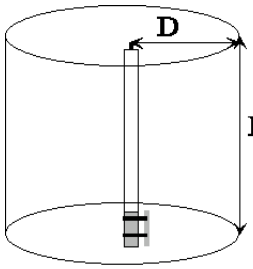


Figure A-4. Example of Near Field/Far Field Crossover

Figure A-4 illustrates the crossover for a 6 dBd gain omni antenna that is 2.74 m (9 ft) in length. As the aperture length and gain change, the crossover point will also change. For the example above, the crossover point is approximately 9.14 m (30 ft) from the radiating antenna. For an antenna with 10 dBd of gain and an aperture length of 3.96 m (13 ft), the crossover point will be over 30.5 m (100 ft). A 3 dBd gain antenna with an aperture length of 457 mm (1.5 ft) will have a crossover point of only 914 mm (3 ft).

A.2.3.1.1 Cylindrical Model

The Cylindrical Model estimates near-field spatially-averaged RF power density for vertical antennas with omnidirectional horizontal patterns. It assumes the antenna's radiated power is uniformly distributed across the surface of a cylinder surrounding it, with no emissions from the top or bottom cylinder surfaces. This model approximates the spatially-averaged RF power density for a person standing near the antenna. The calculation uses a cylindrical surface to represent the spatially-averaged near-field RF energy emission pattern (see Figure A-5). Doubling the value of S yields a conservative estimate of the spatial-peak RF power density.



$$S = \frac{P}{2\pi DL}$$

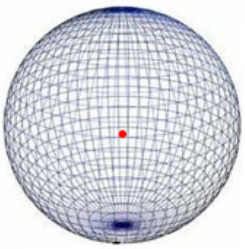
S = Power Density (mW/cm^2)
P = Total Power into Antenna (mW)
D = Distance from Antenna (cm)
L = Length of Antenna Aperture (cm)

Figure A-5. Cylindrical Model

Given a constant RF transmit power, shorter antennas result in higher near fields. Growing RF power increases the RF exposure at a given distance. The closer a person is to the antenna, the greater the corresponding RF exposure levels.

A.2.3.1.2 Spherical Model

In the far field, the antenna radiation pattern is fully formed and RF energy propagates more predictably. In this region, the power density diminishes proportionally to the inverse-square of the distance from the antenna (**1/D²**). Additionally, the RF power density increases or decreases proportionally with the gain of the antenna. For the spherical model, the antenna gain (G) is referenced to a hypothetical isotropic antenna, which is theoretically omnidirectional (emits uniformly in all directions). The following formula is used to calculate power density in the far field:



$$S = \frac{PG}{4\pi D^2}$$

S = Power Density (mW/cm^2)
P = Total Power into Antenna (mW)
G = Gain Ratio of Antenna relative to an Isotropic radiator
D= Distance from Antenna (cm)

Figure A-6. Spherical Model

A.2.4 EME Zoning

After determining the RF exposure levels at a site, an evaluation and classification should be conducted. This classification enables site managers to fully understand the site exposure levels and create procedures that ensure employee and contractor exposure remains below the applicable MPE limits.

A standard category and color-coding system **shall** be implemented at sites where EME levels may exceed the Occupational/Controlled Maximum Permissible Exposure (MPE). The use of floor marks or barriers to clearly delimit areas where public access is restricted **shall** also be used within sites housing RF transmitters and antennas. These category zones are marked by signage (see “Signage” on page A-19) and can be used to determine compliance requirements with the FCC guidelines recently updated via FCC 19-126 https://docs.fcc.gov/public/attachments/fcc-19-126a1.pdf and defined in FCC rules §1.1307(b)(1) https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-1/subpart-I/section-1.1307.

The four zones are described in the following subsections and graphically represented in Figure A-7 on page A-9.

A.2.4.1 Category 1 – Green Zone

Category 1 - Green zones, indicate the lowest EME levels at a site and are typically found in ground areas around towers, and other areas far from transmitting antennas. Category 1 - Green zone exposure levels are below the General Population/Uncontrolled environment MPE limits and allow for continuous exposure. Site design **must** prioritize the maintenance of these low levels. For high equipment-density sites, annual EME evaluations (or more frequently, if necessary as equipment is added or updated,) should be conducted to verify ongoing compliance.

Optionally a green “INFORMATION” sign may offer information to those persons who might be approaching RF sources, per FCC rules. Examples of signage are shown in “EME Action Thresholds Summary” on page A-23.

A.2.4.2 Category 2 - Blue Zone

Category 2 - Blue zones are areas where RF exposure levels exceed the General Population/Uncontrolled environment MPE limits, but are below the Occupational/Controlled MPE limits. This classification offers the highest level of Occupational RF safety, with no time limits and no specific EME safety practices required. Individuals working in these zones **shall** have basic EME awareness, which can be provided through signs, plaques, printed material, or awareness videos to ensure an understanding of the environment. Category 2 Blue zone signs and positive access controls, such as locked doors and gates, **shall** be in place to indicate public access is restricted. Examples of signage are shown in “EME Action Thresholds Summary” on page A-23.

Per FCC rules, under certain controlled conditions, such as on a rooftop with limited access, a sign attached directly to the surface of an antenna will be considered sufficient if the sign specifies a minimum approach distance and is readable at this separation distance and at locations required for compliance with the general population exposure limit.

Equipment rooms and areas around the base of towers **shall** maintain EME levels low enough to allow a Category 2 - Blue zone classification. Verification and certification of this low level may be required on some sites depending on regional or local regulations. If locations are discovered in excess of the limits to maintain Category 2 levels, changes and modifications must be incorporated to reduce EME levels as needed.

Some methods to maintain blue-zone levels are:

- Maintenance of RF transmitters, and ensuring all shields are installed and maintained correctly.
- Not allowing transmit antennas inside equipment rooms or near the ground level of sites.
- Proper use and installation of all RF transmission lines and connectors. When a waveguide carrying high RF power is used, verification of fitting integrity must be performed to ensure there is no RF leakage.

A.2.4.3 Category 3 – Yellow Zone

The yellow zone signifies an area where the spatially- averaged MPE exceeds the applicable Occupational/ Controlled MPE by no more than a factor of ten. Level 3 Yellow zones **shall** be clearly marked with “CAUTION” signage and positive access controls as required per FCC rules. Examples of signage are shown in “EME Action Thresholds Summary” on page A-23.

Positive access control includes locked doors, ladder cages, or effective fences, as well as enforced prohibition of public access to external surfaces of buildings, or generally, affirmative physical measures for preclusion of unauthorized access. It does not include natural barriers, which might limit access effectively in some, but not all cases, or other access restrictions that did not require any action on the part of the licensee or property management.

Individuals within yellow zones must maintain a high level of awareness regarding potential EME exposure. Personnel lacking EME awareness training **shall** not have access to yellow zones. Access for work in these areas is restricted to personnel with adequate knowledge of EME compliance procedures and documented awareness and RF exposure control training.

Per FCC rules, under certain controlled conditions, such as on a rooftop with limited access, a sign may be attached directly to the surface of an antenna within a controlled environment if it specifies the minimum approach distance and is readable at this distance and at locations required for compliance with the occupational exposure limit.

The use of personal RF exposure monitors, although not required, are valuable tools to ensuring safe exposure levels and compliance with FCC rules.

A.2.4.4 Category 4 – Orange/Red Zone

The Orange zone is any area where the spatial-averaged RF power density exceeds the Occupational/Controlled MPE limits by more than a factor of ten and/or in areas where the possibility of contact with radiating devices may cause serious injury. Level 4 Orange zones **shall** be clearly marked with "WARNING/DANGER" signage and positive access controls **shall** be implemented as required per FCC rules.

Per FCC rule, "WARNING" signs with the associated color (orange), controls, or indicators (e.g., chains, railings, contrasting paint, diagrams) are required (in addition to the positive access control established for Category Two) surrounding the area in which the occupational exposure limit in a controlled environment is exceeded by more than a factor of ten.

Per FCC rules, "DANGER" signs with the associated color (red) are required where immediate and serious injury will occur on contact irrespective of the RF power density levels, in addition to positive access control measures, regardless of mitigation actions taken in Categories 2 or 3.

Examples of signage are shown in "EME Action Thresholds Summary" on page A-23.

If locations are identified as red zones, special procedures, engineering considerations and/or restricted access must be implemented to ensure compliance. Some procedures that can be implemented are:

- Restrict access with appropriate "DANGER" signs and positive access controls
- Lock-out/Tag-out procedures for the maintenance of transmitters and antenna systems
- Changes of antenna types used in site design
- Procedures to reduce transmitter(s) RF power
- Use of appropriate EME PPE (discussed in "Personal Protective Equipment (PPE)" on page A-22).

IMPORTANT: RF safety awareness and control training is critically important to ensure personnel are aware of the potential for EME overexposure and know how to mitigate exposure.

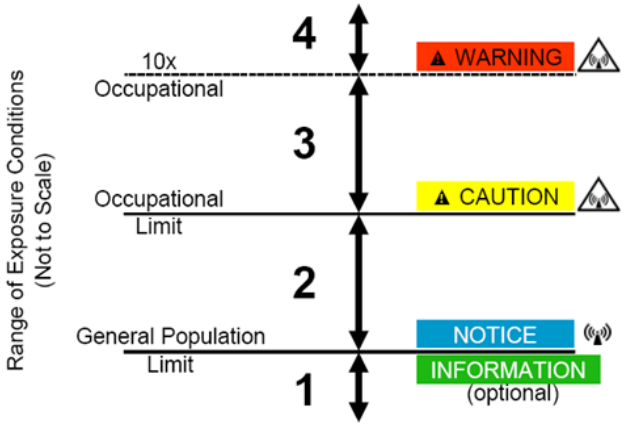


Figure A-7. FCC Graphical Representation of Exposure Level

A.2.5 Characterization Zoning

RF energy exposure is determined by the duration and strength of the electromagnetic field. RF site characteristics largely dictate the potential for EME exposure. Understanding these characteristics is crucial for identifying, predicting and preventing exposure levels that surpass FCC guidelines. This knowledge enables site managers to implement appropriate procedures for personnel working in these areas.

A.2.5.1 Buildings

In dense metropolitan areas, communication sites are typically located on some of the tallest buildings in the area. These sites benefit from the inherent height, negating the need for long antenna feedlines. The closer proximity of the radio transmitters to the antennas minimizes power loss, maximizing the energy radiated. While this enhances coverage, it can potentially elevate EME levels around the antennas. These sites may also have a dense cluster of antennas, and antennas with many transmitters attached. These factors and other key factors like, the frequency band, antenna input power, and aperture height, will influence EME levels.

Most building-mounted antennas, metropolitan or otherwise, are generally positioned on rooftops in a grid-like arrangement. They are often secured to pipe structures with separations as little as 914 mm (3 ft), maximizing antenna density but potentially restricting space for maintenance personnel. Workers performing tasks such as antenna replacement, cable repair, or other general maintenance tasks, may be exposed to elevated RF energy from nearby antennas. Implementing sound safety practices is crucial to prevent such high exposure scenarios. Reducing overall EME exposure levels on a building is the optimal approach to ensuring compliance and minimizing potential hazards.

A.2.5.2 Towers

Antenna supporting structures, or towers, are found in diverse environments, from urban centers to remote rural areas. Their primary function is to elevate antennas to achieve the desired coverage area, with heights ranging from 30.5 m (100 ft) to 610 m (2000 ft). Despite variations in height, the fundamental EME characteristics of these towers are determined by the applications of the antennas they support.

Cellular towers typically employ directional antennas mounted on one or more sides toward respective coverage sectors. Each side can accommodate multiple directional antennas, either side-by-side or stacked vertically. In contrast, Land Mobile Radio (LMR) towers typically feature one or more omnidirectional antennas covering designated LMR bands and highly directional dish antennas for line-of-sight backhaul connectivity.

Cellular configurations generally have a lower risk to Electromagnetic Energy (EME) exposure for tower workers compared to LMR two-way configurations. This is because the RF emissions from cellular directional antennas are directed away from the tower, yielding a significant power density difference between the front and back of the antenna, known as the front-to-back ratio. While this ratio can be substantial (up to 25 dB) in the far field, it is less pronounced in the near field, close to the antenna. Indeed, workers behind the antenna in the near field still experience reduced exposure compared to those in front.

LMR two-way towers require significantly different considerations. As a tower crew ascends these towers, they may encounter numerous antenna mounts at various heights. These mounts can house diverse transmitters, ranging from low-power paging transmitters to high-power transmitters in the 35 MHz frequency range. Although antenna types and mounting arrangements can vary significantly, EME levels may, in close proximity, approach or exceed FCC exposure guidelines. Most LMR two-way antennas are typically omnidirectional with aperture lengths ranging from 1.2 m to 4.6 m (4 to 15 ft), and are usually mounted 1.2 m to 3.6 m (4 to 12 ft) away from the tower structure. The strongest fields are found directly adjacent to the antenna aperture. Therefore, workers **shall** exercise caution and avoid working or stopping directly in front of these antennas unless the transmitters are deactivated (positive confirmation of the deactivation **shall** be ensured). If multiple antennas are grouped at the same level, deactivation of multiple transmitters may be necessary.

The transmitter's duty cycle is another crucial factor to consider regarding EME levels when working at or near antenna systems on towers. Duty cycle considerations will be discussed later.

Star cluster and candelabra mounts present a significant challenge for EME management on towers where five to eight antennas are arranged in a circle each approximately 1.5 m (5 ft) from the tower, as the EME levels in the central area may exceed MPE limits. As this central area is the tower itself, workers must be aware of the field conditions before entering. Personal EME monitors, discussed later, can aid in estimating present EME levels as personnel come near antennas.

Figure A-8 illustrates the modeled EME effects of five PD-10017 antennas transmitting at 100 Watts in the 900 MHz band. Each pixel represents 929 cm^2 (1 sq. ft). Figure A-8 also shows the pattern as if only four, or three, or two of the antennas are transmitting. Workers entering such an area may be exposed at levels exceeding applicable MPE limits and **shall** take appropriate precautions, such as moving quickly through the area, to ensure compliance with recognized exposure guidelines. The overlapping and additive nature of the exposures from multiple antennas in this configuration complicates EME compliance management.

In summary, candelabra and star mounts present unique compliance and maintenance considerations due to the additive EME exposures as the result of the cluster of antennas.

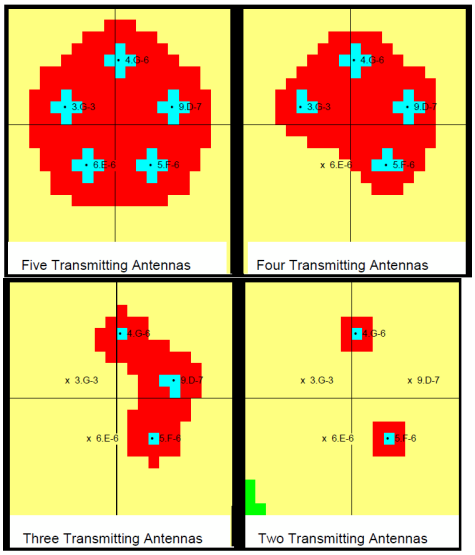


Figure A-8. EME Zone Map of a Tower-Mounted Star Cluster or Candelabra Mount (Resolution 1 sq. ft)

A.3 Engineering Considerations

A.3.1 Antenna Elevation

Elevating antennas above rooftops is a common and effective method for decreasing RF levels at roof level. This technique increases the distance between the antenna and individuals on the roof, thus reducing their exposure levels.

Figure A-9 illustrates the effect of antenna elevation based on data from an 850 MHz Specialized Mobile Radio (SMR) antenna powered by ten 150-watt transmitters through a combiner, resulting in a 550-watt input to a 3.96 m (13 ft) omnidirectional antenna. A similar configuration is not uncommon on many rooftop installations.

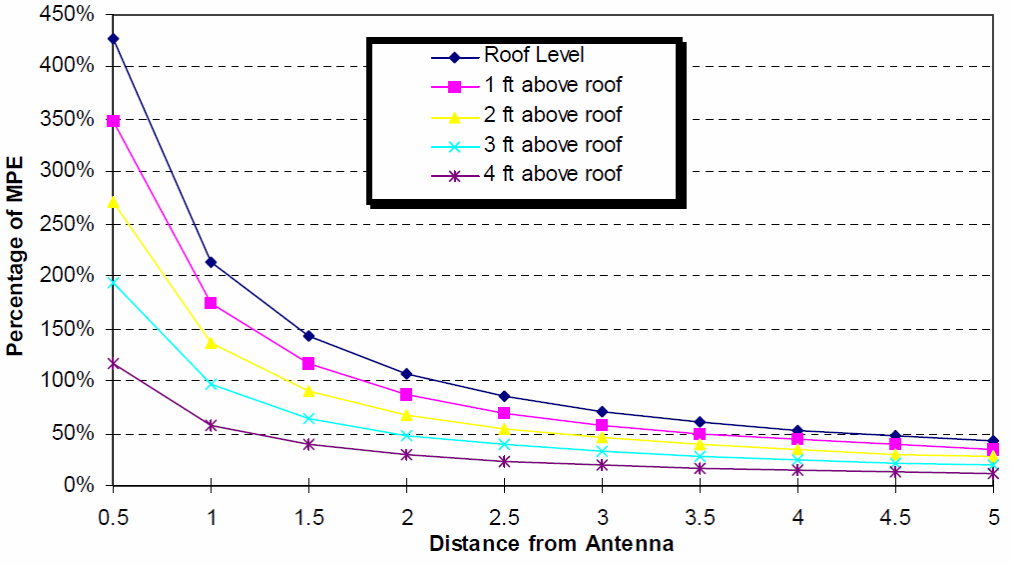


Figure A-9. Exposure vs. Antenna Height Above Roof

Where such an antenna is mounted at roof level, RF exposure may potentially exceed the MPE limits. Measurements indicate fields exceeding 200% of the Occupational/Controlled MPE within 305 mm (1 ft) of the antenna. Although a technician walking through an antenna grid with 1.8 m (6 ft) spacing would maintain approximately a minimum distance of 610 mm (2 ft) from any antenna, exposure levels at this distance from a roof-mounted antenna can still surpass 100% of the MPE. The presence of multiple antennas with similar power densities can compound this issue, potentially leading to excessive MPE in common walking areas. Therefore, minimizing RF fields at roof level is crucial.

The most efficient strategy for reducing these fields on a building, without compromising radio coverage, is to raise the antenna. Elevating an antenna by 1.2 m (4 ft) above the roof can decrease the EME field strength at roof level to approximately 50% of the MPE at the original 305 mm (1 ft) distance. Further increasing the elevation to 1.8 m (6 ft) can achieve a field reduction of over 90%. Each case will be different, requiring a site-specific analysis.

A.3.2 Extending Antennas Away From Towers

Tower climbers may be exposed to high levels of RF energy from active antennas, especially those mounted on short sidearms or directly on the tower. To minimize RF exposure, a good engineering practice is to mount omnidirectional antennas at least 1.52 m (5 ft) away from the tower structure. This frequently ensures that technicians passing through antenna fields during climbs are subject to lower exposure levels.

A.3.3 Co-Located Broadcast Transmitters

Commercial broadcasting transmitter sites (Radio, TV), whether standalone, co-located, or adjacent with two-way transmitter sites, generate EME fields that must be taken into consideration when evaluating a site for compliance. Commercial broadcast station transmitters can have power outputs ranging from 1000 W to beyond 250,000 W, thus creating greater opportunities to exceed FCC RF exposure guidelines. Standalone broadcast sites primarily require consideration of fields from antenna grating lobes or the main radiating beam. Co-located and adjacent sites involve a combination of fields from both broadcast and two-way transmitters. Evaluating each source independently and summing their contributions in terms of respective exposure ratios (RF exposure level divided by the applicable MPE limit) allows for the assessment of the total exposure ratio, hence the MPE compliance.

Broadcast transmitter fields often create a widespread ambient level across the area due to the unique radiation patterns of their antennas. Taking this into account, if a pre-existing broadcast station contributes, for example, 15% of the Occupational/Controlled MPE, the remaining MPE budget for LMR transmitters is reduced to 85%, potentially requiring to lower transmit RF power levels for compliance. In areas exposed to grating lobes from broadcast antennas, precise measurements are essential for accurate compliance analysis.

Special attention is necessary for personnel working on antenna systems at sites co-located or adjacent to broadcasting sites. Where climbing into broadcast antenna fields (co-located or adjacent), transmitter power reduction through pre-coordination with the licensee **shall** be obtained. Extra caution and consideration **shall** be made when climbing through areas exceeding the Occupational/Controlled MPE limits, allowing such levels for brief durations considering the FCC-mandated 6-minute MPE time averaging. Coordinated maintenance activities are crucial in co-located and adjacent scenarios. While the FCC mandates broadcaster cooperation during maintenance, they retain the right to schedule maintenance at specific times. Cooperation between broadcasters and LMR licensees might be necessary to ensure overall site compliance in certain situations.

In the rare occasion where work is being performed at or near an AM broadcast site, it is important to remember the tower is the actual antenna! AM towers can be identified as having several specifically spaced insulators on guy wires and a ceramic insulator at the bottom of the tower separating it from the base. These towers are electrically charged by the transmitter, so great care **shall** be taken to not come in contact with the structure. While AM broadcast radio is low frequency (600 kHz - 1710 kHz), transmit power may be as high or higher as that of an FM broadcast station. The AM radio low frequency allows for a closer proximity while maintaining compliant exposure levels. However, the AM radio RF exposure **shall** be taken into consideration when evaluating an adjacent site.

A.3.4 Location of Directional Antennas

Directional antennas create a focused beam on the horizontal or vertical plane (or both) for optimal coverage in a specific direction. This directional beam may be narrow, like a Yagi antenna with a beamwidth as little as 10 degrees, or somewhat wide, like a panel antenna with a beamwidth of 180 degrees. Within this focused beam, especially at close range, energy levels can be considerably greater than levels to the sides or behind the antenna.

Careful attention must be paid to the antenna directional orientation and the area it aims at. High-power directional transmitting antennas should be positioned so that RF energy levels exceeding Occupational/Controlled MPE limits occur over directions pointing away from regularly accessed worker areas. Furthermore, these antennas **shall** not be installed in a way that results in General Population/Uncontrolled MPE limits being exceeded in nearby residential and/or other public areas.

A.3.5 Antenna Selection

Antenna selection is crucial due to its direct impact on RF exposure levels. Factors such as antenna gain, power handling capabilities and beamwidth (omnidirectional, Yagi, or panel style), can all impact EME levels at sites. Understanding the needs for coverage and weighing in potential RF exposure levels in frequently accessed or public areas, must be taken into consideration for antenna selection. RF exposure modeling of a site may help optimizing antenna selection and placement.

The need for more antennas within limited horizontal space has led to many innovative antenna designs. Among them are antennas that appear to be a single unit but are actually multiple antennas in one. These antennas typically come in two (double), three (triple), or four (quad) collinear arrays housed within a single radome or exposed dipole design. This allows distinct services, such as paging, digital networks, LMR, etc., to share a single antenna in the same band without the need for a combiner. Since the power density emissions from each antenna array combine, potential EME exposure levels may be higher than usual. As tower space continues to come at a premium, these antennas have become popular due to their space-saving nature. Section A.3.6 adds further details.

Another item to consider is the aperture length of an antenna, as it significantly influences RF power density. For instance, a 4.6 m (15 ft) antenna powered at 500 Watts generates about one-third the spatially-averaged power density in the near field compared to a 1.52 m (5 ft) antenna (using the cylindrical model, a cylinder with one-third the height will have one-third the lateral surface area for a given distance, resulting in a potential threefold increase in power density flow across the lateral surface.

Complexity is amplified as varying aperture lengths, gains, antenna input RF powers and beamwidths all complicate evaluating for the potential exposure levels. As an example, a 1.52 m (5 ft) antenna may house two or three (or four) antennas within a shared radome or exposed dipole configuration. In this example, all antennas in the configuration have power densities that combine and must be accounted for when evaluating exposure levels.

A.3.6 Mounting Density of Antennas

Even if the RF emissions from a single antenna are within the FCC guidelines for Maximum Permissible Exposure (MPE) limits, the combined emissions from multiple antennas can surpass the Occupational/Controlled MPE. Figure A-10 and Figure A-11 illustrate the RF fields generated by a single antenna versus the combined fields produced by five antennas installed at roof level when all transmitters are operating concurrently at the respective maximum-rated transmit RF powers.

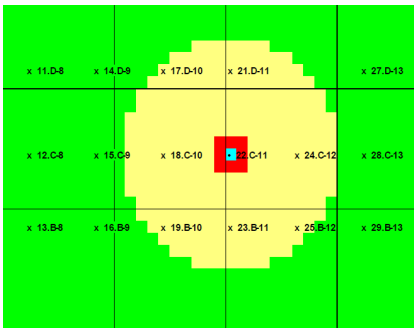


Figure A-10. Composite RF Fields with One Antenna Transmitting

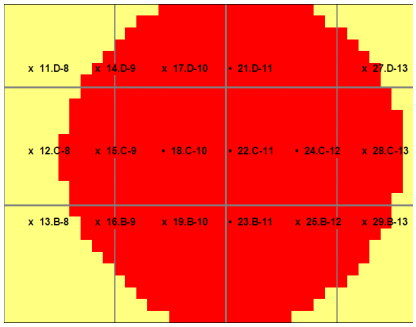


Figure A-11. Composite RF Fields with Five Antennas Transmitting

Figure A-11 illustrates that the combined fields generate levels exceeding the permissible Occupational/Controlled MPE in wide areas around the antennas. In such instances, exposure control is necessary. Potential methods include RF protective clothing, antenna system re-engineering, re-evaluating antenna placement, or power shutdown/reduction during work in the vicinity. Although power shutdown or reduction might seem effective, it could be impractical for wireless communication services and is typically used only for broadcast transmitters. Elevating the antennas above the roof is a favored solution to comply with the Occupational/Controlled MPE levels.

A.3.7 Uptime

Complex antenna sites feature unique characteristics influenced by transmit RF power requirements, frequencies in use, manufacturer of the equipment, equipment specifications, installation techniques, and operational usage. While peak EME levels can be determined from the transmit frequencies and the type of equipment (maximum-rated transmit RF power, cables, combiners, antennas) in use, temporal operational and usage characteristics require monitoring for quantification.

Paging transmitters may exhibit high duty cycles due to numerous pagers. In LMR trunking systems, transmitter activity may fluctuate considerably based on the number of users, agencies, and active incidents. These fluctuations may range from infrequent to almost constant transmissions. Private customer equipment, such as amateur radio or commercial entities, usage can be diverse and unpredictable. The varying characteristics of complex sites supporting these and other different types of services, make predicting actual EME levels generally difficult and potentially unreliable.

Transmitter characteristics may also vary due to cultural and or geographical factors. Sites in Las Vegas, NV may differ significantly from those in San Antonio, TX or New York City, NY. Additionally, site surveys reveal substantial variations in transmitter activity across different time periods where one may see a 30% or more difference in usage between 11:00 a.m. and 2:00 p.m. as compared to 11:00 p.m. and 2:00 a.m.

Uptime, which encompasses all transmitter activity, directly impacts actual RF exposure levels. Calculating uptime reliably can be complex since transmitter usage can change over time. Therefore, uptime cannot be theoretically calculated; it demands measurement through high-speed frequency scanning over extended periods. Thousands of observations across days may be needed to quantify worst-case, average, and instantaneous uptime. This uncertainty makes the practical calculation of uptime inadvisable when assessing EME levels at a site.

Although 100% uptime represents the upper limit of all transmitters being energized, actual usage, while most accurate, is impractical to implement due to its variability over time and the number of antennas in use. Each antenna uptime characteristic depends on combining density, transmitter usage, and activity. While understanding uptime could improve prediction accuracy, its determination is complex and unreliable.

Calculating EME levels using 100% uptime is the most practical approach in evaluating complex communications sites in determining the potential for EME levels to exceed applicable Occupational/Controlled MPE limits.

A.3.8 Antenna Site Documentation

Accurate antenna site evaluations depend on accurate data being utilized. Antenna site documentation is crucial and **shall** be performed in a standardized manner. Two standard documentation methods exist for analyzing EME fields at communications sites. One method offers greater precision but requires more time and effort to evaluate. The second is simpler to implement as it uses a worst-case scenario analysis. Both methods enable engineers to understand the EME environment and implement necessary compliance procedures. Both documentation methods are described in more detail in the following sections.

A.3.8.1 Actual Documentation

The “actual documentation” method offers an accurate picture of the communications site's conditions and equipment in use. Engineers can utilize this documentation method for applications beyond EME analysis, such as planning for site expansions or other site modifications. The “actual documentation” approach necessitates a comprehensive account of transmitters, cables, combiners, duplexers, antennas, and their placements on the tower. In particular, the following details are necessary:

- Transmitter frequencies in use at the site
- Power output of all transmitters
- RF Distribution System (RFDS) loss between transmitter(s) and antenna(s)
- Antenna characteristics and specifications (Aperture, Gain, Pattern)
- Antenna location(s), height, and standoff distances on the tower
- Layout of antenna field (roof or tower)
- Frequencies in use per antenna and/or antenna array
- Uptime characteristics of each service in use per antenna
- Areas frequented by personnel

A.3.8.2 Categorization Documentation

IMPORTANT: Maintaining an inventory of all RF energy sources and their potential EME exposure is essential for understanding the EME environment at any communication site. This necessitates the use of standardized documentation procedures and their routine updates for all communications sites.

Determining the specific coaxial connections between transmitters and antennas at a site can be costly, time consuming, and often unnecessary. The “categorization documentation” method typically identifies the lowest loss coax and highest-powered transmitter for each frequency band in use at the communications site. For compliance calculation purposes, it is then assumed this combination of lowest loss coax and highest-powered transmitter, is used for all antennas in that band. By knowing the frequency bands, spacing, height, and characteristics of all antennas on the tower, a worst-case EME scenario can be approximated. If this conservative assessment indicates compliance, the actual configuration will also be compliant. This worst-case evaluation helps determine if a more detailed analysis is needed. This EME analysis method requires a trained site auditor to identify only the components relevant to EME compliance.

This procedure provides an overestimation of the actual RF exposure levels rather than precise levels, but has the advantage of being simpler to execute and can identify sites needing further investigation with the more detailed “actual documentation” approach.

A.4 Work Practices

Effective management, control, and operation of a communications site are crucial for its quality. All stakeholders invested in the site depend on continuous service. The standards imposed on contractors, customers, and employees are the determining factors in maintaining overall site quality and reliability.

A.4.1 Training and Qualification Verification

The verification of contractor qualifications and training is a critical aspect of maintaining safety and site quality. All contractors **shall** possess a fundamental understanding of EME awareness and demonstrate knowledge of communications site standards. As specialists in their respective fields, contractors are expected to remain fully informed of evolving governmental regulations. Continuous training is essential for contractors to maintain awareness of changes in hardware, technology, and relevant industry and government regulations.

A.4.2 Physical Access Control

Communications sites require physical access control, at a minimum, consisting of locked gates to control vehicle access and locked facilities to prevent access by unauthorized individuals. Towers **shall** have specific access control measures in addition to site access restrictions, ensuring that site access does not automatically grant tower access. Prevention of unauthorized tower climbing **shall** be achieved through fencing, climb prevention devices on the tower itself, or locking barriers. This is crucial to ensure anyone climbing understands the EME conditions, is demonstrably qualified, and carries the necessary safety equipment. Where suitable, card access systems or smart key access systems should be implemented to maintain a log of site traffic, including details of individuals entering and leaving.

A.4.3 Policing

Communications site administration policies and procedures must be enforced for compliance. All technicians and contractors **shall** understand, comply with, and support site policies and procedures. Policy violations **shall** result in contractor disqualification. Working at communications sites is a privilege, and adherence to all policies is mandatory, without exception.

A.4.4 Chain of Authority and Reporting Requirements

Each facility should maintain a site book or folder that details all site-specific policies and procedures, FCC authorizations, FAA Antenna Structure Registration (ASR) information, site owner contacts, including an emergency contact list, and incident notification protocols. Any special situations, local arrangements, or other special information unique to the site should also be documented within this site book.

A.4.5 Understanding Site Responsibilities Under Shared Conditions

Situations often arise where site occupancy and management may involve several external agencies or entities. This includes scenarios where a site is situated on a shared building rooftop, co-located with commercial broadcasting companies or other agencies, or sites located on a shared hilltop. In such instances, these third-party entities may make decisions impacting site safety and operations. A concerted effort must be made to create policies and procedures agreed upon and enforced by all involved parties. These policies and procedures protect the safety of contractors and employees as well as maintain system uptime integrity of all agencies or entities. Coordinating control measures **shall** be implemented to ensure safe tower and equipment maintenance. In cases involving other third-party transmitters, power reduction, lockout/tagout protocols, or restricted maintenance windows may be necessary to maintain compliant EME exposure levels during such maintenance tasks.

A.4.6 General Procedures

General procedures relate to normal practices that are common to all sites. Industry accepted procedures are detailed below and may be found posted at RF sites on a yellow placard labeled “Guidelines for working in radio frequency environments.” An example of the placard is shown in “Signage” on page A-19.

- All personnel **shall** have Electromagnetic Energy (EME) awareness and control training.
  - All workers entering a RF controlled area **shall** understand their potential exposure and steps they can take to reduce their EME exposure. Awareness is a requirement of all workers. This includes not only field engineers, maintenance technicians and site designers, but also others such as site acquisition personnel, building management and service oriented personnel (such as electrical, telephone, elevator and air conditioning mechanics as well as roof repair, painting and window washing crews).
  - Posted signage at entry points (e.g., roof doors) indicates a controlled environment but does not constitute RF exposure awareness and control training. Personnel must receive formal training prior to independent access.
  - The FCC OET Bulletin 65 specifically indicates the requirement to make personnel at a transmitter site “fully aware” of their risk of exposure. Awareness training increases worker sensitivity to potential exposure, thereby assisting proper compliance regarding exposure limits. Awareness training may be given in different formats, such as video, formal classroom, documentation, and/or informal discussions.
- All personnel entering this site must be authorized.
  - Access to the site without an escort is restricted to trained personnel who fully comprehend the EME conditions and all other site-specific safety regulations. Untrained individuals **shall** be accompanied by a trained escort when accessing the site.
- Obey all posted signs.
  - It is crucial to observe and understand all instructions on posted signs at transmitter sites. These safety signs are vital to any safety program, conveying specific messages for safe work in a particular environment. Transmitter site postings are no exception; for instance, some areas may be designated “NO ACCESS” unless specific antennas are shut down.
  - To ensure EME exposure remains below FCC guidelines, understanding and obeying these signs is crucial. Signs designating areas of potential exposure exceeding FCC limits may also identify the requirement for RF personal protective equipment (PPE), such as clothing and/or personal monitors, for workers as an additional precaution
- Assume all antennas are active.
  - As most telecommunications transmissions are intermittent, the status of many transmitters that may be operating at a given site will be unknown. It is crucial to assume that all antennas may be energized and to maintain a safe working distance from each.

  - Detecting the presence of RF energy from a particular antenna at any given moment requires special instruments. While EME measurement surveys may have been performed on the site, these surveys do not assure that a specific antenna is not active at a given time.
- Before working on antennas, notify owners and disable appropriate transmitters.
  - Before working on an antenna, all attached transmitters must be deactivated. Most antennas at a transmitter site are critical for operational and/or mission-critical communications, such as fire, police or emergency services. Regardless of transmitter status, appropriate contact **shall** be made with the owners or operators before attempting any work on an antenna.
  - To prevent service disruption, coordinate with those responsible for the transmitter before turning off equipment. This may require performing work at night or in the early morning. Use Lockout/Tagout tags to prevent accidental activation of the transmitter while antenna work is in progress.
- Maintain minimum 914 mm (3 ft) clearance from all antennas.
  - Studies show that the EME fields close to two-way radio transmitting antennas may be strong enough to exceed the limits specified by the FCC guidelines. A 914 mm (3 ft) clearance is a practical approach to assure that exposure remains within FCC limits unless work is required on an antenna.
  - Work on a **specific** antenna **shall only** be performed after the attached transmitter(s) have been turned off. Maintaining a minimum distance from other potentially active antenna must be considered when working in environments with multiple active antennas. Even a small increase in distance from an antenna can have a substantial effect on reducing the EME exposure. This also applies when working on roof- or tower-mounted equipment like air conditioners, tower lights, or window washing rigs.
- Do not stop in front of antennas.
  - Workers at a rooftop transmitter **shall** avoid stopping near any antenna and continue moving until they are clear of the immediate vicinity. For breaks or lunch, they should choose a location on the roof that maximizes their distance from the nearest antennas.
  - When climbing a tower, workers should choose rest areas that are not in the immediate vicinity of antennas. To reduce exposure to the antenna's main beam, workers should strive to stay below or above omni-directional antennas and behind directional or panel antennas. Continuous movement through high EME fields will help minimize time averaged exposure levels.
- Use personal RF monitors while working near antennas.
  - EME fields are generally undetectable by human senses. Therefore, special care is necessary when working near antennas to prevent overexposure. Personal RF monitors can identify transmitter activity in close proximity to an antenna and alert the wearer when levels exceed set EME values and/or time weighted averages.
  - Wearing a monitor allows workers to confirm that all connected transmitters are off before starting maintenance. If the monitor alarms as they approach an antenna, they **shall** move away from the antenna, identify which transmitters are still active, and disable them.
- Never operate transmitters without shields during normal operation
  - When performing service at antenna sites, technicians may need to troubleshoot and repair radio transmitters. Transmitter power amplifiers include shields designed to contain strong RF fields within the transmitter cabinet. Operating a transmitter without these shields may lead to interference and expose technicians to EME levels exceeding FCC guidelines.
  - While shields must be removed for many maintenance tasks, they **shall** always be properly reinstalled before returning the transmitter to normal operation.
- Do not operate base station antennas in equipment room.
  - Transmitting antennas **shall not** be operated inside shelters, equipment rooms, dispatch centers or false ceilings. This restriction also applies to short-term testing, including temporary installations such as mobile magnet-mount antennas attached to the top of transmitter cabinets or ceiling grids.
  - Using transmit antennas inside shelters, equipment rooms, dispatch centers or false ceilings, may increase EME exposure levels above FCC guidelines and generate undesirable radio frequency interference.

A.4.7 Site-Specific Procedures

To ensure compliance with FCC Guidelines, site-specific procedures that may be unique to a particular site need to be documented and made readily available. These can include:

- Special access and security requirements such as point of contact notifications, badge access, escort requirements, etc.
- Awareness of potential high EME exposure conditions at specific locations
- Special maintenance procedures for antenna and/or equipment repair
- Maintenance procedures unique to the physical site
- Special reporting procedures related to other tenants and owners
- Emergency contacts and incident reporting procedures

A.4.8 Operating Procedures

The antenna site manager is responsible for the control and coordination of all technicians and contractors (personnel). This includes both customer-controlled personnel and those directly contracted with management. All personnel **shall** adhere to specific site procedures for safe operations during the installation and maintenance of antenna systems. These site procedures take precedence over any accepted personnel practices or standards, and all personnel are required to follow them.

A.5 Signage

Various RF/EME signs may be required at or near antenna sites. The minimum requirement is to post an EME notice and/or caution signs, as appropriate, wherever EME levels can exceed those associated with a level 1 green zone as defined earlier. Sign(s) **shall** be posted in a location clearly readable from at least 1.52 m (5 ft) from the boundary where the applicable exposure limits are exceeded. These areas may include street pole antennas, rooftops, towers, areas surrounding broadcast equipment, etc. This ensures individuals approaching and entering these areas are aware of active RF transmitters and/or antennas. All signage **shall** conform to ANSI symbol and color standards and FCC rules for exposure mitigation.

Signs offer a convenient way to convey crucial information to personnel and bystanders. While effective where used correctly, improper use can lead to misinterpretation and unnecessary alarm. Therefore, specific signs are recommended for particular applications, representing the most effective method for communicating important information.

Signs are created using the following standards:

Signal word and associated color: Designates the degree of safety alerting, such as DANGER (red) WARNING (orange), CAUTION (yellow) and NOTICE (blue).

RF energy advisory symbol: The advisory symbol for identifying incident EME consists of black wavefronts radiating from a stylized point source. This symbol is defined in IEEE C95.2 and ANSI Z535.3-2022.

Text Message: The text message **shall** convey the following three items per FCC rules:

- An explanation of the RF source
- Behavior necessary to comply with the exposure limits
- Up-to-date contact information

This section provides guidelines for appropriately posting signs to designate potential EME exposure at sites. Improper implementation could result in inaccurate information being conveyed or unnecessary alarm being created. Examples shown are signs that have been implemented in the United States.

A.5.1 CAUTION Sign for Equipment Rooms

For interior rooms containing RF generating equipment, such as, RF transmitters, computers, filters, combiners, and cables, guidelines **shall** be prominently displayed within the equipment room to ensure all personnel are aware of the operational requirements and to help maintain site compliance.

This sign may also qualify as awareness and control training. Figure A-12 is an example.

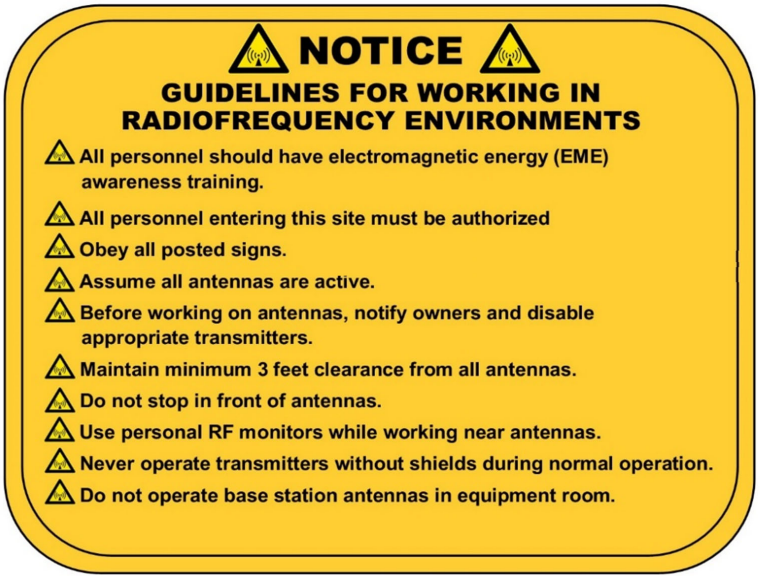


Figure A-12. Site Guidelines Placard Example

A.5.2 Category 2 - NOTICE Sign

A Category - 2 NOTICE sign **shall** be used to delineate the boundary between General Population/Uncontrolled and Occupational/Controlled areas restricted by a barrier, typically at the property fence, gate entrance, equipment room, or roof door. EME levels in these areas must remain below the Occupational/Controlled Maximum Permissible Exposure (MPE). Sites must have standard, mandatory guidelines for workers to ensure the area stays below Occupational/Controlled MPE. EME awareness training is required for all personnel per FCC rules.

The NOTICE sign uses blue in the signal word area. See Figure A-13 for an example.



Figure A-13. Category 2 NOTICE Sign Example

A.5.3 Category 3 –CAUTION Sign

The category 3 - CAUTION sign **shall** be posted to identify controlled areas where RF exposure may exceed the Occupational/Controlled MPE by no more than a factor of ten.

Controls, or indicators (such as chains, railings, contrasting paint, and diagrams) **shall** be required (in addition to the positive access control established for Category 2) surrounding the area in which the exposure limit for Occupational/ Controlled environments may be exceeded.

Mitigation by use of the six-minute time averaging is required for personnel in the area. Other site-specific guidelines may require reduction of RF transmit power before work begins or the use of RF protective (PPE) clothing. Workers **shall not** enter and work in these areas without understanding and obeying the necessary procedures, including posted signs and site guidelines.

All authorized personnel for RF controlled areas **shall** have EME awareness and control training.

The CAUTION sign uses yellow in the signal word area. See Figure A-14 for an example.



Figure A-14. Category 3 CAUTION Sign Example

A.5.4 Category 4 – WARNING/DANGER Signs

The category 4 - WARNING sign identifies controlled areas where RF exposure may exceed the Occupational/ Controlled MPE by more than a factor of ten. Controls, or indicators (such as chains, railings, contrasting paint, and diagrams) are required, in addition to the positive access control established for Category 2, surrounding the area in which the exposure limit for Occupational/Controlled environments is exceeded.

The WARNING sign uses orange in the signal word area.

The category 4 DANGER signs are required where immediate and serious injury will occur on contact (such as an AM broadcast tower), in addition to positive access controls, regardless of other mitigation in place.

Telecommunication contractors and employees **shall not** enter these areas unless special, site-specific procedures are followed. These situations typically are associated with broadcast transmitters operating at high power. If work is required in these areas, the broadcast transmitter **shall** be shut down for the duration of the maintenance and lockout/tagout procedures **shall** be followed per FCC rules.

Engineering evaluation must be performed to determine the special, site-specific procedures, controls and indicators that are required before this area can be entered.

The DANGER sign uses red in the signal word area.

See Figure A-15 for examples of Category 4 – WARNING and DANGER signs.

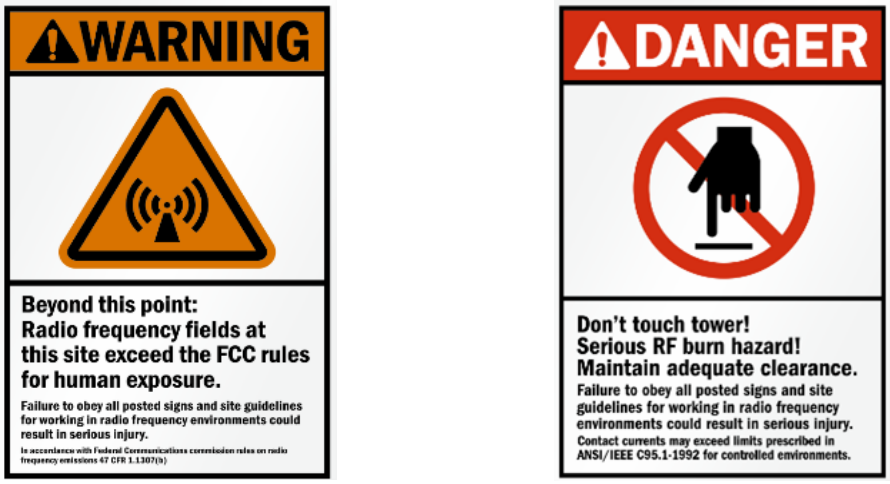


Figure A-15. Category 4 – Warning and Danger Sign Examples

A.6 Personal Protective Equipment (PPE)

A.6.1 Protective Clothing

Should field analysis reveal non-compliant areas with respect to Occupational/Controlled MPE limits, and engineering or work practice solutions prove insufficient to mitigate exposure levels, RF Personal Protective Equipment (PPE) may be the only solution.

FCC OET bulletin 65[1] states *"In general, the use of RF protective clothing may be considered an acceptable mitigation technique for occupational exposures as long as sufficient precautions are taken to comply with all of the clothing manufacturer's recommendations and caveats and to ensure that use of the clothing is confined to RF environments for which it is designed in terms of RF field intensity and frequency range. As with any personal protective equipment, RF protective clothing should be considered as a method of choice only when other engineering or administrative controls cannot be used to reduce exposure or are otherwise impractical."*

Specific OSHA guidance (https://www.osha.gov/laws-regs/standardinterpretations/1993-04-14-2) further notes *"To provide full-body protection, components of the RFR Protective gear must include a full integrated hood, overshoes, and gloves. It is recognized that worker acceptance of fully encapsulating protective clothing will require training and diligent supervision. However, omission of these accessories should only be permitted with substantiating data that ensures compliance with recognized limits for both SAR and Partial Body exposures. Summarily, assuming the above criteria are met, it is our position that RFR Protective clothing can be a valuable addition to existing safety measures for a variety of practical applications, such as FM radio, Television, and microwave tower maintenance, when used within prescribed field parameters."*

For instance, a rooftop with co-located broadcast antennas and/or a heavily congested antenna field might present such a scenario where traditional means of EME exposure mitigation may not be practical. Contractors **shall** be notified if RF protective clothing is mandated for exposure level compliance.

1. FCC OET bulletin 65. (1997). *Evaluating Compliance With FCC Guidelines for Human Exposure to Radio frequency Electromagnetic Fields.* https://www.fcc.gov/general/oet-bulletins-line#65

A.6.2 Personal Monitors

Maintenance on specific antennas **shall** only be performed after the appropriate transmitter(s) have been turned off and lockout/tagout procedures are in place. This prevents accidental activation of the transmitter(s) during maintenance activities.

However, with numerous transmitters often combined into a single antenna, positive confirmation of the deactivation of all transmitters can be challenging. A practical approach to ensure transmitters are off/deactivated involves the use of a personal RF EME monitor. Personal RF EME monitors employ an RF threshold detector that alarms when RF exceeds the set threshold of the device (typically 50% of the Occupational/Controlled MPE limits). These devices are designed to detect a wide range of frequencies and can be used in most environments. Many include data logging and voice logging for later use and documentation.

When approaching an antenna that requires maintenance, the monitor **shall** be placed near the antenna for approximately 30 seconds. If the antenna is still active the monitor will sound an alarm. No alarm sound provides confirmation that all transmitters have been deactivated. This check provides positive confirmation of present EME conditions, ensuring workers operate on inactive antenna(s). Always follow the manufacturer's user instructions.

It is important to note that while some manufacturers suggest that personal monitors can be worn to indicate compliance with FCC rules, this kind of use should be carefully considered. Where used according to the manufacturer instructions, compliance is only confirmed at the monitor location. For instance, if a monitor is worn on a tower climber's belt, their head and shoulders could enter high RF fields without the monitor alarming, potentially giving a false indication of safety. Therefore, it is critically important to follow the stated guidance to place the monitor, away from the body, at several heights near the antenna for approximately 30 seconds.

The personal RF monitor manufacturer's instructions, and guidelines for periodic calibration, **shall** be followed to maintain confidence in personal protection against EME exposure.

A.7 EME Action Thresholds Summary

Table A-4 summarizes the actions required at the various EME thresholds.

Table A-4. EME Action Thresholds

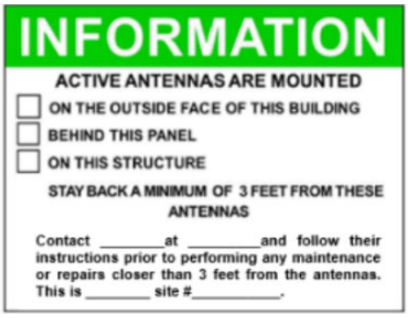
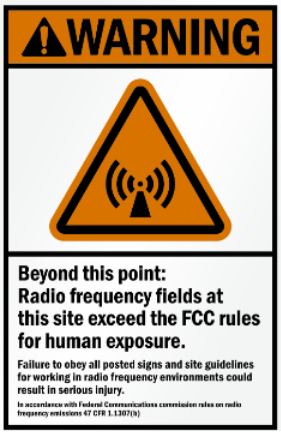
Exposure Conditions	Control Measures	Signage Examples
• RF fields are too weak to cause exposures greater than General Public limit. • Category: 1 - Green Zone • Occupational: <20% • General Public: <100% • Green zone is where continuous exposure is below 100% of General Population/Uncontrolled limit	• No special EME safety practices are required in these areas. • No signage is required, optional information sign with antenna owner, site registration number and contact information.	Optional INFORMATION sign at access location. 

Table A-4. EME Action Thresholds (continued)

Exposure Conditions	Control Measures	Signage Examples
• RF fields could exceed the General Population limit but not the Occupational limits for continuous exposure. • Category 2 - Blue Zone • Occupational: <100% • General Public: >100% • Blue zone is where continuous exposure is below 100% of Occupational/Controlled limits but above General Population/ Uncontrolled limit.	• Restrictive barriers and positive access controls are required. • Personnel **shall** have EME awareness and control training. • Trained supervision and the use of time averaging equal to or less than 30 minutes to evaluate exposure **shall** be employed for transient bystanders (General Public).	NOTICE signage **shall** be posted on/at barriers/doors and must be easily viewed. 
• RF fields exceed Occupational/ Controlled limits for continuous exposure. • Category 3 – Yellow Zone • Occupational >100% to <1000% • TWA: 6 minutes average • Yellow zone is where continuous exposure is above 100% of Occupational/Controlled limits by no more than a factor of ten.	• Restrictive barriers and positive access controls are required. • Clear signage and barriers are required. • Personnel **shall** have EME awareness and control training. • Do not walk in front of antennas. • May require reduction of RF power to mitigate exposure. • Use of exposure time averaging equal to or less than 6 minutes **shall** be implemented. • Use of personal RF exposure monitors may be considered	CAUTION signage **shall** be posted on/ at barriers/doors and must be easily viewed. 

Table A-4. EME Action Thresholds (continued)

Exposure Conditions	Control Measures	Signage Examples
• RF fields exceed all exposure limits. • Category 4 - Orange Zone • Occupational: >1000% • Orange zone is where exposure for Occupational/Controlled limits is exceeded by more than a factor of ten.	• Restrictive barriers and positive access controls are required. • Clear signage and barriers are required. • Personnel **shall** have EME awareness and control training. • No access permitted without category reduction. • May require reduction of RF power to mitigate exposure. • Lockout/tagout measures **shall** be implemented. • Use of personal RF exposure monitors should be considered.	WARNING signage **shall** be posted on/ at barriers/doors and must be easily viewed. 
• Areas where immediate and serious injury will occur on contact. • Still categorized as Category 4 per FCC rules • Signage has red in signal word area.	• Restrictive barriers and positive access controls are required. • Clear signage and barriers are required. • Personnel **shall** have EME awareness and control training. • No access permitted without category reduction. • May require reduction of RF power to mitigate exposure. • Lockout/tagout measures **shall** be implemented.	DANGER signage **shall** be posted on/ at barriers/doors and must be easily viewed. 

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APPENDIX

B

Soil Resistivity Measurements

Soil resistivity directly affects the design of a grounding (earthing) electrode system and is the prime factor determining the resistance to earth of a grounding electrode or grounding electrode system. Therefore, before the design and installation of a new grounding electrode system, the proposed location **shall** be tested to determine the soil's resistivity. See ASTM G57-06R12, BS 7430:2026, IEEE 81-2025, and MIL-HDBK-419A for more information.

Soil resistivity depends upon the soil structure, strata, and rock formations. Soil resistivity can change with depth, temperature, and moisture content. Soil resistivity can also vary from location to location throughout the site. See BS 7430:2026, section 8.4 for more information.

NOTE: The terms “grounding” and “earthing” are used interchangeably throughout this appendix. The terms “ground resistance tester” and “soil resistivity tester” are used interchangeably throughout this appendix.

B.1 Safety

WARNING: To help reduce the risk of electrical shock from buried or unseen power sources, observe all manufacturer's safety information when using the ground resistance tester. See IEEE 81-2025, section 5.1, for additional safety precautions and information.

WARNING: To help protect against shock hazard, insulated electrician's footwear and gloves SHALL be worn while performing soil resistivity testing.

WARNING: To help prevent eye injury, always wear eye protection when striking ground rods with a hammer.

IMPORTANT: Refer to NFPA 70E®, *Standard for Electrical Safety in the Workplace*® for additional electrical safety information.

Procedures in this appendix **shall not** be performed by untrained or unqualified personnel, nor are any procedures herein intended to replace training. It is required that personnel attempting to measure the resistivity of soil receive prior formal training on the subject and on its associated safety hazards. All applicable laws, rules and codes regulating the work on electrical systems **shall** be complied with at all times.

All safety warnings and cautions provided in this appendix and included in the documentation provided with the ground resistance tester **shall** be followed at all times.

B.2 Definitions

Ohm-cm (Ω-cm): the resistance in ohms (Ω) of one cubic centimeter of soil, measured from opposite sides of the cube. Pronounced “ohm centimeter,” not “ohms per centimeter.”

Ohm-m (Ω-m): the resistance in ohms (Ω) of one cubic meter of soil, measured from opposite sides of the cube. Pronounced “ohm meter,” not “ohms per meter.”

Rho (ρ): The Greek letter **ρ** used to represent soil resistivity.

Soil Resistivity (ρ): A measure of how much a volume of soil will resist an electric current (IEEE 81-2025). The electrical resistance between opposite faces of a unit cube of material; the reciprocal of conductivity (ASTM G57). Soil Resistivity (**ρ**) is measured in Ω-cm or Ω-m.

Soil Resistivity (ρ) Mathematical Equations:

$$\rho = R\frac{A}{l}$$

- R = resistance in ohms (Ω)
- A = cross-section area in cm^2 or m^2
- *l* = length in cm or m

Substitute the units for R, A, and *l*:

- $\rho = \Omega\frac{m^2}{m}$
- Reduces to $\rho = \Omega * \boldsymbol{m}$

Or

- $\rho = \Omega\frac{cm^2}{cm}$
- Reduces to $\rho = \Omega * \boldsymbol{cm}$

NOTE: See IEEE 81-2025 and ASTM G57 for additional definitions.

B.2.1 Soil Type Definitions

Soil can be classified into the general categories below. Some sites may have different soil compositions depending on the location, such as gravel and rocks.

Clay



Soil that contains a high percentage of fine particles and colloidal substances and becomes sticky when wet. Clay is generally plastic with appropriate water content and will harden when dried.

Loam



A combination of coarse sand, silt, and clay.

Sand



A loose granular substance, typically pale yellowish brown, resulting from the erosion of siliceous and other rocks and forming a major constituent of beaches, riverbeds, seabeds, and deserts. A finer granular material than sand is referred to as silt, while coarser material is referred to as gravel.

Silt



Has smaller particles compared to sandy soil and is made up of rock and other mineral particles, which are smaller than sand and larger than clay. Silt holds water better than sand.

NOTE: “Gumbo” is soil composed of fine-grain clays. When wet, the soil is highly plastic, very sticky and has a soapy appearance. When dried, it develops large shrinkage cracks.

B.3 Soil Resistivity Variability and Factors Affecting Soil Resistivity

Soil resistivity varies widely by region due to differences in soil type and changes seasonally due to variations in the soil's electrolyte content and temperature. Therefore, it is recommended that these variations be considered when assessing soil resistivity. To help ensure expected grounding electrode system resistance values are achieved throughout the year, worst-case soil resistivity values should be considered when designing a grounding electrode system.

Table B-1 lists ranges of soil resistivity for various types of soil. The values are the expected values that should be seen when measuring soil resistivity (see IEEE 142-2007, Table 4-2 for more details).

Table B-1. Soil Resistivity For Various Soil Types

Soil Type	Resistivity (Ω-cm)		
	Minimum	Average	Maximum
Ashes, brine or cinders	590	2,370	7,000
Concrete (below ground)	– –	3,000	– –
Clay, gumbo, loam or shale	340	4,060	16,300
Clay, gumbo, loam or shale with varying portions of sand and gravel	1,020	15,800	135,000
Gravel, sand or stone with little clay or loam	59,000	94,000	458,000

The resistivity of soil is primarily determined by the electrolyte content of the soil. Electrolytes consist of moisture, minerals and dissolved salts. In general, soil resistivity decreases (improves) as electrolytes increase. Table B-2 and Figure B-1 show soil resistivity changes as a function of soil moisture content. The resistivity of the soil decreases rapidly as the moisture content increases from very little moisture to approximately 15 percent moisture (see IEEE 142-2007, Table 4-3 for more details).

Table B-2. Soil Resistivity Changes as a Function of Soil Moisture

Moisture Content (by weight)	Resistivity (Ω-cm)	
	Top Soil	Sandy Loam
0%	> 10^9	> 10^9
2.5%	250,000	150,000
5%	165,000	43,000
10%	53,000	18,500
15%	19,000	10,500
20%	12,000	6,300
30%	6,400	4,200

Source: *Soares Book on Grounding and Bonding,* 9th Edition (ISBN 978-1890659363).

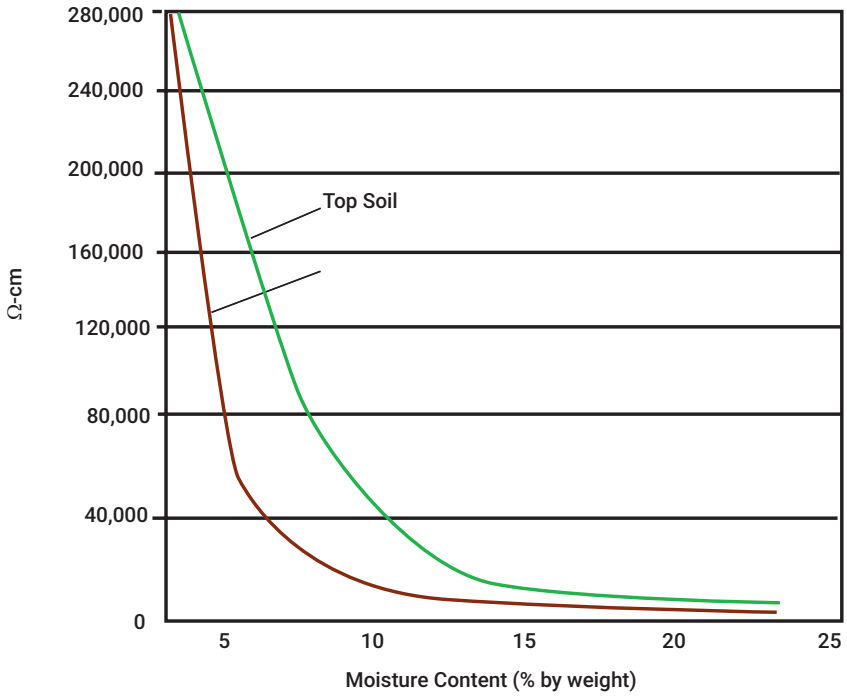


Figure B-1. Soil Resistivity as a Function of Soil Moisture

The resistivity of soil is also affected by its temperature. In general, soil resistivity increases as temperature decreases. Table B-3 and Figure B-2 show soil resistivity changes as a function of soil temperature. As shown, the greatest rate of change in soil resistivity is at the point where moisture in the soil freezes (see IEEE 142-2007, Table 4-4 for more details).

Table B-3. Soil Resistivity Changes as a Function of Soil Temperature

Temperature		Resistivity
°C	**°F**	**(Ω-cm)**
20	68	7,200
10	50	9,900
0 (water)	32 (water)	13,800
0 (ice)	32 (ice)	30,000
-5	23	79,000
-15	5	330,000
Source: *Soares Book on Grounding and Bonding,* 9th Edition (ISBN 978-1890659363).		

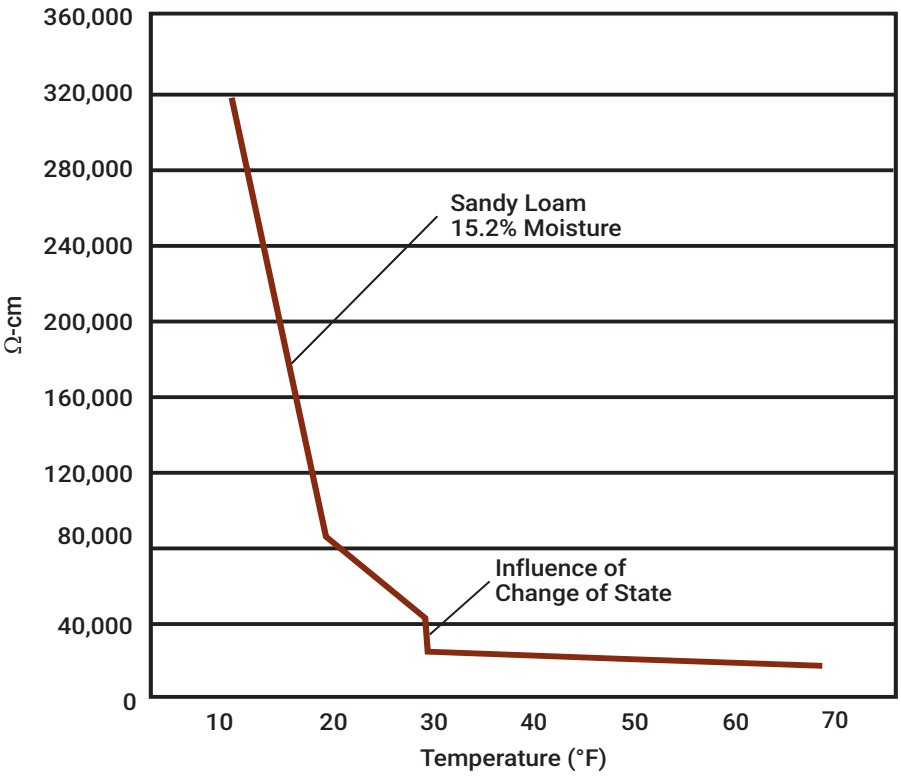
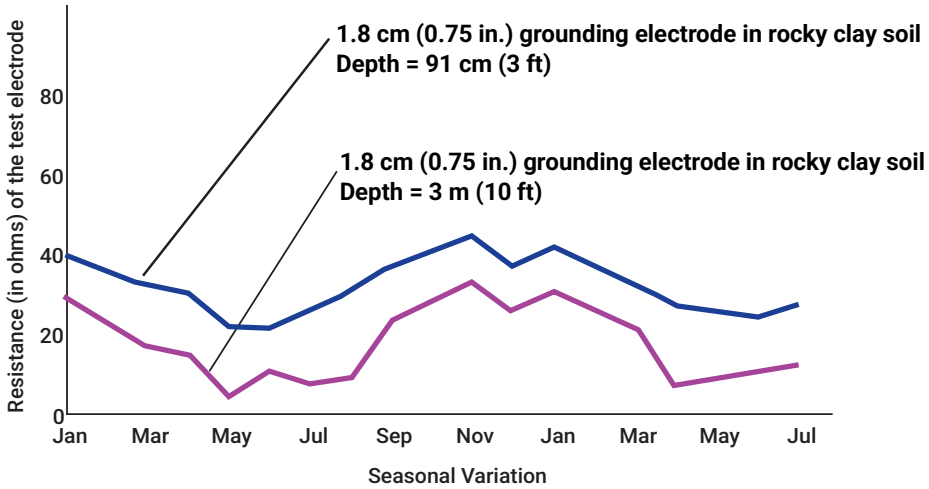


Figure B-2. Soil Resistivity as a Function of Soil Temperature

Because the resistivity of soil is directly affected by its moisture content and temperature, it is reasonable to conclude that the resistance of any grounding electrode system will vary throughout the different seasons of the year. Figure B-3 shows the seasonal variations of the resistance to earth of a grounding electrode.



Data source: *Soares Book on Grounding and Bonding,* 9th Edition (ISBN 978-1890659363).

Figure B-3. Seasonal Variations in Grounding Electrode Resistance

Temperature and moisture content both become more stable as the distance below the surface of the earth increases. Therefore, to be effective throughout the year, a grounding electrode system should be installed as deep as practicable. Best results are achieved when ground rods or other grounding electrodes reach permanent moisture.

B.4 Testing Methods

Two methods of obtaining soil resistivity data are typically used, as follows:

- Four-point (Wenner) method (see BS 7430:2026, FAA-STD-019G, IEEE 81-2025, MIL-HDBK-419A, and NWSM 30-4106:2017 for more information).
- Random core samples

Where practicable, the testing should be performed using the four-point testing method; this is the method described in this appendix. The area indicating the lowest soil resistivity will be the optimum location for placement of the grounding electrode system. A suggested best practice is to perform the test during different seasons of the year whenever practicable. The worst-case measured soil resistivity should then be considered to design a grounding electrode system that will meet the resistance design goal throughout the year.

Random core sampling should be used only if the four-point test cannot be accomplished, such as in metropolitan areas, areas where buried metallic objects may cause misleading readings, or where surface area is insufficient for test performance. Random core sampling **shall** be performed by a geotechnical firm. The random core sample test results can then be used in “Interpreting Test Results” on page B-12 or provided to an engineering firm so they can design an appropriate grounding electrode system.

NOTE: The same core samples taken for foundation design can also be used for conducting the random core sample testing.

Core samples should be taken from at least five different test areas as shown in Figure B-6 at depths of 1.5, 3 and 6.1 m (5, 10 and 20 ft). See FAA-STD-019G, section 4.4.2, and NWSM 30-4109-2017, section 2.8.1, for more information.

B.5 Site Preparation Considerations

IMPORTANT: Do not test an adjacent location if the site location is inaccessible when the testing is scheduled. Reschedule the test so it can be done on the actual site. Significant differences may exist between adjacent sites.

Soil resistivity tests must be performed on the actual site, after the following preparation and conditions have been met:

- The site has been leveled to where the foundation will be placed.
- Soil added to the site is satisfactorily compressed before conducting the test, so it will behave as undisturbed soil.
- No precipitation has occurred within 72 hours.

B.5.1 Required Test Equipment and Supplies

The required test equipment and supplies for performing a soil resistivity test are as follows:

- Ground Resistance Tester designed for four-point testing, including all necessary accessories. Accessories should include the following at minimum:
  - Operator or User Manual
  - Four test rods (typically supplied with tester)

    The test rods should be stainless steel, 610 mm (24 in.) maximum length, 10 mm (0.375 in.) diameter, utilizing a preferred surface penetration of 229 mm (9 in.). Test rods typically come with a four-point testing kit, in lengths from 381 mm (15 in.) to 610 mm (24 in.).

- Four test leads (typically supplied with tester)

  The test leads connect the tester to the test rods. If the leads do not use labels or different colors to correlate the test lead connections between the rods and tester terminals, use tags or four different colors of tape to correlate the connections.

IMPORTANT: The connections must be kept in the correct order to maintain symmetry of testing procedures and maintain consistent results.

- Small sledgehammer
- Tape measure
- Safety glasses
- Gloves
- A photocopy of Figure B-6, for recording and keeping track of several measurements across the site.



Figure B-4. Typical Soil Resistivity Test Kit (image courtesy of AEMC)

B.5.2 Performing Soil Resistivity Test

Perform the test at the location where the site will be built. This procedure describes how to obtain test results for various depths and how to measure the soil resistivity over the entire site.

WARNING: Follow the manufacturer's warning and caution information when using the ground resistance tester.

IMPORTANT: Underground metallic objects such as pipes, cables, conductors or tanks can provide an alternate path for test current from a ground resistance tester (soil resistivity tester), resulting in inaccurate measurements. Chain-link fencing, concrete with rebar and other electrically continuous objects above-grade and parallel to the test also provide an alternate path for the test current. Therefore, do not test in areas with these metallic objects.

B.5.2.1 Measuring At Various Depths

The soil is typically not homogeneous from the surface to the depth being tested, and resistivity varies at different depths. Because of this, the four-point test (performed at various depths and at various locations throughout the site) is used to provide a composite result of the soil resistivity.

The testing depth of a soil resistivity test is determined by the spacing between the four test rods which correspondingly connect to the appropriate terminals on the tester. The recommended practice is to test the soil at various depths to determine the best depth for the grounding electrode system. For example, if the test rods are 1.52 m (5 ft) apart, the measurement is an average of the soil from the surface down to 1.52 m (5 ft). As the spacing between the rods increases, results for correspondingly deeper samples are directly obtained. Table B-4 lists the soil depths measured for different rod spacing distances.

Table B-4. Soil Depth Measured as a Function of Rod Spacing

Rod Spacing	Soil Depth Measured
1.52 m (5 ft)	1.52 m (5 ft)
3 m (10 ft)	3 m (10 ft)
6.1 m (20 ft)	6.1 m (20 ft)
9.1 m (30 ft)	9.1 m (30 ft)
12.2 m (40 ft)	12.2 m (40 ft)

B.5.2.2 Testing Theory and Rod Arrangement

NOTE: The calculated soil resistivity is the average soil resistivity between the soil surface and the depth of the soil equivalent to the rod spacing.

NOTE: The tester terminals may be labeled differently on different tester models. See the tester's User Manual for details. The following tester terminal naming conventions are typical:
- C1, P1, P2 and C2 (the naming convention used throughout this appendix)
- X, Xv, Y and Z
- E, ES, S and H

Table B-5 shows the relationships among commonly-used tester naming conventions.

Table B-5. Commonly Used Tester Naming Conventions

Current Probe 1	Potential/Voltage Probe 1	Potential/Voltage Probe 2	Current Probe 2
C1	P1	P2	C2
X	Xv	Y	Z
E	ES	S	H

Figure B-5 shows the rod arrangement required for testing. The test requires inserting four test rods into the test area, in a straight line, equally spaced, and all at a depth of 229 mm (9 in.). A constant current is injected into the earth from the earth resistance tester through the two outer test rods C1 and C2. The voltage drop resulting from the current flow through the earth is then measured across the inner two test rods P1 and P2.

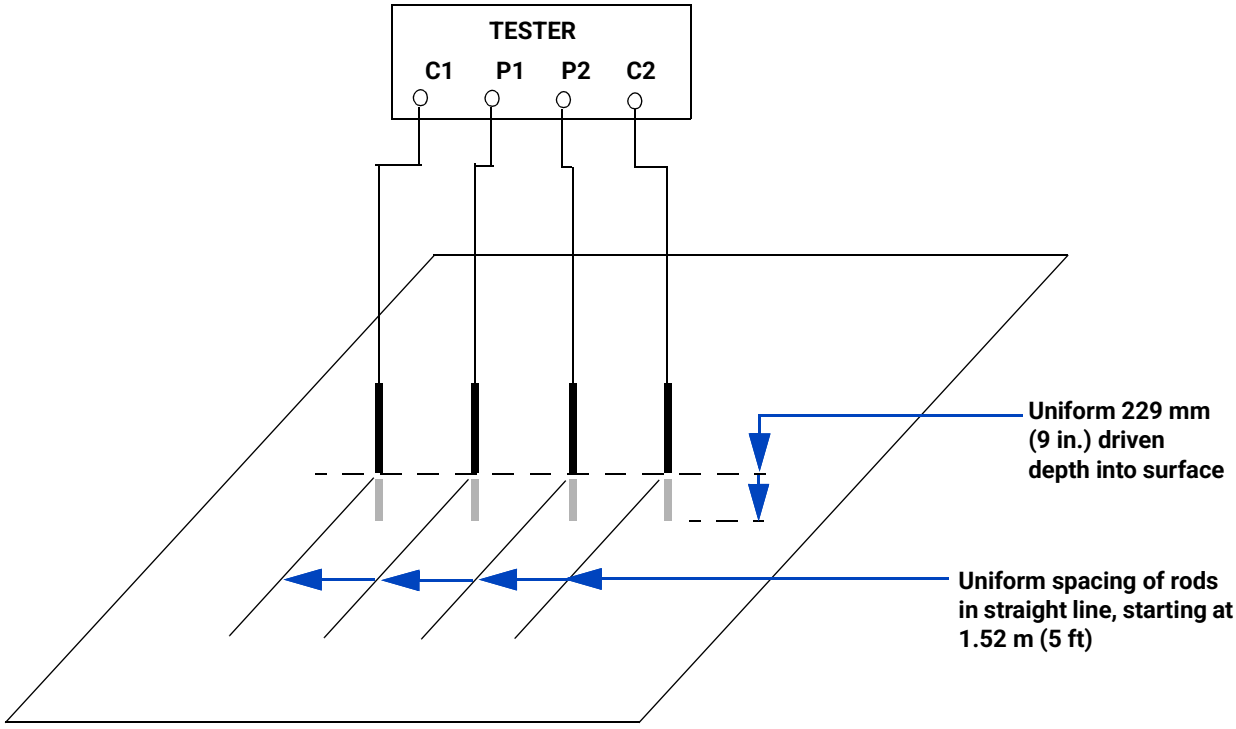


Figure B-5. Rod Arrangement and Spacing

Newer testers display the soil resistivity (ρ) reading directly in Ω-cm, but some older testers display the soil resistivity reading in ohms (Ω). In this case, soil resistivity (ρ) of the tested area must be calculated using the tester value in ohms and one of the following formulas:

$\rho = 191.5 \times A \times R$

Where:

ρ = soil resistivity in Ω-cm

A = Distance between test rods (in feet)

R = Resistance obtained from tester (in ohms)

$\rho = 628 \times A \times R$

Where:

ρ = soil resistivity in Ω-cm

A = Distance between test rods (in meters)

R = Resistance obtained from tester (in ohms)

B.5.2.3 Samples Required to Develop Accurate Site Resistivity Profile

Because stray currents, buried water pipes, cable sheaths, and other factors usually interfere with and distort the readings, measurements should be taken along at least four directions (see FAA-STD-019G, section 4.2.4.2, and NWSM 30-4106:2017, section 2.8.1). Figure B-6 shows the recommended multiple sampling pattern to develop an accurate profile.

NOTE: The more divergent the samples taken, the more accurate the generated soil model will be.

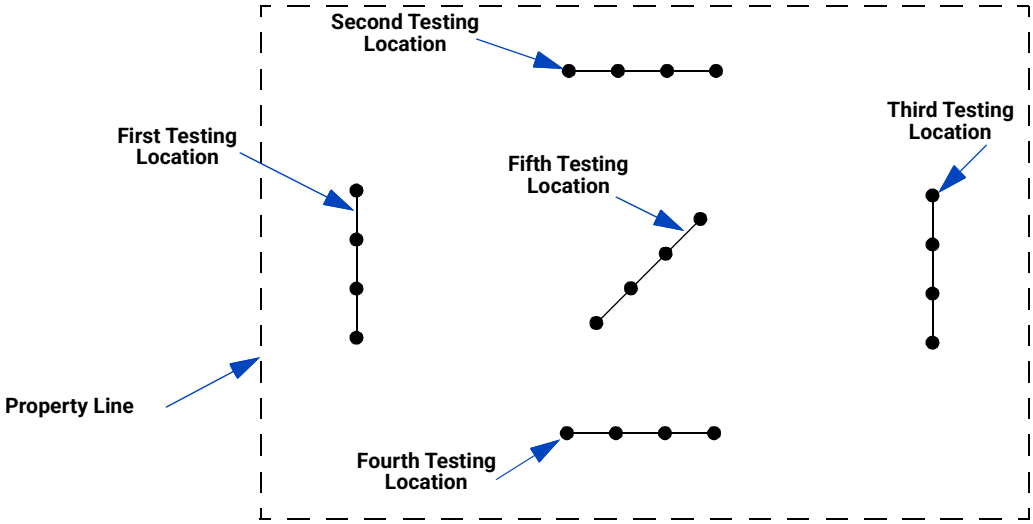


Figure B-6. Recommended Multiple Sampling Pattern Across Site

B.5.2.4 Testing Tips

The test directions must be carefully chosen so they do not parallel any buried metallic objects. Buried metallic objects could affect the measurements because they could provide an alternate path for the test current. Buried objects include, but are not limited to, water pipes, conduits, cables, tanks, metallic fences, or metal rebar within concrete footings.

Select a test direction that is not close to or in parallel with overhead high-voltage lines located nearby. Overhead power lines could induce noise into the meter, creating an invalid measurement. If testing near overhead high-voltage lines is unavoidable, ensure that the test direction and test leads are perpendicular to the overhead lines to help minimize induced noise. Noise induction can be further reduced by twisting the test leads together (see the meter's User Manual for more information).

To ensure good contact with the earth, compact the soil directly around the test rods to remove air gaps formed when inserting the rod. If the reading is unstable or displays an error indication, double-check the connection and the meter range setting. If the range is correct, try adjusting the test current. An effective way of decreasing the test rod resistance to earth is by pouring water (or sports drink, which is high in electrolytes) around the rod, as illustrated in Figure B-7. Adding moisture helps achieve a better electrical connection and does not influence the overall results.

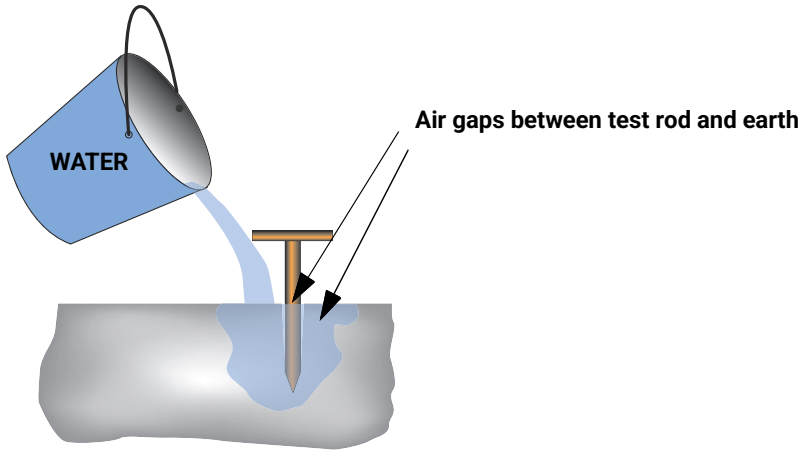


Figure B-7. Improving Electrical Contact by Adding Water to the Soil

B.5.2.5 Soil Resistivity Measurement Procedure

WARNING: Follow the manufacturer's warning and caution information when using the ground resistance tester.

IMPORTANT: Review the tester's User Manual prior to performing the following tests.

Perform the following procedure to obtain soil resistivity readings.

1. On the tester, verify that the jumper strap between the C1 and P1 terminals is disconnected (if applicable).
2. Starting at the “First Test Location” shown in Figure B-6, drive four test rods into the soil to a depth of 229 mm (9 in.), in a straight line and spaced 1.52 m (5 ft) apart (as shown in Figure B-5).

IMPORTANT: The test rods must be connected in the order specified in Step 3. If the test rods are connected incorrectly, an inaccurate reading will result.

3. Using test leads, connect the C1, P1, P2 and C2 terminals to their respective test rods, as shown in Figure B-5.
4. Turn the tester on. Press the test button and read the display.
   - If the reading is not stable or displays an error indication, double-check the connection and meter range setting.
   - If the range is correct, try adjusting the test current. An effective way of decreasing the test rod resistance to earth is by pouring water or sports drink around the rod. Adding moisture is insignificant; it will only achieve a better electrical connection and will not influence the overall results.
5. Record the measurement obtained in the appropriate “Meter Readings” space on the photocopy of the “Soil Resistivity Worksheet” on page B-17.
6. Remove the test rods from the soil.
7. In the same location on the site and along the same line as the previous test, repeat steps 2 through 6 for the remaining spacings listed on the “Soil Resistivity Worksheet”.
8. Prepare to take measurements for the next test location shown in Figure B-6. Repeat steps 2 through 7 for this location.
9. Repeat steps 2 through 8 for all remaining test locations specified in Figure B-6.
10. On the Soil Resistivity Worksheet copy, calculate and record soil resistivity (ρ) for each of the 25 readings taken in the steps in this procedure.

B.5.3 Interpreting Test Results

Depending on the type of grounding electrode system to be installed, proceed to one of the following subsections. Test results are interpreted according to MIL-HDBK-419A.

- “Calculating Single Ground Rod System Resistance” on page B-13
- “Calculating Grounding Electrode System Resistance With Multiple Ground Rods in a Straight Line” on page B-21
- “Calculating Grounding Electrode System Resistance With Multiple Ground Rods in Ring Configuration” on page B-25
- “Calculating Grounding Electrode System Resistance With Ground Rods in Grid Configuration” on page B-25

IMPORTANT: Calculations in the following sections require the ground rods to be installed vertically. Ground rods installed horizontally or partially horizontal require more complex calculations and are beyond the scope of this appendix. Consultation with an engineering firm is recommended for more complex calculations.

NOTE: The interpreted test results are typically conservative because the effects of the horizontal connecting conductors (typically ground rings) are not considered in the following calculations. Consideration of the horizontal connecting conductors requires complex calculations that are beyond the scope of this manual. An engineering firm may be required to perform calculations that consider the effects of the horizontal connecting conductors.

B.5.3.1 Calculating Single Ground Rod System Resistance

For a single ground rod, the resistance can be easily calculated using a nomograph. Example calculations are shown in Figure B-8, Figure B-9, and Figure B-10.

If calculations show excessive resistance for a given rod length and diameter, recalculate substituting a larger diameter rod and/or longer rod. In this manner, the proper ground rod size and length for a particular site can be determined. Figure B-10 shows an example where resistance to earth is improved by substituting a longer rod of larger diameter.

NOTE: Increasing the length of a rod has significantly more impact on the resistance to earth than increasing the diameter.

Perform the following procedure to calculate the resistance of the single grounding electrode.

1. Make a photocopy of Figure B-11.
2. On the **d** scale of the nomograph, plot a point corresponding to the diameter of the ground rod to be used.
3. On the **L** scale of the nomograph, plot a point corresponding to the length of ground rod to be used.
4. Draw a line connecting the **d** and **L** points.
5. Plot ρ value from Soil Resistivity Worksheet on the ρ scale of nomograph.

NOTE: The value used in this step should be selected according to the desired ground rod length. For example, a 3 m (10 ft) ground rod uses the value measured with a 3 m (10 ft) spacing (test depth) and a 6 m (20 ft) ground rod uses the value measured with a 6 m (20 ft) spacing (test depth). An exact ρ value may not always be available for the desired ground rod length. In these cases, use the closest value available or perform additional tests for the desired ground rod length.

6. Where the line connecting the **d** and **L** points intersects the **q** line, draw a new line from this point to the point plotted on the ρ scale. Extend this line to the **R** scale. This is the resistance for a single ground rod.

B.5.3.1.1 Example Worksheet and Nomograph

Figure B-8, Figure B-9, and Figure B-10 show example readings and calculations from a completed worksheet and nomograph.

- Figure B-8 shows example readings, as entered from field Ground Resistance Tester measurements and the resulting Soil Resistivity calculations.
- Figure B-9 shows an example of a completed nomograph.
- Figure B-10 shows a second nomograph filled-in with calculations for grounding electrode resistance improvement using a larger-diameter and longer rod.

Location "1 of 5" 3 m (10 ft) spacing is measured on Ground Resistance Tester. In this example, tester reads "2.1 Ω".

"2.1" is written in "Meter Readings" column for Location "1 of 5" (10 ft spacing) in Worksheet.

ρ value for Location "1 of 5" 10 ft spacing is calculated using formula on Worksheet.

ρ value of "4021.5" is written in "Soil Resistivity Calculations" column for Location "1 of 5" (10 ft spacing) in Worksheet.

Location	Spacing (Test Depth)	
	1.52 m (5 ft)	3 m (10 ft)
Meter Readings (steps 2 through 5)		
	4.2	2.1
	4.5	2.5
	4.2	2.3

	ρ= 4021.5	ρ= **4021.5**
	ρ= 4308.8	ρ= 4787.5
	ρ= 4021.5	ρ= 4404.5

Figure B-8. Example Worksheet

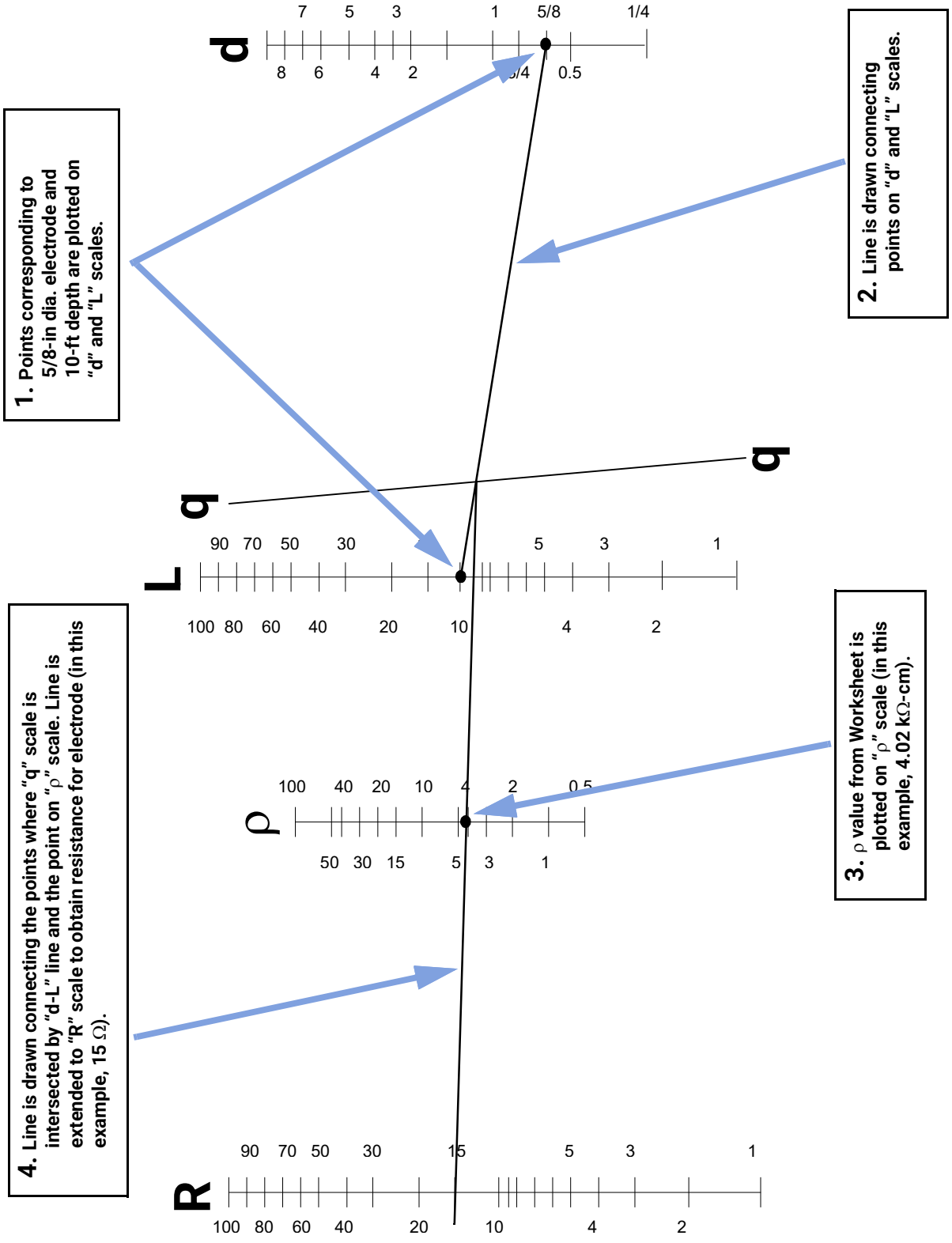


Figure B-9. Example Nomograph (sheet 1 of 2)

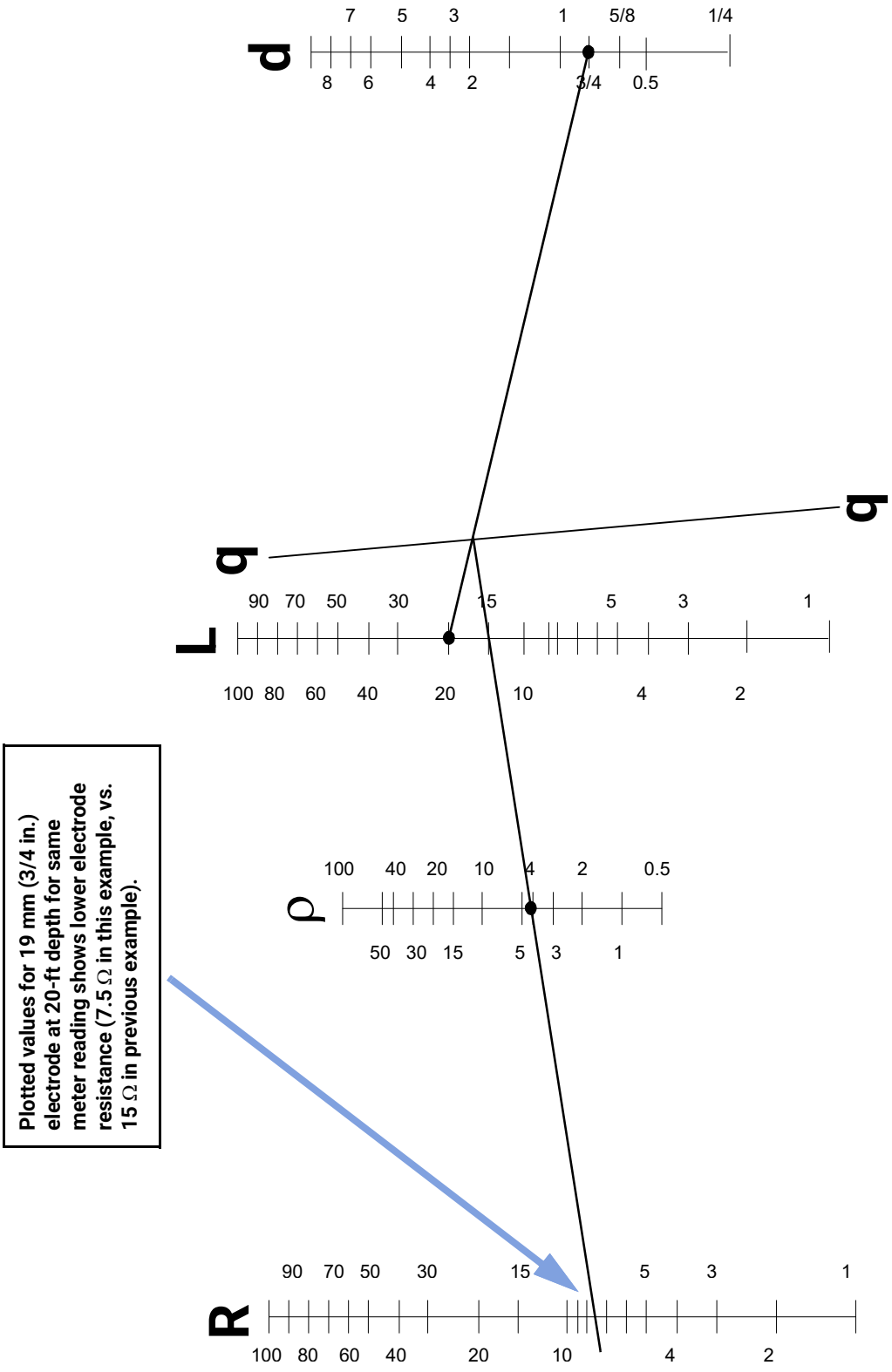
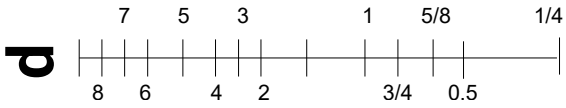


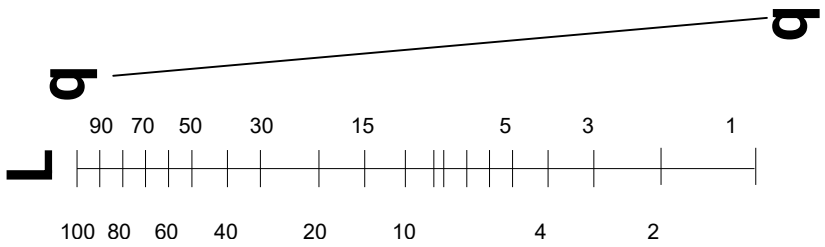
Figure B-10. Example Nomograph (sheet 2 of 2)

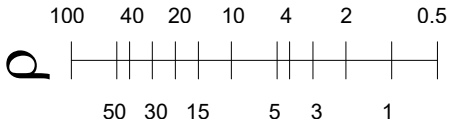
Table B-6. Soil Resistivity Worksheet

Location	Spacing (Test Depth)				
	1.52 m(5 ft)	3 m(10 ft)	6.1 m(20 ft)	9.1 m(30 ft)	12.2 m(40 ft)
Meter Readings (steps 2 through 5)					
1 of 5					
2 of 5					
3 of 5					
4 of 5					
5 of 5					
Soil Resistivity Calculations (step 10)					
$\rho = 191.5 \times A \times R$ ρ = soil resistivity in Ω-cm A = Distance between test rods (in feet) R = Resistance obtained from tester		**OR**	**$\rho = 628 \times A \times R$ ρ = soil resistivity in Ω-cm A = Distance between test rods (in meters) R = Resistance obtained from tester**		
1 of 5	ρ=	ρ=	ρ=	ρ=	ρ=
2 of 5	ρ=	ρ=	ρ=	ρ=	ρ=
3 of 5	ρ=	ρ=	ρ=	ρ=	ρ=
4 of 5	ρ=	ρ=	ρ=	ρ=	ρ=
5 of 5	ρ=	ρ=	ρ=	ρ=	ρ=
Test completed by:			**Notes:**		
Date:					
Client / Project:					
Site Location/ID:					
Ground Resistance Tester Model:_____ S/N:_____ Calibration date:_____					
Soil Description:					
Ambient Conditions Temperature:_____ Present conditions (dry, rain, snow):_____ Date of last precipitation:_____					

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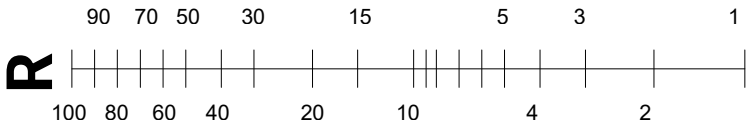


Figure B-11. Soil Resistivity Nomograph

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B.5.3.2 Calculating Grounding Electrode System Resistance With Multiple Ground Rods in a Straight Line

For a grounding electrode system with multiple ground rods in a straight line (as shown in Figure B-12), the system resistance can be calculated as described in the following procedure.

1. Perform soil resistivity test as described in "Soil Resistivity Measurement Procedure" on page B-12.
2. Calculate the resistance of one ground rod as described in "Calculating Single Ground Rod System Resistance" on page B-13. The ρ value used in this step should be from a test location located in the same area as the intended parallel ground rods installation. Write down this number.
3. Sketch a proposed layout of the ground rod arrangement using equally spaced rods in a line.

NOTE: The stipulations regarding rod spacing specified in "Grounding (Earthing) Electrodes" on page 4-10 must be observed when planning rod layout.

4. Make a photocopy of Figure B-13 on page B-23.
5. Calculate the effective resistance of the proposed layout using the photocopy of "Combined Resistance Graph (Ground Rods Arranged in Line or Ring)" as follows:

5.1 Noting the number of rods to be used, locate this number on the Number of Rods axis of the graph.

5.2 Note the spacing of the rods in the proposed layout in terms of spacing as related to length of rods. On the graph, "**s=L**" is spacing equal to length of rod "**s=2L**" is spacing equal to twice the length of rod, and so on. Locate the spacing line on the graph (**s=L**, **s=2L, s=3L, s=4L**) corresponding to the proposed spacing.

5.3 At the point on the graph where the Number of Rods line intersects the appropriate spacing line, note the Combined Resistance number at the left.

5.4 Multiply the Combined Resistance number by the resistance of a single ground rod noted in step 2 of this procedure. This is the approximate resistance of the proposed grounding electrode system.

B.5.3.2.1 Example Layout and Graph

Assuming a layout as shown in Figure B-12 with the following characteristics:

- Eight rods (each of 8-ft length) are spaced at 4.9 m (16 ft) points (or "2L" in terms of the graph) along a line.
- Soil resistivity measurement (step 1 in "Calculating Grounding Electrode System Resistance With Multiple Ground Rods in a Straight Line" on page B-21) is 4021.5 Ω-cm for a 3 m (10 ft) test depth.
- Resistance of single ground rod (step 2 in "Calculating Grounding Electrode System Resistance With Multiple Ground Rods in a Straight Line" on page B-21) is 15 Ω.

System resistance is calculated as follows:

1. Using Figure B-14: because eight rods are used, "8" line on **Number of Rods** on the graph is selected.
2. Because rod spacing is 4.9 m (16 ft) or "2L" of rod length, "**s=2L**" line on graph is selected.
3. At the intersection of the "8" line and the "s=2L" line, draw a horizontal line to the **Combined Resistance** axis at left. Note the point where the horizontal line crosses the **Combined Resistance** axis (in this case, at approximately "**18**" (or 18% of single rod resistance).
4. Single rod resistance of 15 Ω is then multiplied by 18% (0.18) to obtain the system's resistance to earth:

$$15\Omega \times 0.18 = 2.7\ \Omega$$

In this example, the overall resistance to earth of the proposed grounding electrode system would be 2.7 Ω.

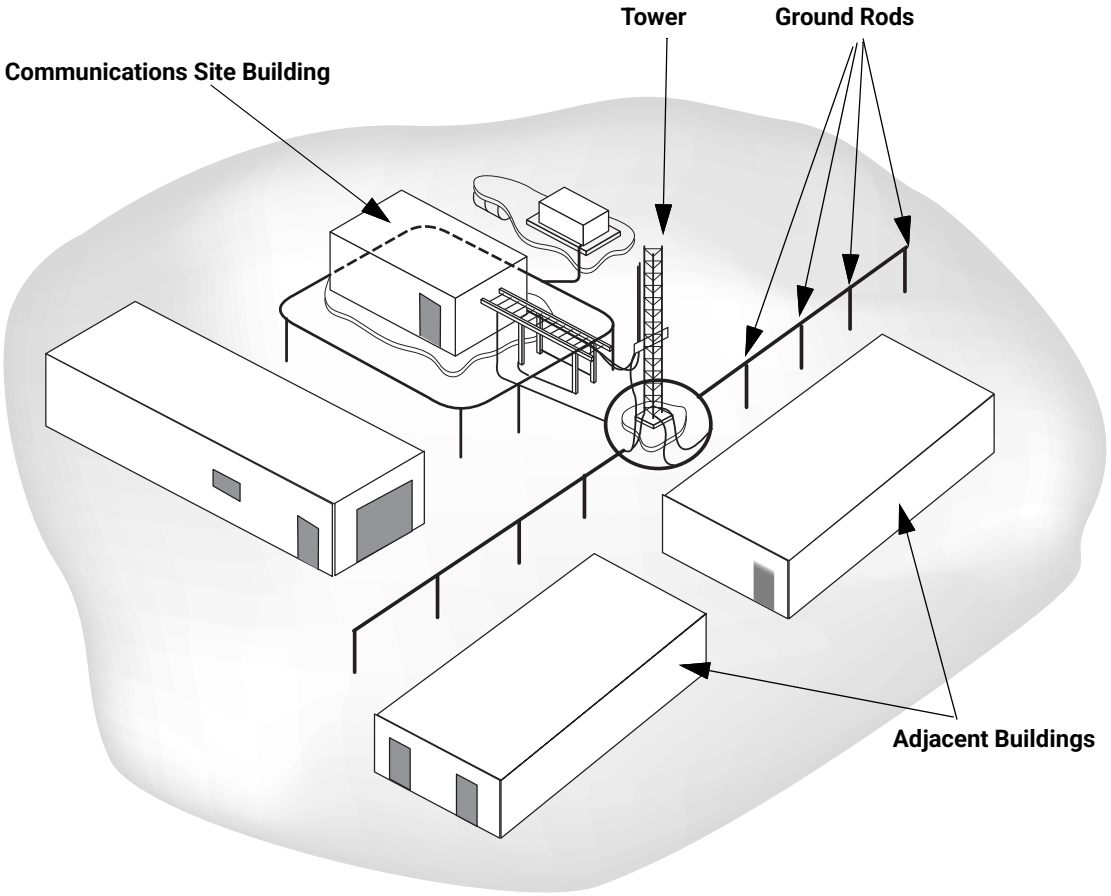


Figure B-12. Example of Multiple Grounding Electrodes in a Straight Line

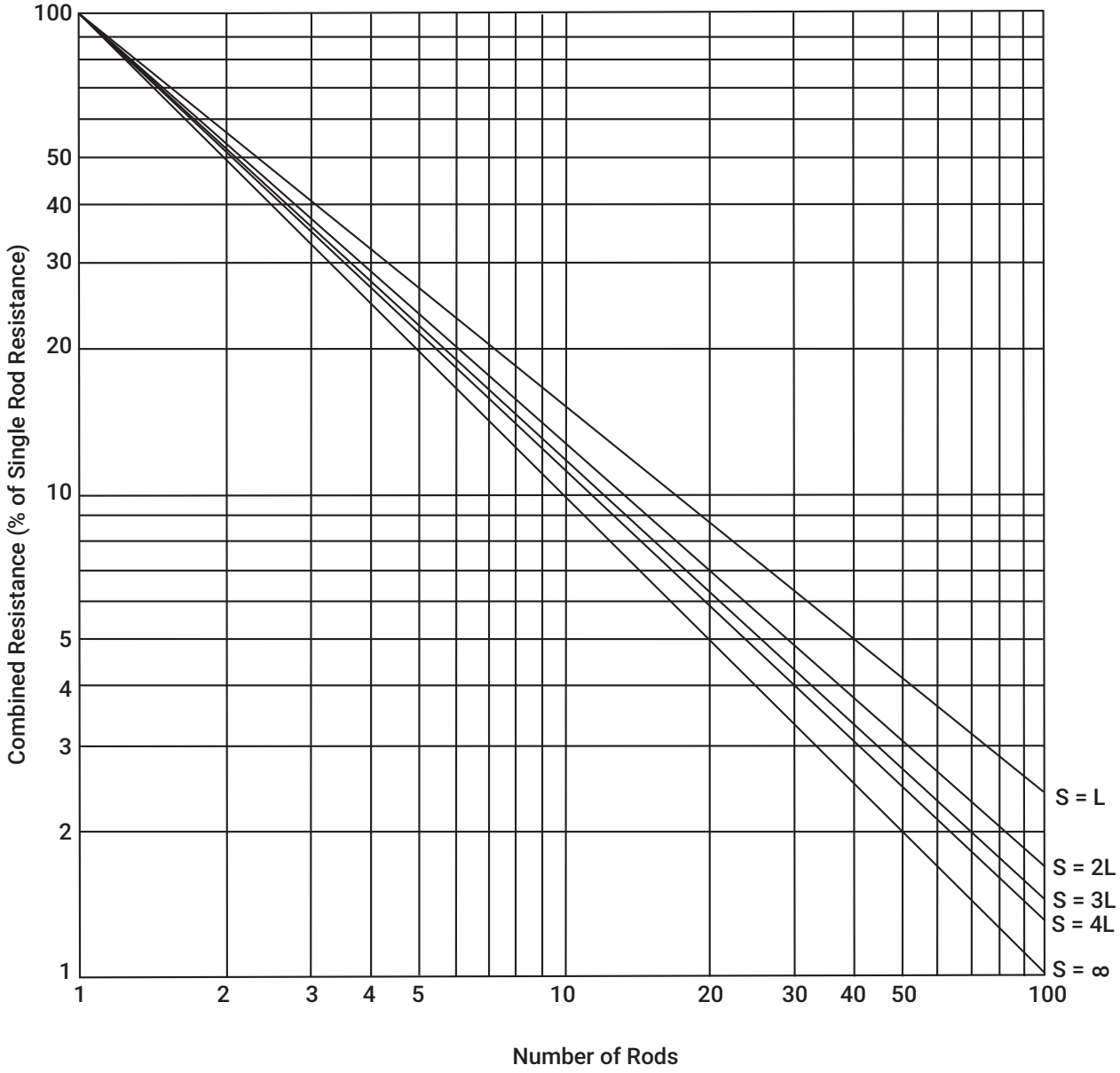


Figure B-13. Combined Resistance Graph (Ground Rods Arranged in Line or Ring)

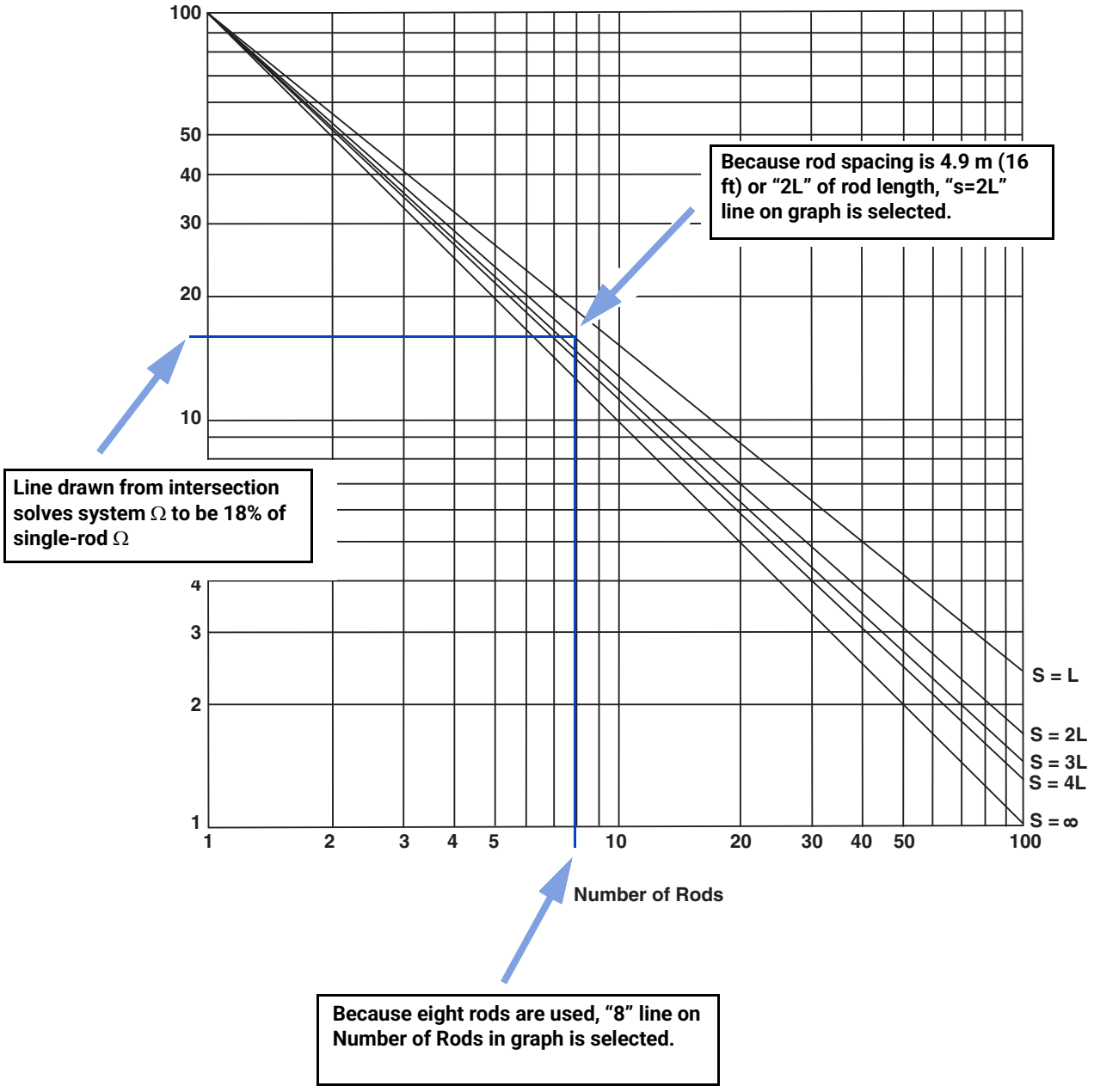


Figure B-14. Example Calculation of Ground Rods Arranged In Straight Line

B.5.3.3 Calculating Grounding Electrode System Resistance With Multiple Ground Rods in Ring Configuration

For a grounding electrode system with multiple parallel ground rods installed in a ring configuration (as shown in Figure B-15), the system resistance is calculated in the same manner as ground rods placed in a straight line.

When planning a ring configuration layout and performing calculations, note the following:

- All rods in the system **shall** maintain equal or greater separation from adjacent rods.
- The distance between rods **shall** be figured in a direct path to adjacent rods, not the circumference distance of the ring.

NOTE: The stipulations regarding rod spacing specified in “External Building and Tower Ground Ring” on page 4-25 must be observed when planning rod layout.

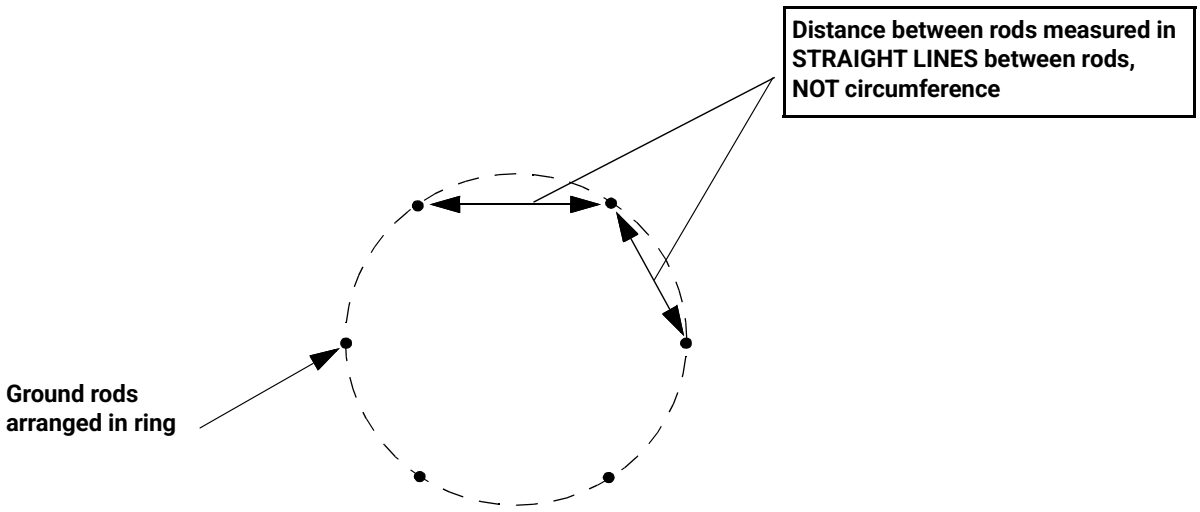


Figure B-15. Ring Configuration Planning and Resistance Measurement Considerations

B.5.3.4 Calculating Grounding Electrode System Resistance With Ground Rods in Grid Configuration

For a grounding electrode system consisting of a ground rod grid configuration (as shown in Figure B-16), the system resistance can be calculated as described in the following procedure.

1. Perform soil resistivity test as described in “Soil Resistivity Measurement Procedure” on page B-12.
2. Calculate the resistance of one ground rod as described in “Calculating Single Ground Rod System Resistance” on page B-13. The ρ value used in this step should be the average of all test locations at the site (see Figure B-6). Alternatively, the worst-case value can be used for a more conservative calculation. Write down this number.
3. Sketch a proposed layout of the ground rod arrangement using equally spaced rods across the proposed area.

NOTE: The stipulations regarding rod spacing as specified in “General Ground Rod Requirements” on page 4-12 must be observed when planning rod layout.

4. Calculate the area of the proposed grid system in square feet.

NOTE: This procedure requires that grid measurements be entered in square feet. If metric measurements have been made, the measurements must be converted to feet. See Appendix G, “General Conversions and Formulas”, for conversion formulas.

5. Make a photocopy of Figure B-17.

6. Calculate the effective resistance of the proposed layout using the photocopy of “Combined Resistance Graph (Ground Rods Arranged in Grid)” as follows:

6.1 Noting the number of rods to be used, locate this number on the **Number of Rods** axis of the graph.

6.2 Note the square footage of the proposed rod layout. Locate the curve on the graph most closely corresponding to the proposed square footage.

6.3 At the point on the graph where the **Number of Rods** line intersects the appropriate square footage curve, note the **Resistance Ratio** number at the left.

6.4 Multiply the **Resistance Ratio** number by the resistance of a single ground rod noted in step 2 of this procedure. This is the approximate resistance of the proposed grounding electrode system.

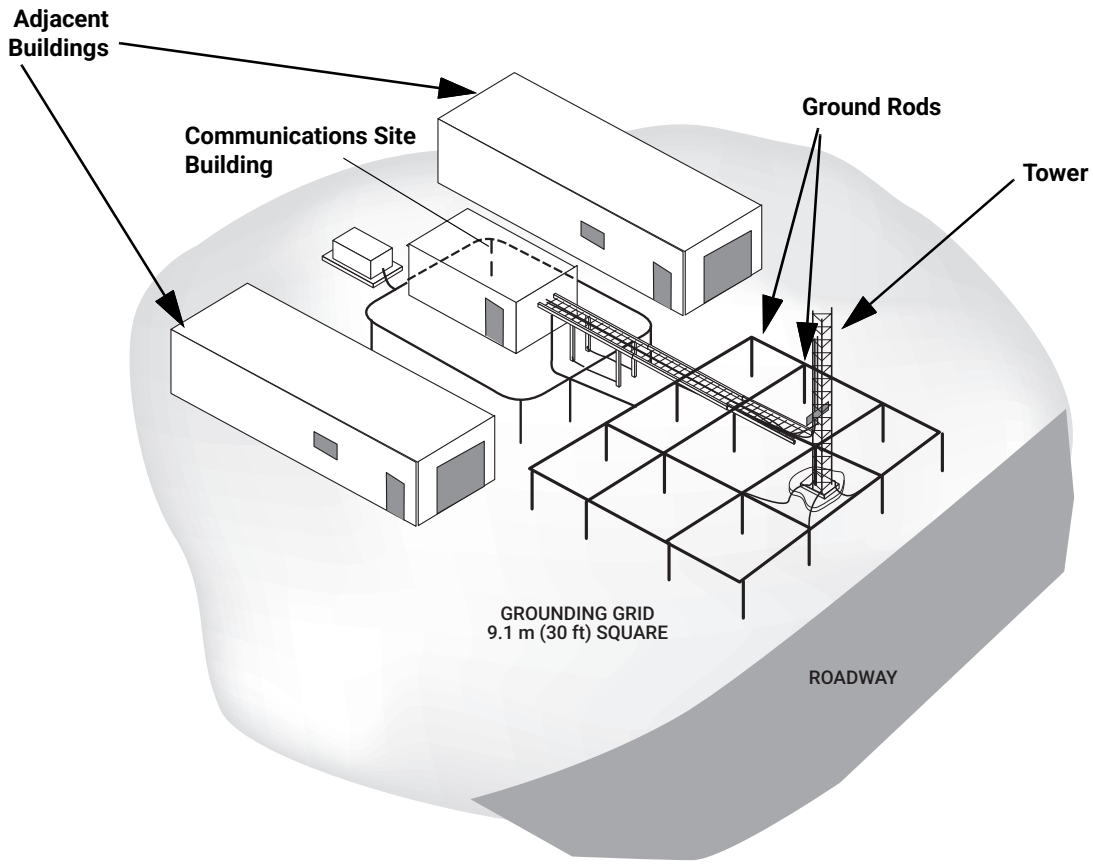


Figure B-16. Example of Multiple Ground Rod Grid Configuration

B.5.3.4.1 Example Layout and Graph

Assuming a layout as shown in Figure B-16 with the following characteristics:

- 16 rods equally spaced across a 30 × 30 ft grid (900 sq. ft).
- Soil resistivity measurement (step 1 in "Calculating Grounding Electrode System Resistance With Ground Rods in Grid Configuration" on page B-25) is 4021.5 Ω-cm.
- Resistance of single rod (step 2 in "Calculating Grounding Electrode System Resistance With Ground Rods in Grid Configuration" on page B-25) is 15 Ω.

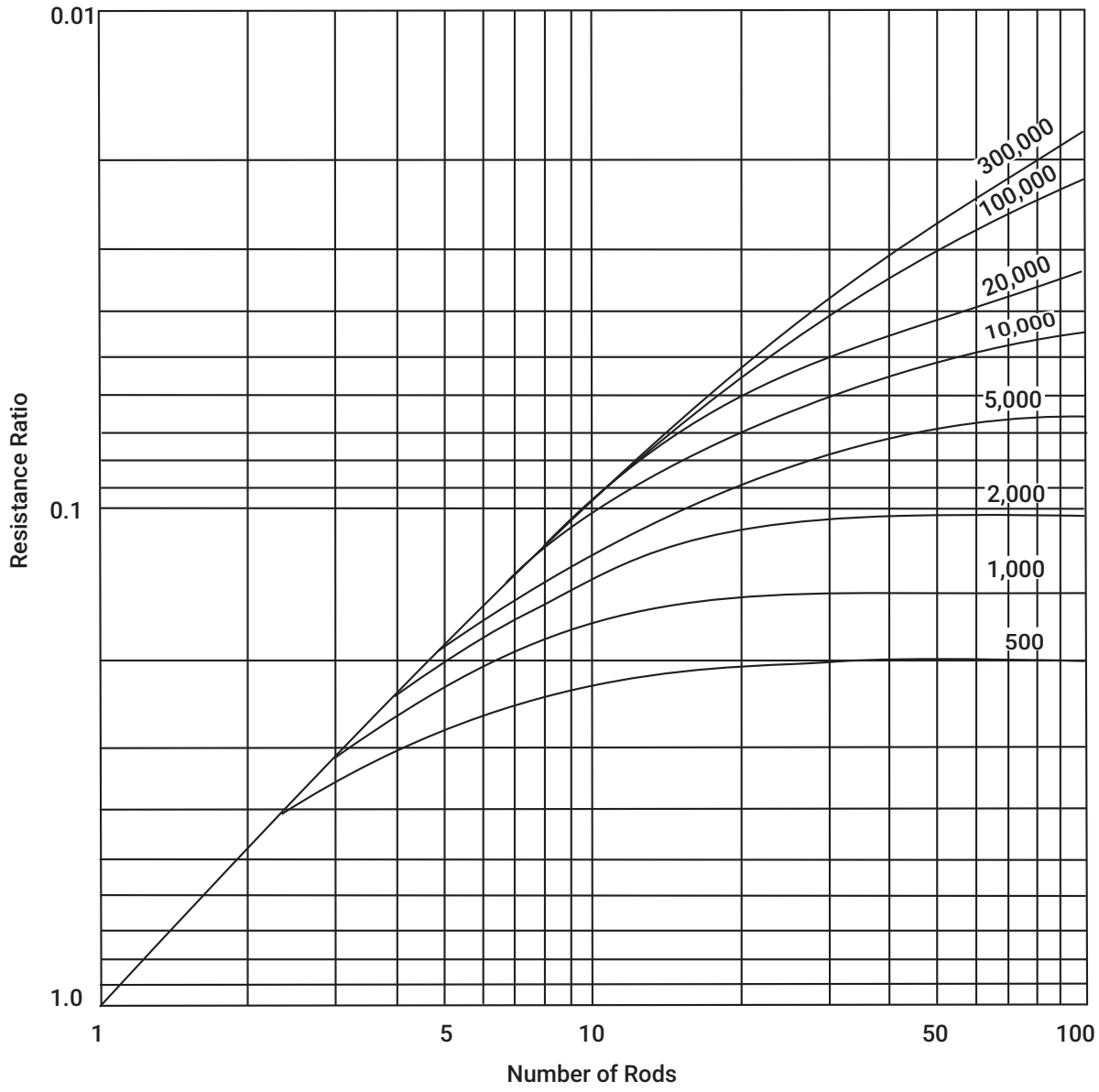


Figure B-17. Combined Resistance Graph (Ground Rods Arranged in Grid)

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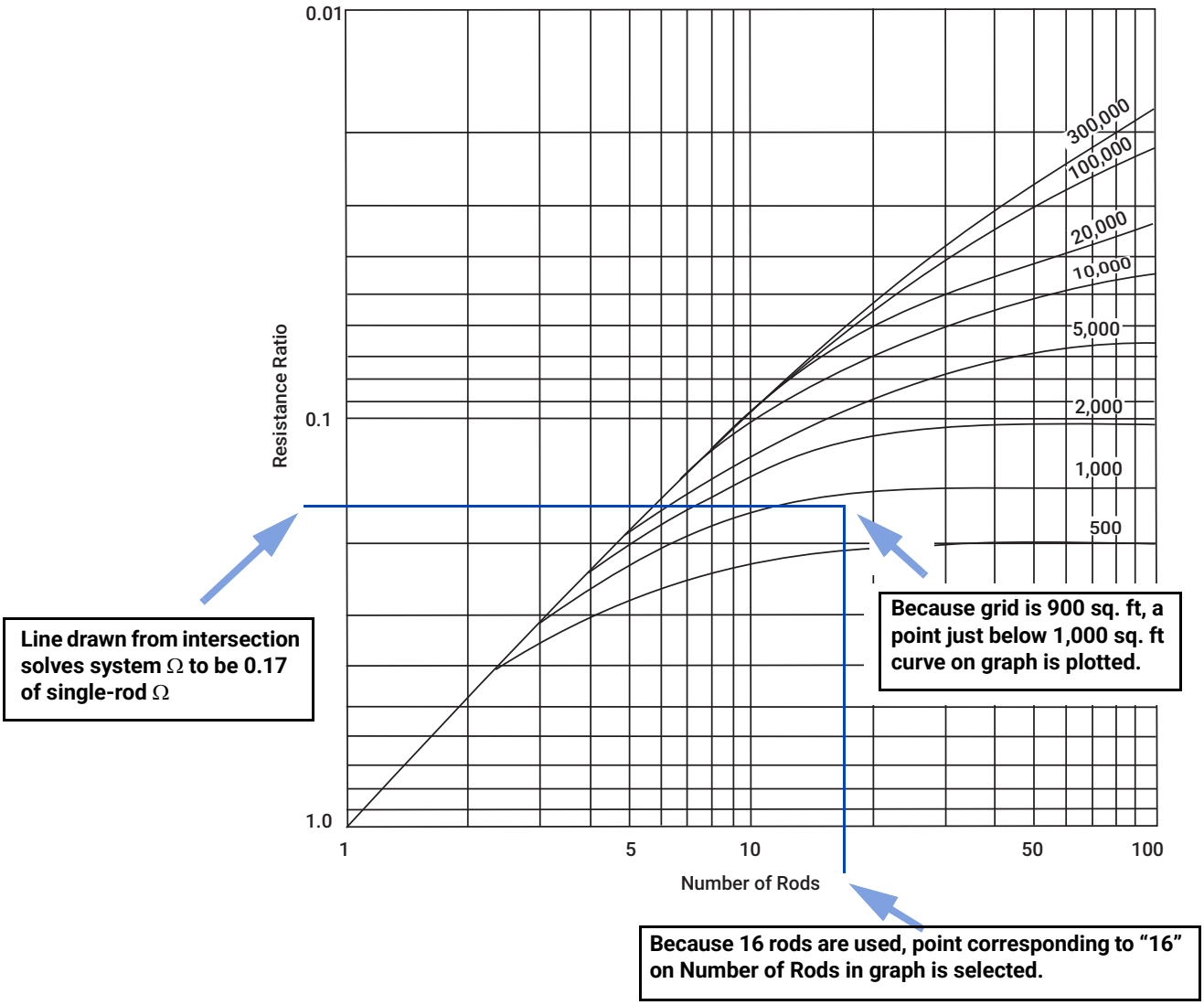


Figure B-18. Example Calculation of Ground Rod Grid Configuration

System resistance is calculated as follows:

1. See Figure B-18. Because 16 rods are used, the point corresponding to "16" on **Number of Rods** on the graph is selected. Draw a line vertically from the "16" point on the graph.
2. Because the grid is 900 sq. ft, a point just below the **1,000** sq. ft curve on graph is plotted on the line drawn on the graph.
3. At the point plotted in the previous step, (intersection of "900" sq. ft and "16" rods), draw a horizontal line to the **Resistance Ratio** axis at left. Note the point where the drawn horizontal line crosses **Resistance Ratio** axis (in this case, at approximately ".17").
4. The single ground rod resistance of 15 Ω is then multiplied by 0.17 to obtain the resistance to earth of the system:
   15Ω × 0.17 = 2.55 Ω

In this example, the overall resistance to earth of the proposed grounding electrode system would be 2.55 Ω.

B.5.3.5 Simplified Calculations

IEEE 142-2007 (also known as the IEEE Green Book™) offers a simplified method to **approximate** the total resistance to earth of a system consisting of 2 to 24 ground rods placed one rod length apart in a line, hollow triangle, circle or square. The resistance to earth of a single ground rod must first be calculated using methods described in this chapter (see “Calculating Single Ground Rod System Resistance” on page B-13). The resistance to earth of the system can then be approximated using the following formula and Table B-7.

$$R_{total}\ (\Omega) = \frac{\text{resistance of single rod}}{} * \textit{multiplication factor (F) from}$$

Table B-7. Multiplication Factors for Multiple Ground Rods

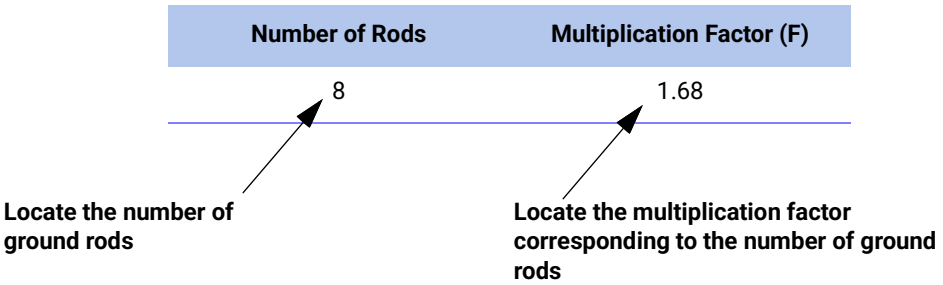
Number of Rods	Multiplication Factor (F)
2	1.16
3	1.29
4	1.36
8	1.68
12	1.80
16	1.92
20	2.00
24	2.16
Source: IEEE 142-2007, Table 4-6	

Example Calculation: Assuming a layout similar to that shown in Figure B-12 with the following characteristics:

- 8 ground rods are spaced 2.4 m (8 ft) apart.
- Resistance of single ground rod is 15Ω.

The grounding electrode system resistance is approximated using the formula and table as follows:

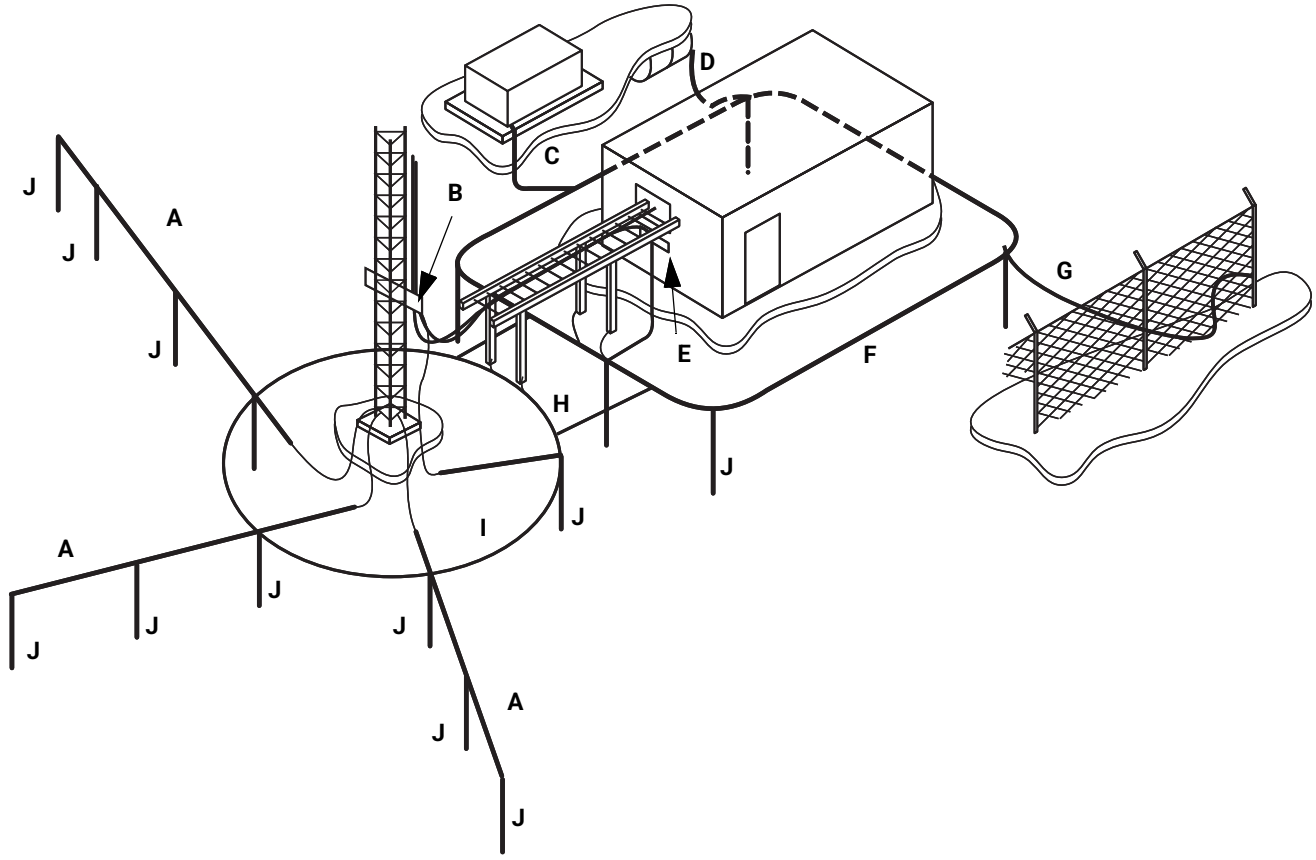
As shown in Table B-7, the multiplication factor for 8 ground rods is 1.68.



$$R_{total} = \frac{15\Omega}{8} * 1.68 \approx \mathbf{3.15\Omega}$$

B.5.3.6 Estimating Resistance of Complex Ground Rod Systems

Complex ground rod systems consist of multiple subsystems bonded together to form an overall site ground rod system. Figure B-19 shows a typical complex ground rod system.



A: Grounding Radials
B. Tower Ground Busbar and Down Conductor
C. Generator Grounding Conductor
D. Buried Fuel Tank Grounding Conductor
E. External Ground Busbar
F. Shelter Ground Ring
G. Fence Grounding Conductor
H. Ground Ring Bonding Conductors (2 minimum)
I. Tower Ground Ring
J. Earthing Electrodes (Ground Rods)

Figure B-19. Typical Complex Grounding Electrode System

NOTE: The following method is an approximation and should be considered accurate to ± 20%. If greater accuracy is required, consultation with an engineering firm is recommended.

Resistance of a complex ground rod system can be **approximated** by breaking the system into subsystems. Typically, a ground rod system can be broken down into the following individual subsystems:

- Building ground ring
- Tower ground ring
- Tower radial grounding conductors

For a complex ground rod system consisting of the subsystems described in this section or similar multiple subsystems, the overall system resistance can be approximated as described in the following procedure.

NOTE: Adjacent subsystems should not be laid out closer than the ground rod spacing distance used within a particular subsystem. This is because as subsystems become closer than this distance, the effectiveness of their combined resistance value decreases.

1. Perform soil resistivity test as described in “Soil Resistivity Measurement Procedure” on page B-12.
2. Calculate the resistance of one ground rod as described in “Calculating Single Ground Rod System Resistance” on page B-13. The ρ value used in this step should be the average of all test locations at the site (see Figure B-6). Alternatively, the worst-case value can be used for a more conservative calculation. Record this number for the following calculations.
3. Sketch a proposed layout of the ground rod arrangement using equally spaced rods across the proposed area.

NOTE: The stipulations regarding rod spacing as specified in “General Ground Rod Requirements” on page 4-12 must be observed when planning rod layout.

4. Calculate the resistance of the building ground ring subsystem as described in “Calculating Grounding Electrode System Resistance With Multiple Ground Rods in Ring Configuration” on page B-25. Write down the result.
5. Calculate the resistance of the tower ground ring subsystem as described in “Calculating Grounding Electrode System Resistance With Multiple Ground Rods in Ring Configuration” on page B-25. Write down the result.
6. Calculate the resistance of the tower radial grounding conductor subsystem as follows:

6.1 Calculate and record the resistance of each **individual** tower radial grounding conductor as described in “Calculating Grounding Electrode System Resistance With Multiple Ground Rods in a Straight Line” on page B-21.

NOTE: If the radial grounding conductor does not contain ground rods, the resistance to earth of the radial grounding conductor can be calculated as follows:

Buried Horizontal Length of Wire (straight)
D<<L

$$R = \frac{p}{\pi L}\left[\ln\left(\frac{(2L)}{(2aD)^{1/2}}\right) - 1\right]$$

R = resistance of electrode in ohms
ρ = soil resistivity in ohm-meters
L = conductor length in meters
a = conductor radius in meters
D = conductor depth in meters

D << L (D is much less than L)

6.2 Using the results obtained in the preceding step, calculate the **combined (parallel) resistance of the tower ground radials as follows:**

$$R_{total} = \frac{1}{\frac{1}{R_{radial1}} + \frac{1}{R_{radial2}} + \frac{1}{R_{radial\ ...n}}}$$

NOTE: The ground rods associated with the tower ground ring are not included in the calculation of the tower radial grounding conductors.

7. Noting the resistances determined for the subsystems, calculate the combined (parallel) resistance of **all subsystems** as follows:

- subsystem 1 (building ground ring subsystem; step 4)
- subsystem 2 (tower ground ring subsystem; step 5)
- subsystem 3 (tower ground radial subsystem; step 6)

$$R_{total} = \frac{1}{\frac{1}{R_{subsystem1}} + \frac{1}{R_{subsystem}} + \frac{1}{R_{subsystem3}}}$$

NOTE: Total resistance does not include incidental influence from site fencing, buried fuel tanks or other objects not included in these calculations. More complex grounding systems or highly accurate results where other objects exist, require the assistance of an engineering firm.

B.5.3.6.1 Example Calculation of Complex System

Assuming a layout as shown in Figure B-19 with the following characteristics:

- Soil resistivity measurement (step 1 in "Estimating Resistance of Complex Ground Rod Systems" on page B-31) is 4021.5 Ω-cm.
- Building ground ring (step 4 in "Estimating Resistance of Complex Ground Rod Systems" on page B-31) using four rods, each with a resistance of 15 Ω. Building ground ring subsystem calculates to approximately 4.35 Ω.
- Tower ground ring (step 5 in "Estimating Resistance of Complex Ground Rod Systems" on page B-31) using three rods, each with a resistance of 15 Ω. Tower ground ring subsystem calculates to approximately 5.55 Ω.
- Tower radial grounding conductor subsystem (step 6 in "Estimating Resistance of Complex Ground Rod Systems" on page B-31) as shown in Figure B-19. Total resistance of this subsystem is as follows:
  - Radial "A" has three ground rods. Resistance of this radial calculates to approximately 5.55 Ω.
  - Radial "B" has two ground rods. Resistance of this radial calculates to approximately 8.1 Ω.
  - Radial "C" has two ground rods. Resistance of this radial calculates to approximately 8.1 Ω.

Tower ground radial calculates to 2.34 Ω, as shown in the following example using the formula provided in step 6:

$$R_{tower\ radial} = \mathbf{2.34\ \Omega} = \frac{1}{\frac{1}{\mathbf{5.55\Omega}} + \frac{1}{\mathbf{8.1\Omega}} + \frac{1}{\mathbf{8.1\Omega}}}$$

Overall system resistance is calculated as follows:

1. The individual resistances of the three subsystems are noted:
   - **Building ground ring = 4.35 Ω**
   - **Tower ground ring subsystem = 5.55 Ω**
   - **Tower ground radial = 2.34 Ω**
2. The combined (parallel) resistance of all the subsystems is now calculated as follows:

$$R_{\text{total}} = 1.19\ \Omega = \frac{1}{\frac{1}{4.35\Omega} + \frac{1}{5.55} + \frac{1}{2.34\Omega}}$$

In this example, the calculated effective overall resistance of the proposed system would be approximately **1.19 Ω**.

APPENDIX C

Electrostatic Discharge Protection in Equipment Rooms and Dispatch Centers

C.1 Background Information

Static electricity is defined as an electrical charge that is caused by an imbalance of electrons on the surface of a material. This imbalance of electrons produces an electric field that can influence other objects at a distance. Electrostatic Discharge (ESD) is defined as the transfer of electrical charge between bodies at different electrical potentials.

ESD can severely affect the performance and reliability of electronic equipment. ESD failures may occur at a site and not immediately be detected because voltage levels that can cause component failure are below the perception threshold of the individual. See IEEE 1100-2005, section 6.4.3.3, for more information.

Electrostatic charges are built up on the human body by triboelectric charging. Triboelectric charging occurs when two materials come in contact and are then separated, resulting in a transfer of positive or negative ions. Just by walking across an unprotected floor when the humidity level is low, a person can create a triboelectric charge buildup in the range of 25,000 volts or more. Cathode-ray tube video terminals can also generate intense electric fields that can transfer high amounts of electrostatic charges to the human body. Normally, discharges from the hand are imperceptible below potentials of 3000 volts; for sensitive areas such as the face, the threshold of perception may be 500 volts or lower (ATIS-0600321.2020, section 4).

Electrostatic buildup and discharge in a dispatch room can be very annoying to the operator especially when the high voltage energy discharges through the operator's headset earpiece. Not only can the high voltage discharge cause annoyance and pain due to the high voltage heat transfer, but it can also cause data and audio signal corruption and equipment damage.

Measures to control ESD **shall** be taken when designing for this environment. Most ESD problems are mitigated through proper bonding and grounding techniques, relative humidity control (between 40% and 55% relative humidity is ideal), and attention to the resistivity of flooring and furniture.

Requirements in this appendix are based on ANSI, ANSI/ESD, ATIS, FAA, and IEEE standards. Additional information on ESD control can be found on the Electrostatic Discharge Association website: http://www.esda.org.

NOTE: Electrostatic discharge (ESD) is often the cause of electrical shock complaints from dispatch center personnel.

C.2 Equipment Handling and Storage

To reduce ESD damage to electronic equipment, wrist straps connected to ground **shall** be worn when handling static-sensitive devices (see “Wrist Straps” on page C-2). ESD-protected packaging **shall** be available for containing modules and boards removed from equipment. Static-dissipative work surfaces and grounded dissipative (or conductive) floor surfaces should be used in equipment rooms. Storage areas should contain grounded cabinets or grounded permanently static-dissipative shelves. Ground points for wrist straps should be provided at strategic locations near equipment sensitive to electrostatic discharge.
See ATIS-0600334.2019(R2024), section 12, for more information.

C.3 Measures for Controlling Electrostatic Discharge

Depending on the environment and mobility requirements of personnel, there are several ways to address ESD concerns. The least costly ways are more restrictive to personnel mobility and require more focus on established and institutionalized operating procedures, such as use of wrist straps. These means will not help to eliminate the occurrence of ESD, but will help to dissipate the electrostatic charge from the person's body and keep it from entering the communications system equipment.

There are many strategies for minimizing ESD events. The following sections provide some options but are not all-inclusive. As a rule, not all of these techniques will be either necessary or desirable to establish an ESD-protected area. The appropriate ESD protection strategy should be based on the application and the advantages and disadvantages of each ESD protective method. See ATIS-0600321.2020, section 4, for more information.

C.3.1 Equipment Bonding, Grounding and Surge Protection

All equipment installed in an equipment room and at a network operator (dispatch) position **shall** be properly bonded and grounded according to the requirements of Chapter 5, "Internal Bonding and Grounding (Earthing)" section 5.10.5.

Surge suppression should be provided in accordance with "Surge Protection for Dispatch Centers and Operator Positions" on page 7-66.

IMPORTANT: In addition to ESD protective measures, all equipment in an equipment room and at a network operator position **shall** be properly grounded, bonded, and protected from surges using Surge Protective Devices (SPD).

C.3.2 Wrist Straps

IMPORTANT: Personnel servicing electronic equipment **shall** wear a wrist strap as appropriate to prevent ESD damage to the equipment. ESD wrist straps **shall** meet the requirements of ANSI/ESD-S20.20-2021 or later.

Personnel can be equipped with an ESD-rated wrist strap. The person connects the wrist strap to an effectively grounded jack before connecting to the headset jack or touching equipment or grounded objects. The wrist strap **shall** provide dissipative resistance values and other safety measures as described within ANSI/ESD S1.1-2021 or later and ANSI/ESD S20.20-2021 or later. Figure C-1 shows an example of a wrist strap grounded through the equipment rack.



Figure C-1. Grounded Wrist Strap in Use

C.3.3 Relative Humidity Control

IMPORTANT: Rooms containing network operator positions (dispatch centers) should maintain a relative humidity within the range of 40% to 55% (ATIS-0600321.2020, section 4.1).

Control of the relative humidity can be an effective means for helping control ESD occurrences because higher relative humidity aids in static dissipation and is associated with lowered triboelectric charging. When the humidity drops below 40%, ESD events are more likely to occur. If humidity is kept above 55%, electrolytic corrosion may affect equipment performance, and microbial contamination may occur. See ATIS-0600321.2020, section 4.1 for more information.

Table C-1 lists typical voltage levels at different relative humidity levels.

Table C-1. Examples of Static Generation Typical Voltage Levels

Means of Generation	10-25% RH	65-90% RH
Walking across carpet	35,000 Volts	1,500 Volts
Walking across vinyl tile	12,000 Volts	250 Volts
Worker at bench	6,000 Volts	100 Volts
Poly bag picked up from bench	20,000 Volts	1,200 Volts
Chair with urethane foam	18,000 Volts	1,500 Volts
Electrostatic Discharge Association website: http://www.esda.org		

C.3.4 Flooring

Carpeting or floor tiles within an equipment room or dispatch center, including raised flooring, should have a resistance to ground measurement of between 10^6 and 10^{10} ohms when measured using the test method of ANSI/ESD STM7.1-2020 (ATIS-0600321.2020, section 4.2). Existing flooring that does not meet this requirement should be treated with a topical solution such as an anti-static floor wax or spray solution. The effectiveness of anti-static solutions is temporary and varies with floor material and relative humidity. Flooring resistance should be monitored at least every two weeks to verify conformance to the requirements in this section. See ATIS-0600321.2020, section 4.2, and ANSI/ESD STM7.1-2020 for more information.

Where ESD protective flooring is used, observe the following:

- ESD protective flooring **shall** be installed per the manufacturer's recommendations.
- ESD protective flooring and floor coverings **shall** be installed, grounded and tested by trained installers.
- Personnel entering the equipment room or dispatch area should wear ESD dissipative footwear or dissipative foot straps. The footwear should provide dissipative resistance values as described in ANSI/ESD STM97.1-2015 or later.

Where ESD protective flooring is not installed at a dispatch position or equipment room, an ESD protective floor mat **shall** be installed at the work areas. Where ESD protective floor mats are installed, observe the following:

- The floor mat should provide dissipative resistance values between 10^6 and 10^{10} ohms when measured using the test method of ANSI/ESD STM7.1-2020 or later.
- The floor mat **shall** be effectively bonded to the operator position bonding busbar (see section 5.10.5.1).
- Personnel should wear ESD dissipative footwear or dissipative foot straps. The footwear should provide dissipative resistance values as described in ANSI/ESD STM97.1-2015 or later.
- Personnel should stand on the floor mat before connecting to the headset jack or touching equipment or grounded objects.

C.3.5 Chairs

Chairs used in dispatch centers should be ESD protective and have a resistance to ground measurement of between 10^6 and 10^{10} ohms when measured using the test method of ANSI/ESD STM12.1-2019 or later. Such chairs usually operate in conjunction with ESD protective flooring (See “Flooring” on page C-3.). See ATIS-0600321.2020, section 4.3, and ANSI/ESD STM12.1-2019 for additional information.

ESD protective chairs should incorporate a continuous path between all chair elements and the ground point. The ground point of a static dissipative chair should be the static dissipative chain or the conductive casters that provide electrical continuity to the ESD flooring material. See FAA-STD-019G, section 5.8.6.4, for additional information.

IMPORTANT: Non-dissipative floor mats or chair mats **shall not** be placed over dissipative flooring material. If floor mats are used, they **shall** be of a dissipative material with a grounding conductor that is effectively bonded to the operator position bonding busbar (see section 5.10.5.1).

C.3.6 Dispatch Position Desktops

IMPORTANT: To help avoid ESD, the operator must touch the ESD protective desktop or ESD protective mat before connecting to the headset jack or touching equipment or grounded objects.

Work surfaces on operator position desktops should have a resistance to ground measurement of between 10^6 and 10^{10} ohms when measured using the test method of ANSI/ESD STM4.1-2017 or later. If an existing desktop does not meet this requirement, an ESD protective mat can be installed under and around the keyboard and mouse. To be effective, the ESD protective desktop or ESD protective mat must be bonded to the operator position bonding busbar (see section 5.10.5.1). See ATIS-0600321.2020, section 4.4, ANSI/ESD STM4.1-2017 and FAA-STD-019G for additional information.

C.3.7 Video Display Terminals

NOTE: Installing liquid crystal display (LCD) or Light Emitting Diode (LED) monitors is recommended, as they do not generate the high electrostatic fields common to cathode-ray tube (CRT) monitors.

If a CRT monitor is used, installation of an electrostatic shield such as a grounded bezel or a conductive anti-glare shield that is bonded to the common grounding point will be of some benefit (ATIS-0600321.2020, section 4.6).

C.4 ESD Control Program

After preventive measures have been implemented to help eliminate or dissipate electrostatic charges, an effective ESD control program should be established to maintain the environment. For additional information on how to establish an effective ESD control program, see Part Two - Principles of ESD Control at the Electrostatic Discharge Association website (https://www.esda.org/about-esd/esd-fundamentals/part-2-principles-of-esd-control).

APPENDIX

D

Testing/Verification of Grounding (Earthing) Electrode System and Bonding Continuity

This appendix provides procedures for performing resistance testing of the site grounding electrode system. The resistance of a grounding electrode system **shall** be measured after its installation and before it is bonded to the electric utility neutral conductor or any other utility, such as the telephone ground or metallic pipes. See Chapter 4, “External Grounding (Earthing) and Bonding”, for grounding electrode system resistance requirements.

Periodic testing should be performed annually when the site grounding electrode system can be safely disconnected from the electric utility neutral conductor (if using the fall-of-potential test). A suggested best practice is to perform the test at three-month intervals for the first year and every 21 months thereafter (MIL-HDBK-419A).

IMPORTANT: The procedures in this appendix are not intended for sites with multiple utility power services or other complex power applications. Consultation with an engineering firm is recommended in these applications.

IMPORTANT: Except for new site construction, measuring the grounding electrode system resistance may not always be practicable. This is often the case for tenant installations (customer rents a room or space within an existing shelter or equipment room), communications shelters co-located onsite with other buildings and/or towers, and existing sites. Consultation with an engineering firm may be required.

NOTE: Throughout this appendix the terms *grounding* and *earthing* are used interchangeably.

D.1 Safety

Procedures in this appendix **shall not** be performed by untrained or unqualified personnel, nor are any procedures herein intended to replace proper training. Personnel attempting to measure the resistance of a grounding electrode system **shall** receive formal training on the subject and its associated safety hazards. All applicable laws, rules and codes regulating the work on electrical systems **shall** be complied with. See IEEE 81-2025, section 5.1, for more information.

All safety warnings and cautions listed within this appendix and the ground resistance tester documentation **shall** be followed.

WARNING: A lethal voltage can exist between the grounding system electrode under test and a remote ground. Because the current and potential electrodes are located at points representing remote earth, the leads to these electrodes must be treated as though a voltage could exist between the test leads and any point on the grounding electrode system under test. Personnel SHALL NOT allow hands or body parts to contact the circuit between points of possible high-potential difference under any circumstances. See IEEE 81-2025 for more information.

WARNING: To help protect against shock hazards, insulated electrician's footwear and gloves SHALL be worn while performing grounding electrode system testing.

WARNING: Check for current on the grounding electrode conductor before disconnecting. Never disconnect the ground of a live circuit. Disconnecting the ground of a live circuit could cause severe injury or death.

WARNING: Only qualified personnel SHALL open an electrical panel to attempt a ground resistance measurement. Lethal voltages may be present.

WARNING: Appropriate fall restraint and fall arrest techniques SHALL be observed when climbing or using any personnel lift. Applicable national and local codes SHALL be followed.

WARNING: To help prevent eye injury, always wear eye protection when striking ground rods with a hammer.

IMPORTANT: Refer to NFPA 70E®, Standard for Electrical Safety in the Workplace® for additional electrical safety information.

D.2 Overview

Grounding electrode system testing can be performed using one of the following methods (see IEEE 81-2025 for more information):

D.2.1 Fall-of-Potential Testing

The fall-of-potential test is the most widely accepted. This test may require access to areas extending beyond the site property lines. When testing a multi-bonded complex grounding electrode system (commonly used at communication sites), the distance required for testing is directly related to the effective diagonal distance of the buried grounding electrode system (including grounded fence posts).

D.2.2 Clamp-on Ground Resistance Test (also known as Clamp-on Ohmmeter Test)

The clamp-on ground resistance test has gained wide acceptance as an effective alternative to the fall-of-potential test, especially at urban sites where the necessary land is unavailable for the fall-of-potential test. This test can only be performed after the AC utility has been connected to the site and various feed conductors are accessible.

D.2.3 Combined Soil Resistivity Testing with Clamp-on Ohmmeter Testing

This method should only be used in cases where fall-of-potential testing and clamp-on ohmmeter testing cannot provide a suitable evaluation. An engineering firm then uses the data obtained from soil resistivity testing and clamp-on ohmmeter testing to determine the grounding electrode system resistance.

D.3 Prerequisites for Testing

This section provides the prerequisites for the tests listed in “Overview” on page D-2. Some guidance is also given where the testing prerequisites cannot be met.

D.3.1 Fall-of-Potential Test

Fall-of-Potential testing is possible only if the following conditions are met:

- Sufficient land area is available to perform the test. The outer reference probe may need to be inserted into soil beyond the site property line (see “Testing Area Requirements” on page D-8). Testing using a clamp-on ohmmeter may be an option where sufficient land area is unavailable.
- The grounding electrode system must be temporarily isolated from the electric utility grounded conductor (may be a neutral conductor) and other utility grounds, such as telephone or cable television. Isolation must include removing any secondary paths to the utility grounds.

NOTE: A suggested best practice in new construction is to test the grounding electrode system resistance before it is bonded to the electric utility ground, other utility grounds, and other items that may provide a secondary path to the utilities.

D.3.2 Clamp-on Ground Resistance Test

Clamp-on ohmmeter testing is possible only if the following conditions are met:

- The site is supplied with commercial power. Sites supplied only by a generator or other non-commercial power source may not be suitable for clamp-on ohmmeter testing of the grounding electrode system resistance. Bonding continuity testing can still be completed using the clamp-on ohmmeter.
- A grounded conductor (may be a neutral conductor) is present and part of an extensive electric utility grounding system.
- The grounding electrode system is connected to the electric utility grounded conductor (may be a neutral conductor).
- For a single grounding electrode system, the grounding electrode conductor is accessible to the clamp-on ohmmeter at a point between the grounding electrode and any other connection (such as the telephone service provider ground or a metallic pipe).
- For sites using a multi-bonded complex grounding electrode system (commonly used at communications sites), a point on the neutral conductor before its first bond to the site is available for using the clamp-on ohmmeter.

NOTE: The clamp-on ohmmeter test can be performed at a site if the electric utility is not yet connected, if the electric utility ground is available nearby. A temporary test jumper may be clamped to the site grounding electrode system and the nearby utility ground. The clamp-on ohmmeter is placed around this test jumper for a grounding electrode system resistance reading. All other utility grounds must be disconnected from the site. See Figure D-20 for an example.
The resistance of the test jumper should be tested and factored out of the grounding electrode system resistance reading. The resistance can be measured with an ohmmeter or by clipping the ends of the test jumper together and placing the clamp-on ohmmeter around the jumper. See Figure D-12 for loop resistance examples.

D.3.3 Combined Soil Resistivity and Clamp-on Ohmmeter Test

Combined soil resistivity and clamp-on ohmmeter testing is possible only if the following conditions are met:

- The system is designed so that gathering of individual grounding electrode system component resistance values can be measured with a clamp-on ohmmeter. An engineering firm uses this data and an as-built diagram to determine the grounding electrode system resistance. For example, large ground test wells are installed over several ground rods to allow clamping around the ground rod with a clamp-on ohmmeter (this would provide the resistance of each ground rod). See “Site AC Power Disconnect Requirements” on page D-23 for electric utility connection requirements.
- A soil resistivity test has been performed at the site, and the results are available for the engineering firm. See Appendix B, “Soil Resistivity Measurements”, for soil resistivity information.
- A grounding electrode system as-built diagram is available for the engineering firm.

D.3.4 Testing Prerequisites Not Met

A supplemental grounding electrode system can be installed if any of the conditions described in “Prerequisites for Testing” on page D-2 and its subsections cannot be met. This supplemental grounding electrode system should be designed and installed to allow easy disconnecting for testing purposes. Alternatively, ground test wells can be strategically installed in the supplemental system to allow for easy clamp-on ohmmeter testing of the system or portions of the system. See Figure D-1 and Figure D-16 for examples.

- Figure D-1 shows easy testing of the individual radial grounding conductors.
- Figure D-16 shows convenient testing of the entire supplemental grounding electrode system.

The scenario described in the preceding paragraph is not common in new construction but may be encountered when installing equipment at an existing site where documentation of the grounding electrode system is incomplete or not available. Installation of a supplemental grounding electrode system may be the only method to verify the resistance to earth.

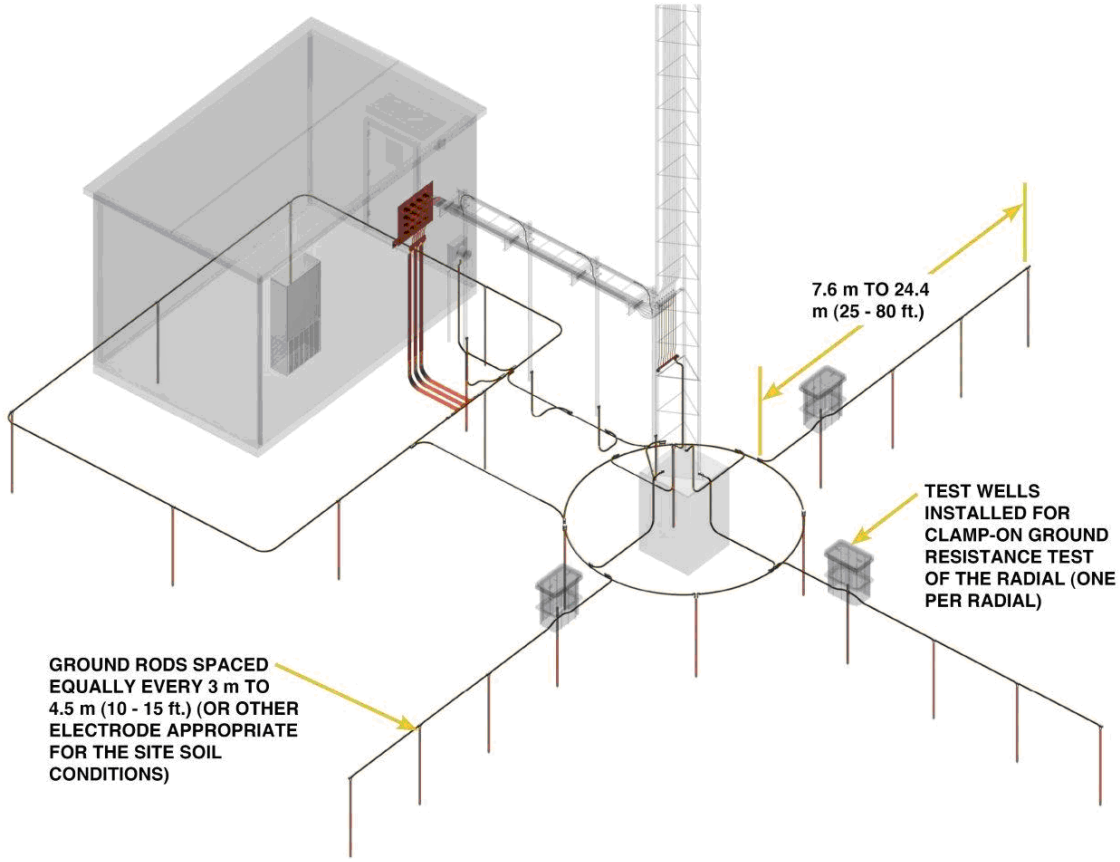


Figure D-1. Supplemental Grounding Electrode System With Test Locations

D.4 Fall-of-Potential Testing Procedure

D.4.1 Test Description and Theory

The fall-of-potential test is the most widely accepted and recommended test method. This procedure is documented in IEEE 81-2025, BS 7430:2026, MIL-HDBK-419A, NFPA 780-2026 and NWSM 30-4106:2017, which should be referred to for more details.

The principle of grounding electrode system resistance measurements is shown in Figure D-2. R is the grounding electrode or grounding electrode system under test, Y is the auxiliary potential electrode, and Z is an auxiliary current probe. A known current is passed through the grounding electrode system under test (R) and returns through the auxiliary current probe (Z). The ground resistance tester measures the voltage (V) between R and Y. With the known test current (I) and measured voltage (V) between R and Y, the ground resistance tester applies Ohm's law (R=V/I) to display the resistance.

IMPORTANT: The grounding electrode system under test must be isolated from the utility power ground and all other utility grounds (such as the telephone service provider ground). To achieve an accurate measurement, all test current from the meter must flow through the grounding electrode system under test. If the grounding electrode system under test is not isolated, the test current divides among all available paths, resulting in an inaccurate measurement of the grounding electrode system.

In the fall-of-potential test, two test rods are driven into the soil. These rods are placed in a straight line from the grounding electrode system to be tested (referred to here as connection **X**). One of the test rods, rod **Z**, is placed at a known distance from the **X** connection. The other test rod (rod **Y**) is placed at various distances between the **X** connection and rod **Z**. If a known current is applied between the **X** connecting point and rod **Z**, a voltage (E) difference exists between the **X** connection and rod **Y**. The ground resistance tester measures the voltage drop between the **X** connection and rod **Y** and converts the measurement to a resistance reading using Ohm's Law (R= E/I). In this manner, the resistance between the **X** connection and rod **Z** can be measured. The multiple readings obtained during this test are entered and plotted as data points on a graph. From the graph, the resistance of the grounding electrode system can be determined.

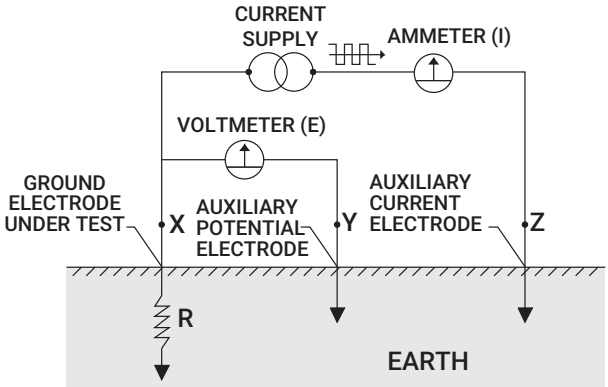


Figure D-2. Principles of Grounding Electrode Resistance Measurement

NOTE: Voltage may be abbreviated as E or V.

NOTE: The tester terminals may be labeled differently on different tester models. See the tester's User Manual for details.
For example, the following naming conventions are typical:

X, **Y** and **Z** on a three-terminal tester (the naming convention used throughout this appendix)
X/Xv, **Y** and **Z** on a four-terminal tester
X, **P** and **C** on a three-terminal tester
C1/P1, **P2** and **C2** on a four-terminal tester
E/ES, **S** and **H** on a four-terminal tester

To obtain accurate ground resistance measurements, the Z probe must be placed far enough away from the grounding electrode system under test (see “Testing Area Requirements” on page D-8). The effective resistance areas (spheres of influence) of the grounding electrode system under test (X), the test probe (Y) and the auxiliary current probe (Z) must not overlap (see “Ground Rod Resistance Characteristics and Sphere of Influence” on page 4-10 for additional information). Figure D-3 is an example of the effective resistance areas improperly overlapping. Overlapping effective resistance areas will result in an inaccurate ground resistance reading.

NOTE: Multiple Y location readings must be taken and plotted on a graph. Correctly spaced probes result in a plateau on the graph (see “Interpreting Test Results” on page D-16).

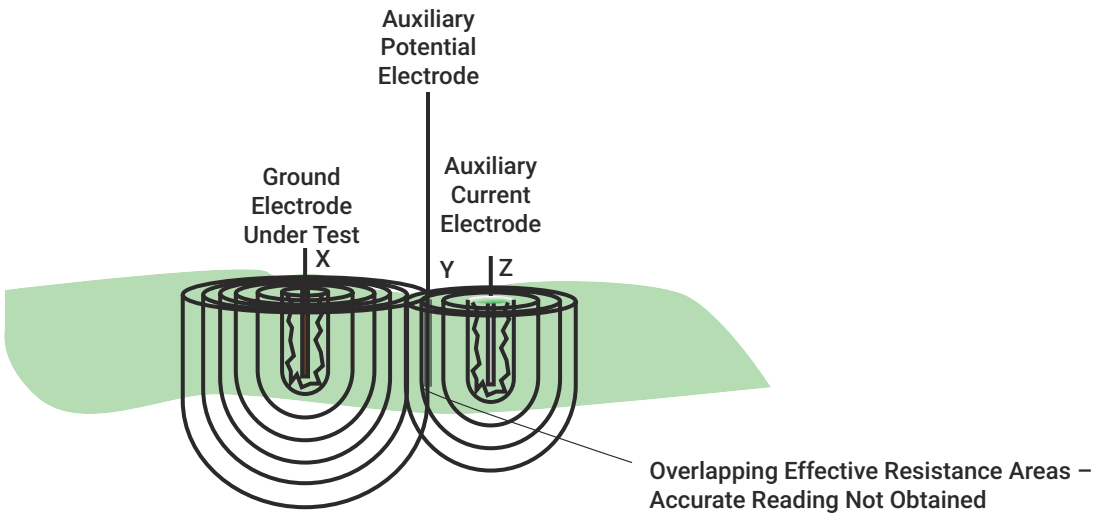


Figure D-3. Effective Resistance Areas Improperly Overlapping

D.4.1.1 Meter and Test Accuracy Considerations

Fall-of-potential resistance measurements have accuracy limitations that can affect the measured pass/fail limit. While the accuracy limitation does not affect most readings, it may have an impact on measurements that slightly exceed the resistance design goal for the site. The Z probe spacing affects the test accuracy. For example, a Z probe spacing of 5 x has a 90% accuracy, and a Z probe spacing of 10 x has a 95% accuracy. See Table D-1 for resistance accuracy versus Z probe spacing.

Table D-1. Resistance Measurement Accuracy vs. Z Probe Spacing

Accuracy	Probe Spacing
90%	5 x diagonal under test
95%	10 x diagonal under test
98%	25 x diagonal under test
99%	50 x diagonal under test
Source: MIL-HDBK-419A	

In addition to the measurement accuracy related to the Z probe spacing, the meter has accuracy limitations that should be considered for measurements that just exceed the resistance design goal for the site. Common meters have an accuracy of ±2% of the reading; this is the assumed accuracy throughout this manual (see the meter's User Manual).

The following examples show the measurement tolerance for Light Duty (25 Ω), Standard Duty (10 Ω), and Extra Duty (5 Ω) sites for 5 x and 10 x Z probe spacings.

- **Light Duty: Design Goal 25 Ω**

  Meter accuracy = ± 2% of reading

  5 x Z probe spacing accuracy = 90%

  10 x Z probe spacing accuracy = 95%

  Applying the measurement accuracy and then the meter accuracy, the acceptable pass/fail upper limits are as follows:

  - 5 x Z probe spacing upper limit = **28.0** Ω
  - 10 x Z probe spacing upper limit = **26.8** Ω

- **Standard Duty: Design Goal 10 Ω**

  Meter accuracy = ± 2% of reading

  5 x Z probe spacing accuracy = 90%

  10 x Z probe spacing accuracy = 95%

  Applying the measurement accuracy and then the meter accuracy, the acceptable pass/fail upper limits are as follows:

  - 5 x Z probe spacing upper limit = **11.2** Ω
  - 10 x Z probe spacing upper limit = **10.7** Ω

- **Extra Duty: Design Goal 5 Ω**

  Meter accuracy = ± 2% of reading

  5 x Z probe spacing accuracy = 90%

  10 x Z probe spacing accuracy = 95%

  Applying the measurement accuracy and then the meter accuracy, the acceptable pass/fail upper limits are as follows:

  - 5 x Z probe spacing upper limit = **5.6** Ω
  - 10 x Z probe spacing upper limit = **5.4** Ω

D.4.2 Required Test Equipment and Supplies

The following test equipment and supplies are required for performing the fall-of-potential test:

- Fall-of-potential ground resistance tester (with supplied User Manual)
- Meter test leads and probes
- Small sledgehammer
- Tape measure
- Safety glasses
- Insulated electrician's footwear and gloves
- Several photocopies of Table D-7, which are needed to record and keep track of several measurements across the site.
- Several photocopies of Figure D-21, which are needed to graph the resistance profile across the measurement area. Alternatively, a simple spreadsheet program can be used to graph the measurements.

D.4.3 Preparation for Testing

D.4.3.1 Testing Area Requirements

The fall-of-potential test requires a reference test rod (outer reference test probe Z) be placed outside the field of influence of the grounding electrode system. In some cases, this required location is outside of the site property line. Figure D-4 shows a typical site layout and its required spacing distance between the site and the reference test rod. The following stipulations apply:

- For a **single ground rod**, the distance of the reference probe **shall** be minimally 5 times, to preferably 10 times, the depth of the ground rod from the surface of the soil to the bottom of the buried ground rod. For fall-of-potential testing distance measurements, the planar center of a single ground rod is the rod connecting point above ground.
- For a **multi-bonded complex grounding electrode system**, the distance of the reference probe **shall** be minimally 5 times, to preferably 10 times the diagonal distance of the grounding electrode system. For fall-of-potential testing distance measurements, the planar center of a multi-bonded complex grounding electrode system is the extreme edge of the system in the direction of where the test probes are inserted. Table D-1 shows the relationship between resistance measurement accuracy and reference Z probe spacing.

IMPORTANT: If radial grounding conductors are used in the grounding electrode system (as in Figure D-1), they must be considered when measuring the diagonal distance. This diagonal distance is then used to determine the required Z probe placement.

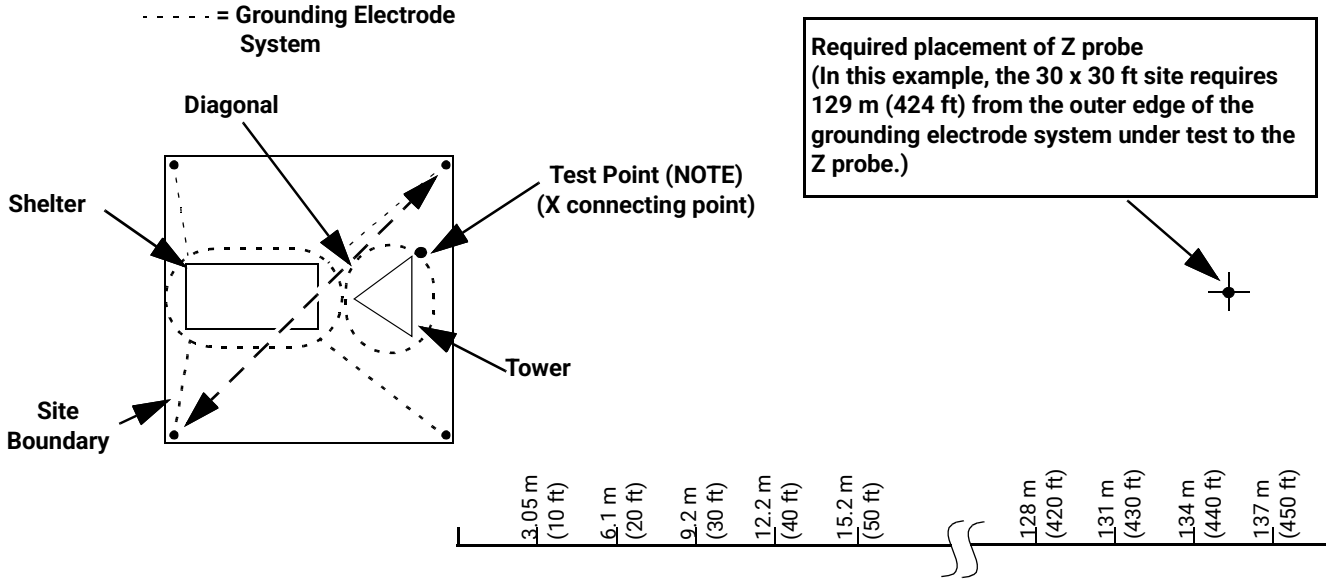


Figure D-4. Outer Reference Electrode (Z Probe) Placement for a Typical Site

NOTE: The connection point of meter X clip is typically on the outer edge of the grounding electrode system, such as a fence post grounding conductor or tower leg grounding conductor.

NOTE: Any required permissions **shall** be obtained for accessing and placing a test probe on adjacent property.

Use Table D-2 or Table D-3 to obtain the value for the10-times spacing distance between the site and the outer reference test probe (Z). Table D-2 provides values in feet, and Table D-3 provides values in meters. For the minimum 5 times distance, divide the resulting numbers by 2.

Table D-2. Required Z-Probe Spacing for Site Lengths and Widths (In Feet)

	Site Length (ft)									
Site Width (ft)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
10	141	224	316	412	510	608	707	806	906	1005
20	224	283	361	447	539	632	728	825	922	1020
30	316	361	424	500	583	671	762	854	949	1044
40	412	447	500	566	640	721	806	894	985	1077
50	510	539	583	640	707	781	860	943	1030	1118
60	608	632	671	721	781	849	922	1000	1082	1166
70	707	728	762	806	860	922	990	1063	1140	1221
80	806	825	854	894	943	1000	1063	1131	1204	1281
90	906	922	949	985	1030	1082	1140	1204	1273	1345
100	1005	1020	1044	1077	1118	1166	1221	1281	1345	1414
110	1105	1118	1140	1170	1208	1253	1304	1360	1421	1487
120	1204	1217	1237	1265	1300	1342	1389	1442	1500	1562
130	1304	1315	1334	1360	1393	1432	1476	1526	1581	1640
140	1404	1414	1432	1456	1487	1523	1565	1612	1664	1720
150	1503	1513	1530	1552	1581	1616	1655	1700	1749	1803
160	1603	1612	1628	1649	1676	1709	1746	1789	1836	1887
170	1703	1712	1726	1746	1772	1803	1838	1879	1924	1972
180	1803	1811	1825	1844	1868	1897	1931	1970	2012	2059
190	1903	1910	1924	1942	1965	1992	2025	2062	2102	2147
200	2002	2010	2022	2040	2062	2088	2119	2154	2193	2236

Table D-3. Required Z-Probe Spacing For Site Lengths and Widths (In Meters)

Site Width (m)	Site Length (m)									
	3	6	9	12	15	18	21	24	27	30
3	43	68.3	96.3	125.6	155.4	185.3	215.5	245.7	276.1	306.3
6	68.3	86.3	110	136.2	164.3	192.6	221.9	251.5	281	310.9
9	96.3	110	129.2	152.4	177.7	204.5	232.3	260.3	289.3	318.2
12	125.6	136.2	152.4	172.5	195	219.8	245.7	272.5	300.2	328.3
15	155.4	164.3	177.7	195	215.5	238	262.1	287.4	313.9	340.8
18	185.3	192.6	204.5	219.8	238	258.8	281	304.8	329.8	355.4
21	215.5	221.9	232.3	245.7	262.1	281	301.8	324	347.5	372.2
24	245.7	251.5	260.3	272.5	287.4	304.8	324	344.8	367	390.4
27	276.2	281	289.3	300.2	313.9	329.8	347.5	367	388	410
30	306.3	310.9	318.2	328.3	340.8	355.4	372.2	390.4	410	431
33	336.8	340.8	347.5	356.6	368.2	381.9	397.5	414.5	433.1	453.2
37	367	371	377	385.6	396.2	409	423.4	439.5	457.2	476
40	397.5	400.8	406.6	414.5	424.6	436.5	449.9	465.1	482	499.9
43	428	431	436.5	443.8	453.2	464.2	447	491.3	507.2	524.3
46	458.1	461.2	466.3	473	482	493	504.4	518.2	533.1	549.6
49	488.6	491.3	496.2	502.6	510.8	520.9	532.2	545.3	559.6	575.2
52	519	521.8	526	532.2	540.1	549.6	560.2	572.7	586.4	601
54.9	549.6	552	556.3	562	569.4	578.2	588.6	600.5	613.3	627.6
57.9	580	582.2	586.4	591.9	598.9	607.2	617.2	628.5	640.7	654.4
60.1	610.2	612.6	616.3	621.8	628.5	636.4	645.9	656.5	668.4	681.5

D.4.3.2 Test Direction and Other Test Tips

Choose a test direction (determined by the location of the Z probe) that does not parallel any buried metallic objects that could impact the measurements by providing an alternative path for the test current. Such buried objects include water pipes, conduits, cables, tanks, concrete footings (due to the rebar), and so on.

Choose a test direction that is not near overhead high-voltage lines and does not parallel them. The overhead power lines can induce noise into the meter, creating an invalid measurement. If the test must be performed close to the overhead high-voltage lines, ensure the test direction and test leads are perpendicular to the overhead lines. This should reduce any induced noise. Further noise induction can be reduced by twisting the test leads together (see the meter's User Manual for more information).

Compact the soil directly around the auxiliary test electrodes to ensure good contact with the earth. If the meter displays errors and/or has difficulty obtaining a stable measurement, there may be too much auxiliary probe contact resistance. An effective way of decreasing the auxiliary probe contact resistance is to pour water (or sports drink) around the auxiliary rod, as illustrated in Figure D-5. Adding moisture helps achieve a better electrical connection and does not influence the overall results. Do not pour water around an electrode under test.

IMPORTANT: Do not pour water around a grounding electrode under test. Doing so artificially enhances the measurement, resulting in an inaccurate reading. Water **shall** only be added to an auxiliary test probe.

NOTE: Contact the meter manufacturer or engineering firm for testing recommendations on asphalt or other hard surfaces.

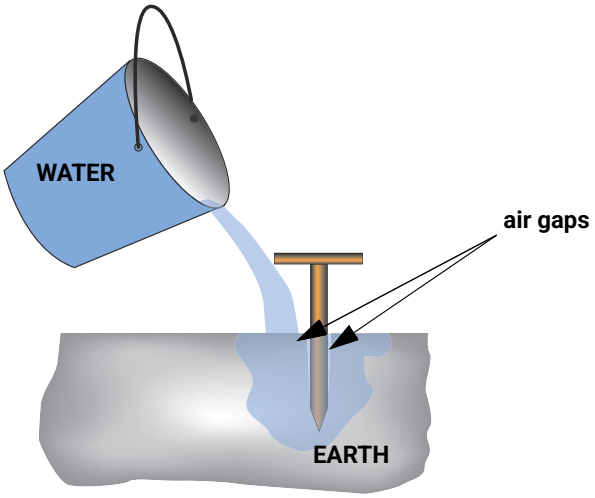


Figure D-5. Improving Electrical Contact by Adding Water to the Soil

D.4.3.3 Site AC Power And Other Utility Disconnect Requirements

To perform the fall-of-potential test, the site grounding electrode system must be disconnected from the electric utility grounded conductor (may be a neutral) and any other ground (such as telephone service provider ground). Isolating the site grounding electrode system from the electric utility ground (and other utility grounds) is required to allow testing that is limited to the site grounding electrode system. Attempting to perform measurements while the site remains connected to the electric utility ground (or other utility ground) artificially enhances the grounding electrode system reading, resulting in measurement error.

NOTE: A suggested best practice in new construction is to test the grounding electrode system resistance before it is bonded to the electric utility ground, other utility grounds, and other items that may provide a secondary path to the utilities.

At an existing site supplied by commercial AC power, the following steps must be taken before performing a fall-of-potential test:

1. Coordinate the test with the customer and/or site owner and all other affected parties.
2. Arrange for the site to have the commercial electric utility turned off. If the site must remain operational while testing is performed, the site should be switched to a backup power source if it is available.

WARNING: Check for current on the grounding electrode conductor before disconnecting. Never disconnect the ground of a live circuit. Disconnecting the ground of a live circuit could cause severe injury or death.

3. Have the site grounding electrode system isolated from the electric utility grounded conductor by a qualified electrician, ensuring that it has no secondary path to the site via a conduit or other connection (this can be verified using a multi-meter). The only way to achieve this at a communications site with a multi-bonded complex grounding electrode system is to disconnect the utility grounded conductor (may be a neutral) from the site, including the bond normally located inside the utility meter base.

4. Remove any other grounding electrode connection that may influence the measurement of the onsite grounding electrode system, such as the telephone service provider ground and metallic water/gas pipes.

D.4.3.4 Fall-of-Potential Test Procedure

Figure D-6 shows typical ground resistance tester connections and test probe orientations.

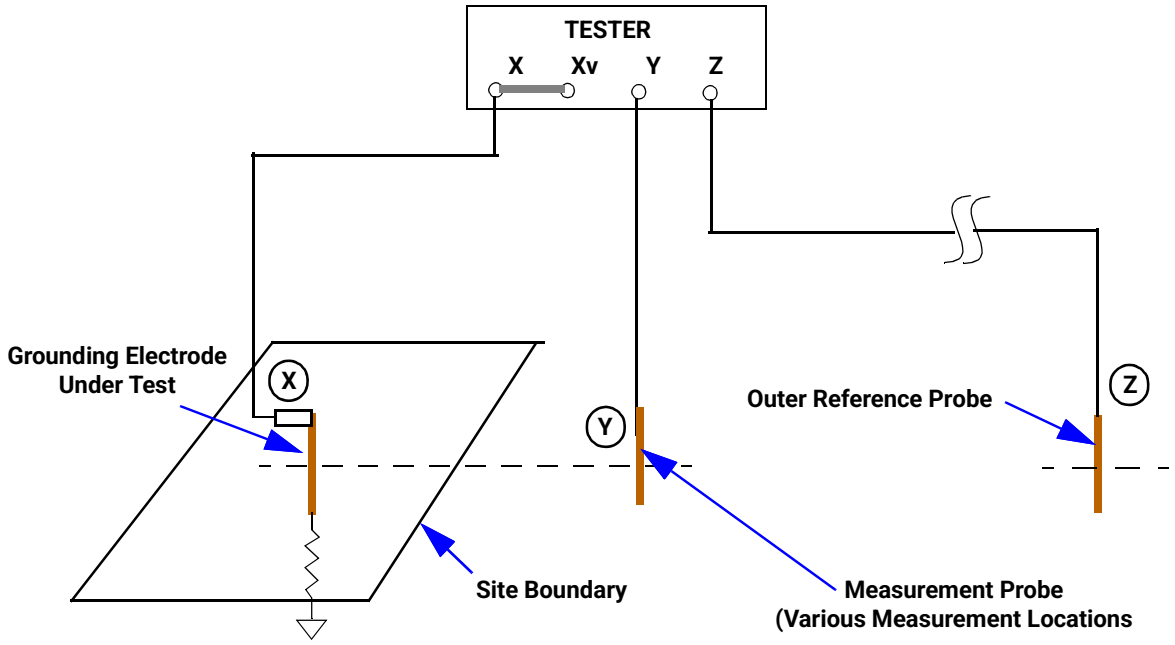


Figure D-6. Typical Ground Resistance Tester Connection

WARNING: Follow the ground resistance tester manufacturer's warning and caution information. Follow furnished instructions when inserting and removing test rods into soil. Make certain this procedure is fully understood before proceeding.

Perform the fall-of-potential test as follows:

1. Isolate the grounding electrode system as described in “Site AC Power And Other Utility Disconnect Requirements” on page D-12.

2. On the Ground Resistance Tester, connect test leads to the **X**, **Y and Z** terminals.

3. Short the **X** and **Xv** connections on the Ground Resistance Tester, if applicable.

4. Connect the **X** test lead to the grounding electrode system under test. This is typically via a test clip connection to an external ground busbar or grounding conductor.

5. Connect the **Y** test lead to the measurement (**Y**) probe.

6. Determine the required placement of outer reference probe (**Z**) according to section “Testing Area Requirements” on page D-8.
7. Place the outer reference probe (**Z**) into the soil at the determined location. Connect the outer reference probe (**Z**) to meter terminal **Z**.
8. Note the distance of the outer reference probe (**Z**) from the grounding electrode system (this distance will be used in determining subsequent measurements). On a photocopy of the fall-of-potential test worksheet (on page D-33), write this distance in the “99%” space.
9. Place the measurement probe (**Y**) in the soil starting close to the area of the grounding electrode system under test. This location must be outside the confines of the grounding electrode system and metallic fence (if present). Take a measurement.
10. On the fall-of-potential test worksheet photocopy, write the reading in the “1%” row of the worksheet.
11. Place the measurement probe (**Y**) at 5% of the distance between the grounding electrode system '**X**' connection and the outer reference probe (**Z**). Take a measurement.

Example: Assuming a “99%” distance of 131 m (430 ft), **Y** probe would be placed at 6.55 m (21.5 ft) for “5%” measurement location.

IMPORTANT: Placement of the measurement probe (**Y**) must be along a straight path between the grounding electrode system '**X**' connection and the outer reference probe (**Z**).

12. On the fall-of-potential test worksheet photocopy, write down the reading in the appropriate row of the worksheet.
13. Place the measurement probe (**Y**) at 10% of the distance between the grounding electrode system '**X**' connection and the outer reference probe (**Z**). Take a measurement.

Example: Assuming a “99%” distance of 131 m (430 ft), **Y** probe would be placed at 13.1 m (43 ft) for “10%” measurement location.

14. Write down the reading in the appropriate row of the fall-of-potential test worksheet photocopy.
15. Repeat steps 13 and 14 for all remaining test locations on the worksheet.
16. Make a photocopy of the fall-of-potential test graph form (page D-35). On the photocopy, plot a graph of the measured resistances for all points listed on the worksheet. Figure D-7 is an example measurement graph.
17. Proceed to “Interpreting Test Results” on page D-16.

If sufficient access area exists, the entire procedure should be repeated in different directions facing away from the center of the grounding electrode system. Repeating the procedure is recommended in case metal pipes or similar conductive objects are buried within the test area. Metal pipes or similar conductive objects may result in an inaccurate reading.

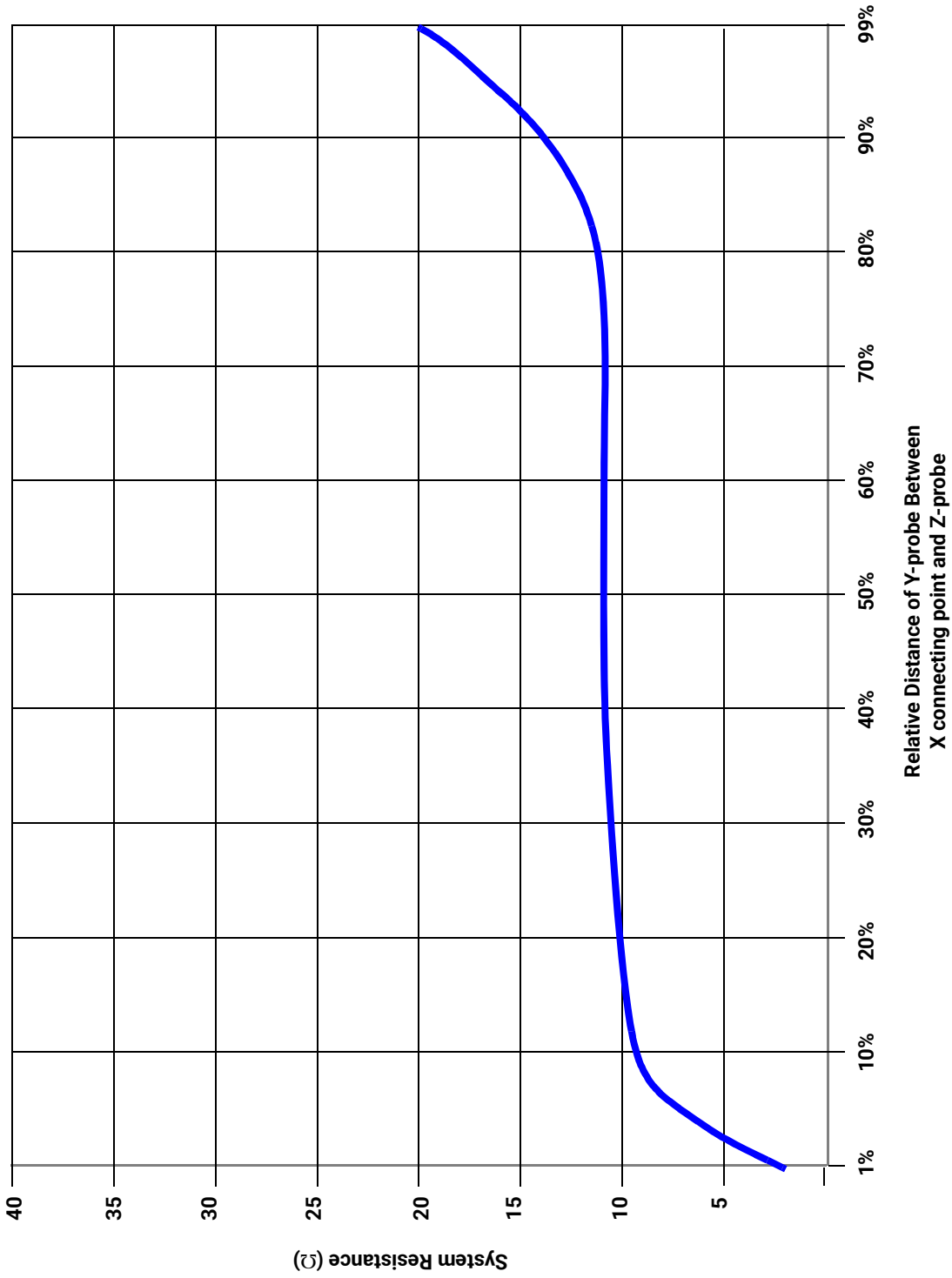


Figure D-7. Fall-of-Potential Test Graph Example

Table D-4. Sample Fall-of-Potential Test Data

Distance from Grounding Electrode System Grid		Test Data
Percentage	**ft (m)**	**Ohms (Ω)**
1%	0	2.5 Ω
5%	21.5 ft (6.55 m)	7 Ω
10%	43 ft (13.1 m)	9.5 Ω
20%	86 ft (16.2 m)	11.3 Ω
30%	129 ft (39.3 m)	11.4 Ω
40%	172 ft (52.4 m)	11.4 Ω
50%	215 ft (65.5 m)	11.5 Ω
60%	258 ft (78.6 m)	11.5 Ω
70%	301 ft (91.7 m)	11.6 Ω
80%	344 ft (104.8 m)	11.9 Ω
90%	387 ft (117.9 m)	13.7 Ω
99%	430 ft (131 m)	20 Ω

D.4.3.5 Interpreting Test Results

This section provides information on interpreting fall-of-potential grounding electrode system resistance tests. For the resistance of a grounding electrode system to be correctly determined using the fall-of-potential method, multiple Y probe measurements must be taken and plotted on a graph as described in “Fall-of-Potential Test Procedure” on page D-13. A simple spreadsheet program can be used to graph the measurements.

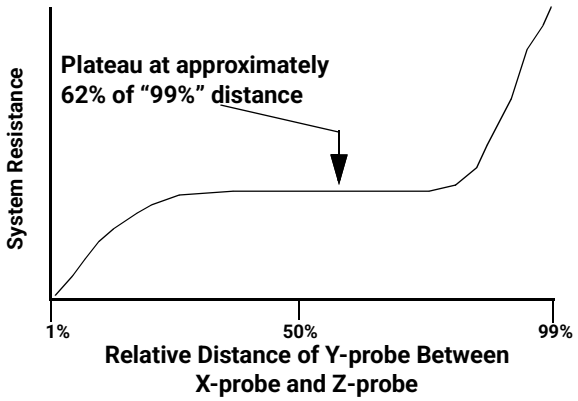
Using Figure D-8, assess the test results as follows:

- Valid Test: At approximately 62% of the total distance (“99%” distance), a plateau or “flat spot” should be noticeable in the plot, as shown in the top example of Figure D-8. The resistance at this plateau is the validated resistance of the system under test.
- Invalid Test Graph (insufficient distance of Z-probe): If there is no plateau on the plot, shown in the middle example of Figure D-8, the test is considered invalid because the Z probe is not far enough from the X probe.
- Invalid Test Graph (erroneous connection to neutral): If there appears to be a plateau on the plot, but the curve has very little change until the point nearest the remote current probe, as shown in the bottom example of Figure D-8, the test is considered invalid because an erroneous connection of the grounding electrode system to an electric utility neutral or other utility ground, remains.
- Figures D-9, D-10 and D-11 show additional fall-of-potential graphs relating to the effective resistance area (sphere of influence) of the grounding electrode system.

IMPORTANT: For a fall-of-potential test to be valid, multiple Y probe measurements must be taken and plotted on a graph, and the graph must contain a plateau. Graphs that do not contain a plateau are not valid; therefore, the test must also be considered invalid.

VALID TEST GRAPH

At approximately 62% of the total distance, a plateau or "flat spot" should be noticeable in the plot. The resistance at this plateau is the resistance of the system under test.

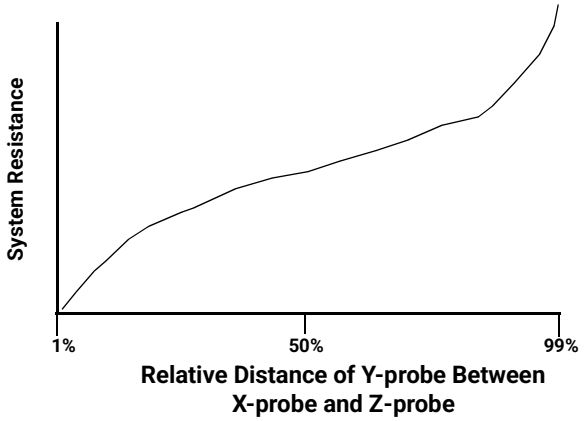


THE FARTHER THE Z PROBE IS SPACED AWAY FROM THE SITE, THE LARGER THE PLATEAU MAY BE.

INVALID TEST GRAPH (Z-Probe Spacing)

The Z probe is not placed far enough from the grounding electrode system.

Reposition Z-probe farther away from X connecting point and repeat test.



INVALID TEST GRAPH (Connection to neutral)

Due to a connection that still exists to the electric utility neutral conductor or other utility, the resulting curve has very little change until the point nearest the remote current probe. No valid plateau exists.

Disconnect the utility ground connection and repeat test.

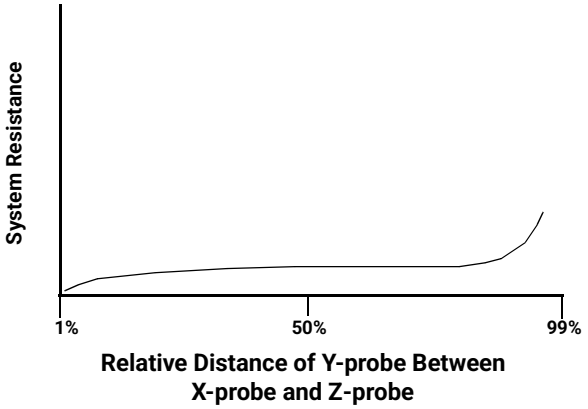


Figure D-8. Typical Fall-of-Potential Test Graph Results

Figure D-9 shows a valid fall-of-potential graph. The graph contains a sharp rise at the beginning, a plateau in the middle and a sharp rise near the end. A plateau is obtained because the Z probe is spaced far enough away that the effective resistance areas (spheres of influence) of the grounding electrode system and the Z probe do not overlap.

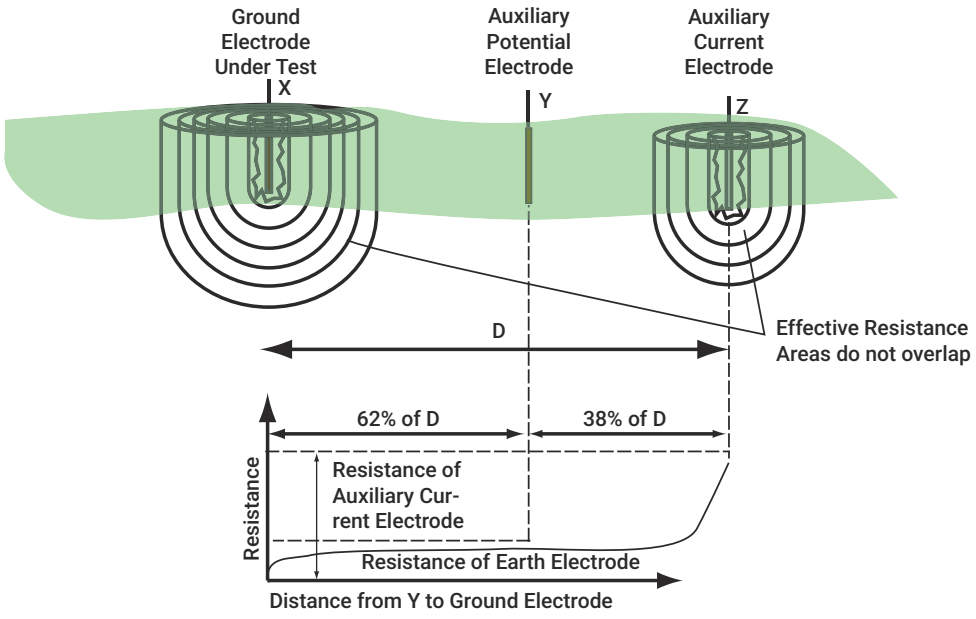


Figure D-9. Valid Test Graph: No Overlap of Effective Resistance Areas of X, Y and Z

Figure D-10 shows an invalid fall-of-potential graph. The graph does not contain a plateau in the middle. A plateau was not obtained because the Z probe was not spaced far enough away from the grounding electrode system. The improper Z probe spacing caused the effective resistance areas (spheres of influence) of the grounding electrode system and the Z probe to overlap.

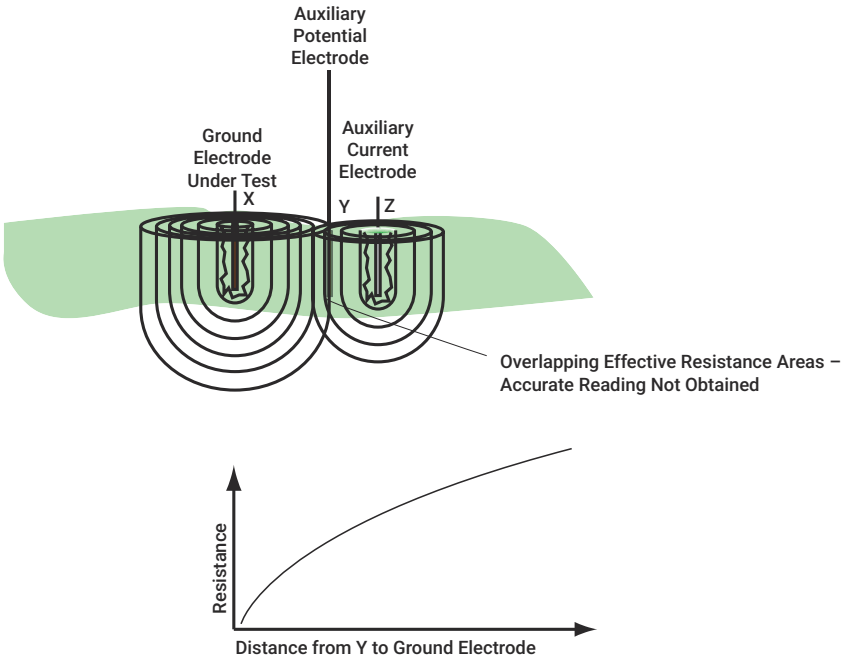


Figure D-10. Invalid Test Graph: Effective Resistance Areas of X, Y and Z Overlap

Figure D-11 shows an invalid fall-of-potential graph. The graph has very little change until the point nearest the remote current probe (Z). This graph response indicates a test performed while the electric utility or other utility ground is still connected to the grounding electrode system. Note that the grounding electrode system's effective resistance area (sphere of influence) is contained within the AC utility sphere of influence.

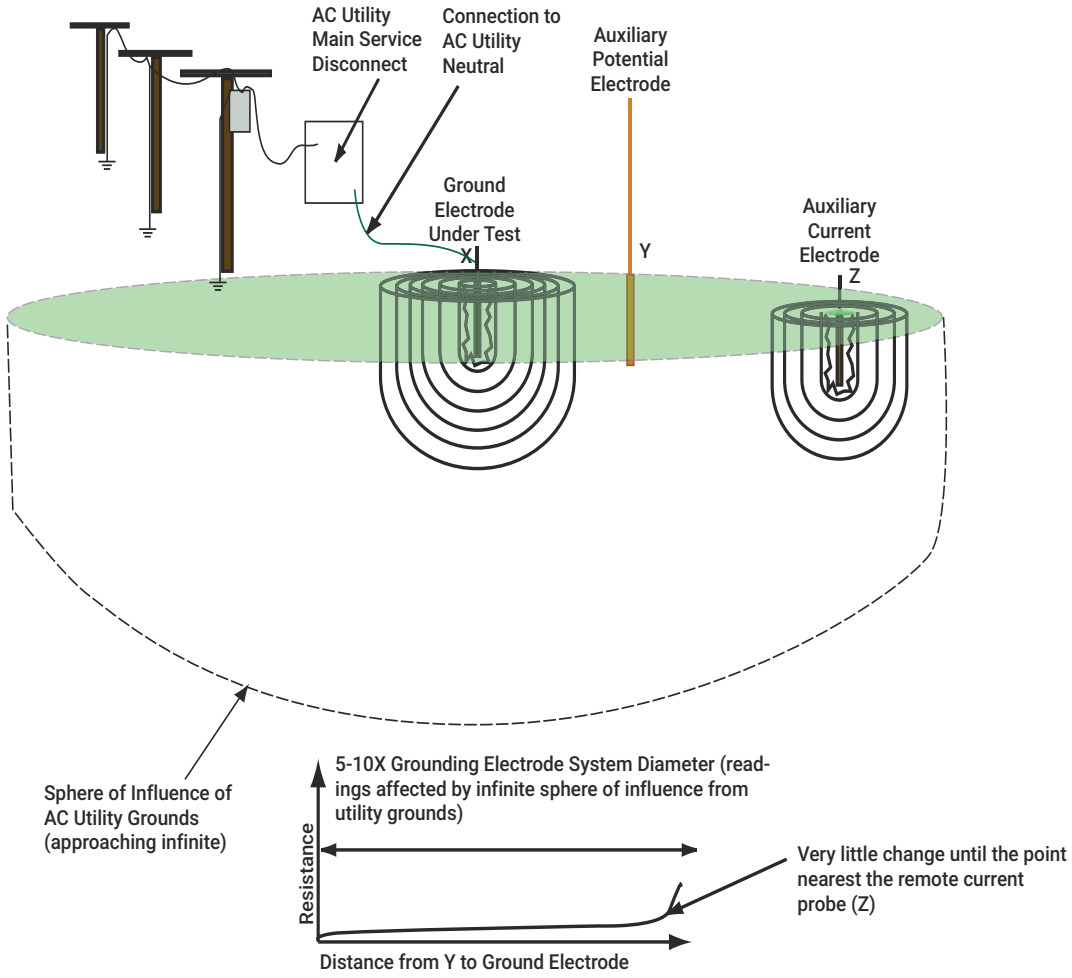


Figure D-11. Invalid Test Graph: The Grounding Electrode System is Not Isolated From the AC Utility Ground

D.5 Clamp-On Ohmmeter Testing Procedure

The clamp-on ground resistance test (also known as the clamp-on ohmmeter test) is an effective alternative to the fall-of-potential test (see BS 7430:2026, section 9.3.4, and IEEE 81-2025, section 8.5). The clamp-on ohmmeter test can be used in many applications that might not be practicable for the fall-of-potential test. Such applications may include testing at sites with limited available land for the fall-of-potential test or testing live sites where isolation of the AC utility power ground may not be practicable.

The clamp-on ohmmeter test can be performed on a single grounding electrode and a multi-bonded complex grounding electrode system (such as at a communications site). However, the test can only be accurately performed on sites supplied by commercial power.

The test is considered very reliable for a single grounding electrode system and can be easy to perform. However, for a multi-bonded complex grounding electrode system (such as at a communications site), the test is more challenging to perform and may result in an error reading due to parallel paths. The test procedure in this section has provisions to help avoid such errors.

IMPORTANT: If the electrical service provided by the electric utility does not contain a grounded conductor that is bonded to the extensive electric utility grounding system, the clamp-on ohmmeter will not give an accurate reading. In these cases, there is no effective low resistance return path (zero ohm reference) for the meter.

NOTE: In addition to testing the resistance of a grounding electrode system, the clamp-on ohmmeter is also an effective tool for verifying bonding connections. See “Clamp-on Ohmmeter Bonding Continuity Testing” on page D-30.

D.5.1 Test Description

The clamp-on ohmmeter works by inducing a low-frequency test current (usually between 1 kHz and 3.4 kHz) from a known voltage source into a conductive loop. The magnitude of the test current is a function of the loop resistance (Ohm’s law). The meter operator must determine and understand what loop they are measuring. The placement of the meter determines the loop being measured.

Figure D-12 illustrates some conductive loops and meter readings based on meter location.

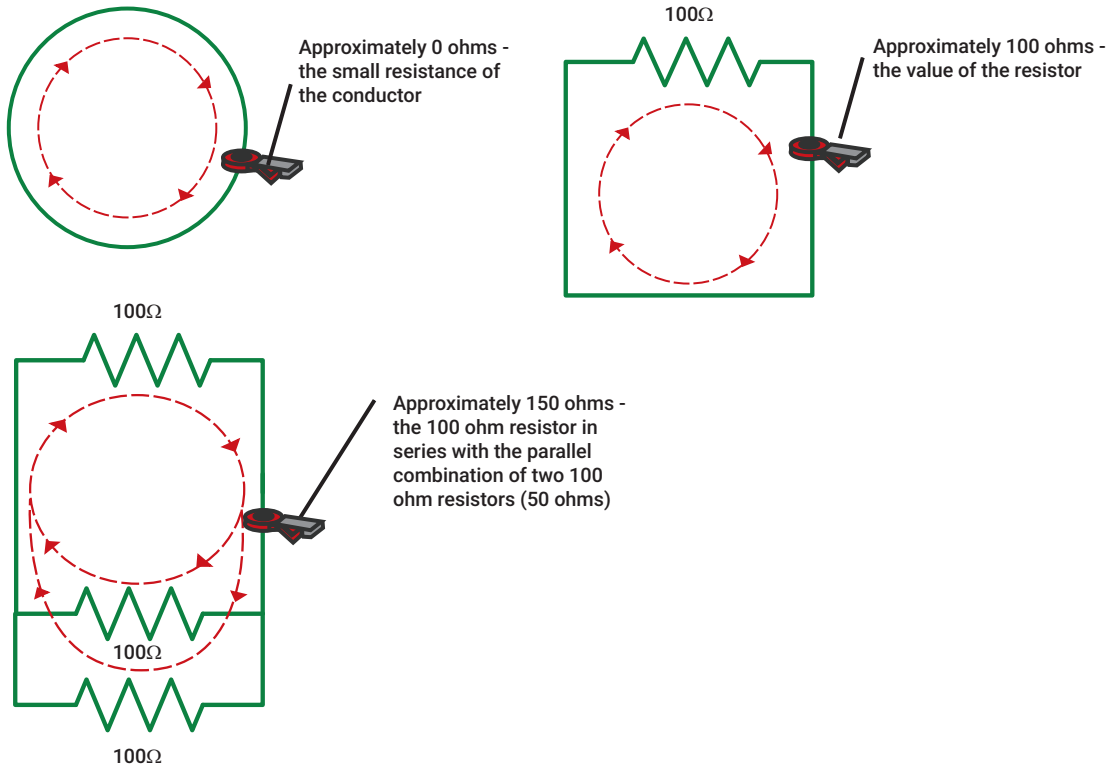


Figure D-12. Clamp-On Ohmmeter Reading Fundamentals

In the case of testing the resistance of a grounding electrode system, the following form the loop:

- The grounding electrode system
- The earth
- The electric utility’s extensive ground system
- The electric utility grounded conductor (may be a neutral)

In summary, the loop in this case consists of the grounding electrode system under test, which is in series with the parallel combination of all the grounding electrodes that are part of the utility (this includes the ground rods from every house, commercial building, utility transformers and any other grounds that are part of the utility power grid). The total effective resistance of the parallel utility grounds is typically very low. Therefore, its value has little impact on the loop resistance.

The test current (I) flows from the grounding electrode system through the earth and returns to the grounding electrode system (and the meter) via the electric utility grounding system and multi-grounded neutral conductor. The meter then measures this current and converts the measurement to a resistance reading using the known voltage (E) and Ohm's Law (R= E/I). The meter displays the resistance of the grounding electrode system in ohms. Because the electric utility grounding system is so extensive (typically less than 1 ohm), it has little effect on most readings, but may become a factor when trying to measure lower resistance values (see Section D.5.1.1 below).

Figure D-13 provides a schematic representation of how the clamp-on ohmmeter measures the resistance of a grounding electrode system.

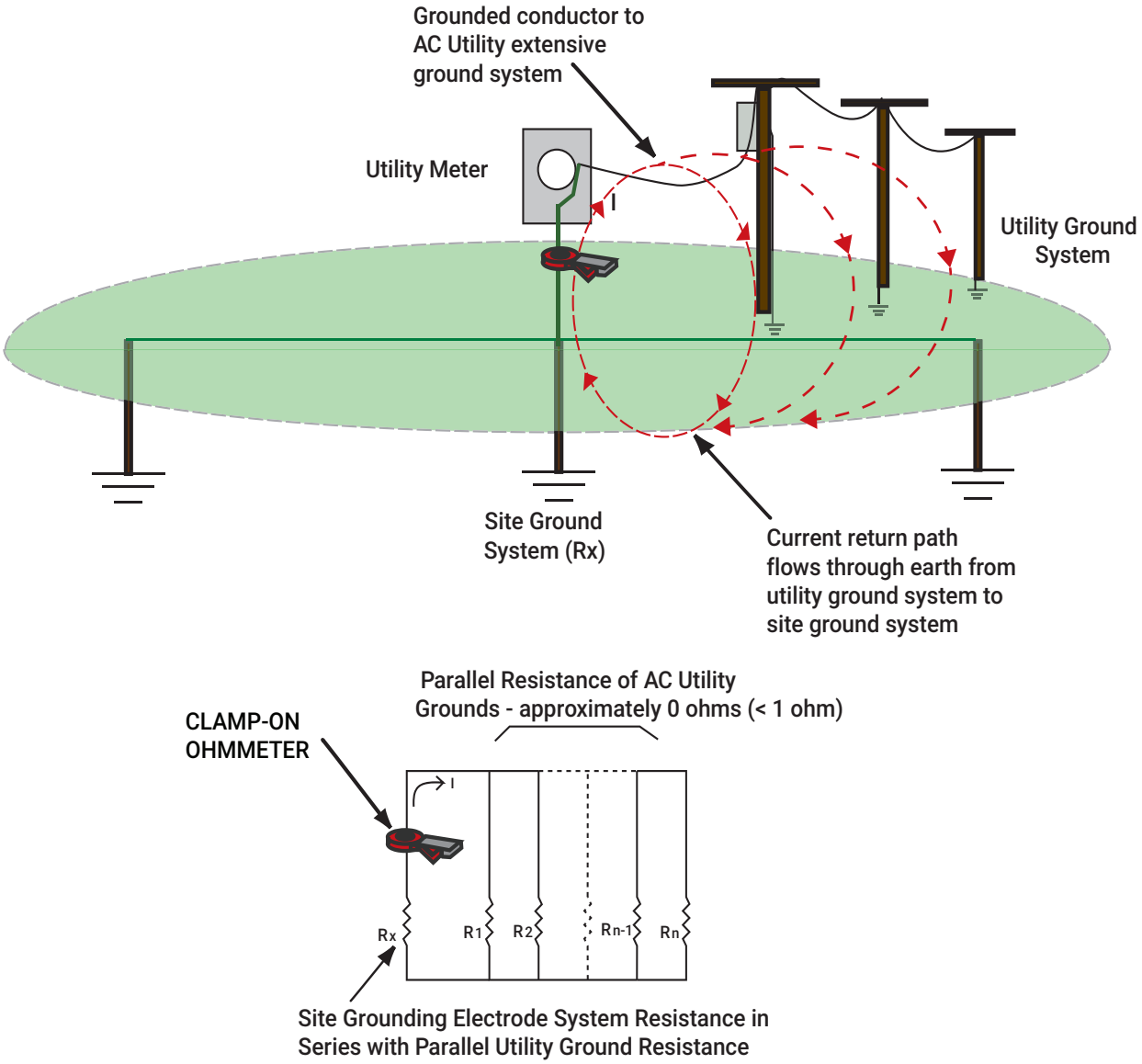


Figure D-13. Clamp-On Ground Resistance Measurement of Site Grounding Electrode System

Figure D-14 illustrates how the combined near-zero resistance of the many utility grounds provides the return path for the clamp-on ohmmeter measuring the resistance of a grounding electrode system.

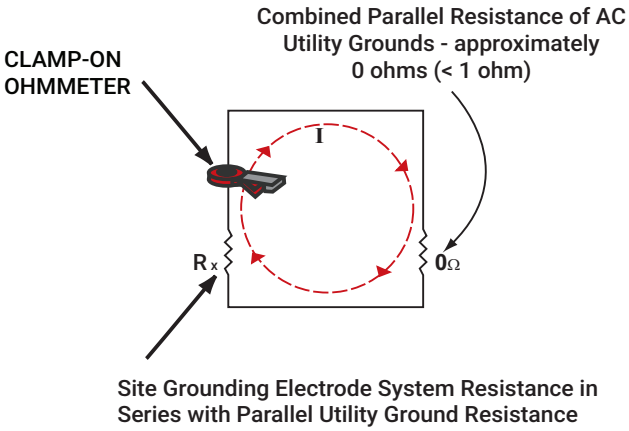


Figure D-14. Clamp-On Ground Resistance Measurement of Site Grounding Electrode System

D.5.1.1 Meter and Test Accuracy Considerations

Clamp-on ground resistance measurements have accuracy limitations that can affect the measured pass/fail limit. The utility ground resistance adds to the measured grounding electrode system value displayed on the meter. While the resistance of the utility ground is typically very low (< 0.5 Ω), it can affect measurements that just exceed the resistance design goal value.

The utility ground should be considered 0.5 Ω at urban sites and can be more at rural sites. This value should be subtracted from the measured value to best evaluate the site's grounding electrode system resistance. For example, the measured value at a Standard Duty site is 10.4 Ω. In this example, the grounding electrode system resistance value should be considered 9.9 Ω (10.4 - 0.5 = 9.9 Ω), therefore, meeting the Standard Duty site's 10 Ω resistance design goal. See BS 7430:2026 and IEEE STD 81 for more information.

If the measured value is significantly higher (for example, +25%) than the engineered design, consult with the design engineer. In these cases, a fall-of-potential test may be needed to confirm the grounding electrode system resistance value. Also, see “Supplemental Grounding Techniques to Help Achieve Resistance Design Goal” on page 4-82 regarding supplemental grounding for sites that do not meet their resistance design goal.

If the measured value meets the design goal requirement, no further consideration of the utility ground is required to determine the pass/fail criteria. For example, the measured value of the grounding electrode system displayed by the meter is 9.5 Ω. In this case, the measured value meets the 10 Ω requirement for a Standard Duty site.

In addition to the measurement inaccuracy caused by utility ground, the meter also has accuracy limitations that should be considered for measurements that just exceed the resistance design goal for the site. Table D-5 summarizes the measurement accuracies for common clamp-on ground resistance meters.

Table D-5. Typical Clamp-on Ohmmeter Accuracy Value

Measurement Range	Accuracy (% of reading)	Additional Measurement Uncertainty
1 - 9.999 Ω	± 1.5%	± 0.1 Ω
10 - 49.999 Ω	± 1.5 - 2.0%	± 0.1 - 0.5 Ω
50 - 99.999 Ω	± 1.5 - 2.0%	± 0.5 Ω
100 - 200 Ω	± 3.0 - 5.0%	± 1.0 Ω

The following examples show the measurement tolerance for Light Duty (25 Ω), Standard Duty (10 Ω), and Extra Duty (5 Ω) sites.

- **Light Duty:**

  25 Ω design goal plus 0.5 Ω for the utility ground = 25.5 Ω

  Applying the accuracy tolerances from Table D-5, the acceptable pass/fail upper limit is **26.5** Ω (± 2.0% ± 0.5 Ω).

- **Standard Duty:**

  10 Ω design goal plus 0.5 Ω for the utility ground = 10.5 Ω.

  Applying the accuracy tolerances from Table D-5, the acceptable pass/fail upper limit is **11.2** Ω (± 2.0% ± 0.5 Ω).

- **Extra Duty:**

  5 Ω design goal plus 0.5 Ω for the utility ground = 5.5 Ω

  Applying the accuracy tolerances from Table D-5, the acceptable pass/fail upper limit is **5.7** Ω (± 1.5% ± 0.1 Ω).

D.5.2 Required Test Equipment and Supplies

The following test equipment and supplies are required to perform a clamp-on ground resistance test:

- Clamp-on Ground Resistance Tester (with supplied User Manual)
- Insulated electrician's footwear and gloves
- Test jumpers for temporary connections
- A photocopy of Table D-8 to record measurements.

D.5.3 Preparations for Testing

D.5.3.1 Site AC Power Disconnect Requirements

This test **does not** require disconnecting the site's grounding electrode system from the electric utility grounded conductor (may be a neutral). The electric utility grounded conductor is required for the meter to display a valid reading. However, for a multi-bonded complex grounding electrode system, it may be necessary to deenergize the site from commercial power if significant unbalanced current flow is present on the grounded conductor. Unbalanced current flow may create noise on the meter, resulting in the inability of the meter to display an accurate reading. The clamp-on ohmmeter typically indicates the noise condition (see the meter's User Manual).

NOTE: If the communications site requires power, a backup generator may be used during the clamp-on ohmmeter test.

NOTE: The clamp-on ohmmeter test can be performed at a site if the electric utility is not yet connected, as long as the electric utility ground is available nearby. A temporary test jumper may be clamped to the site grounding electrode system and to the nearby utility ground. The clamp-on ohmmeter is then placed around this test jumper for a grounding electrode system resistance reading. All other utility grounds must be disconnected from the site. See Figure D-20 for an example.
The resistance of the test jumper should be tested and factored out of the grounding electrode system resistance reading. The resistance can be measured with an ohmmeter or by clipping the ends of the test jumper together and placing the clamp-on ohmmeter around the jumper. See Figure D-20 for an example.

For a site supplied by commercial AC power that contains a neutral conductor which is part of an extensive electric utility grounding system and the site contains a multi-bonded complex grounding electrode system, the following steps must be taken first:

1. Coordinate the test with the customer and/or site owner and all other affected parties.
2. Arrange for the site AC power to be turned off and the site switched to a backup power source if it is available. Any current on the neutral conductor (even if less than 3 – 5 amps) can result in a false reading. It is therefore recommended that the commercial power be turned off to eliminate any currents on the neutral conductor that can affect the meter's ability to give an accurate reading.
3. Removing other utility ground connections (such as telephone) may be necessary, depending on their location. This is typically required for a multi-bonded complex grounding electrode system.

D.5.3.2 Clamp-On Ohmmeter Test Procedures

Depending on whether the site uses a single grounding electrode system (or equivalent) or a multi-bonded complex grounding electrode system, proceed to “Single Grounding Electrode System Testing (or Equivalent)” on page D-24 or “Multi-Bonded Complex Grounding Electrode System Testing” on page D-26 as applicable.

CAUTION: Follow the clamp-on ohmmeter manufacturer's warning and caution information.

D.5.3.3 Single Grounding Electrode System Testing (or Equivalent)

For a site using a single grounding electrode system (or equivalent), perform the test as follows:

1. Locate the grounding electrode connection outside the shelter or the single conductor connecting to the grounding electrode.
2. Clamp the meter around the grounding electrode conductor, ensuring that the meter is positioned below any other utility connection (such as the telephone service provider ground or a water pipe). See Figure D-15 and Figure D-16 for examples.
3. Set the meter to the **Amps** scale and check the grounding electrode conductor for current. Any current on the grounding electrode conductor (even if less than 3 – 5 amps) can result in a false reading. See the meter's User Manual for error conditions resulting from excessive current flow.

WARNING: Any significant current on the grounding electrode conductor could indicate a serious problem and should be investigated by qualified personnel. Motorola Solutions recommends any current above 500mA be reported to the site owner and investigated (the current loading at the site can directly affect this reading; therefore, this current should be measured when the site is at operational load). Consultation with the authority having jurisdiction (AHJ) and/or an electrical engineering firm should be considered.

4. Set the meter to the **Ohms** scale and note the reading. If no noise or other errors are indicated on the meter, this is the resistance of the grounding electrode system under test.
5. Record the reading on a photocopy of the Clamp-on Ohmmeter/Ammeter Test worksheet (page D-37). A digital photograph showing the meter location and displayed resistance value is also recommended.

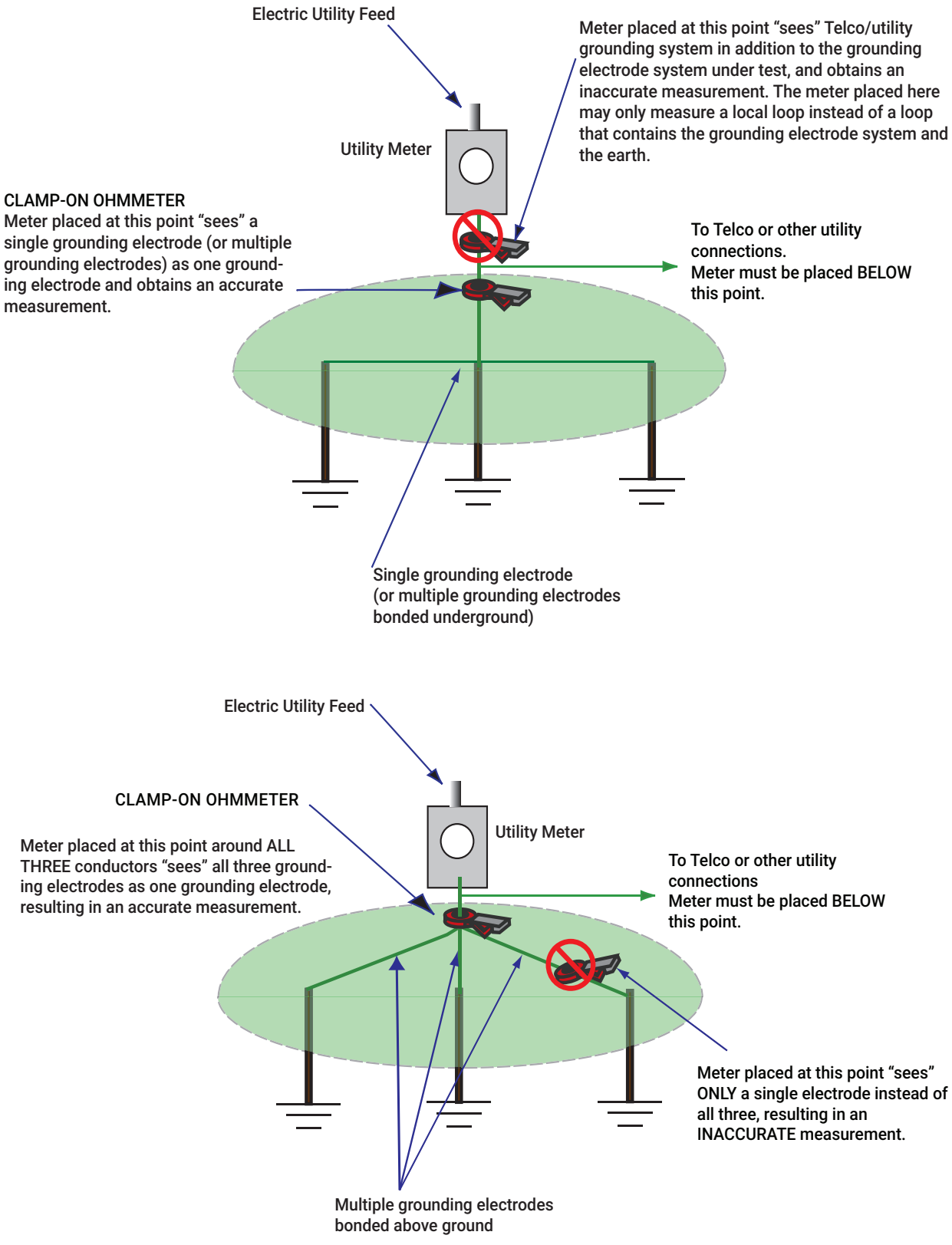


Figure D-15. Clamp-On Ohmmeter Placement

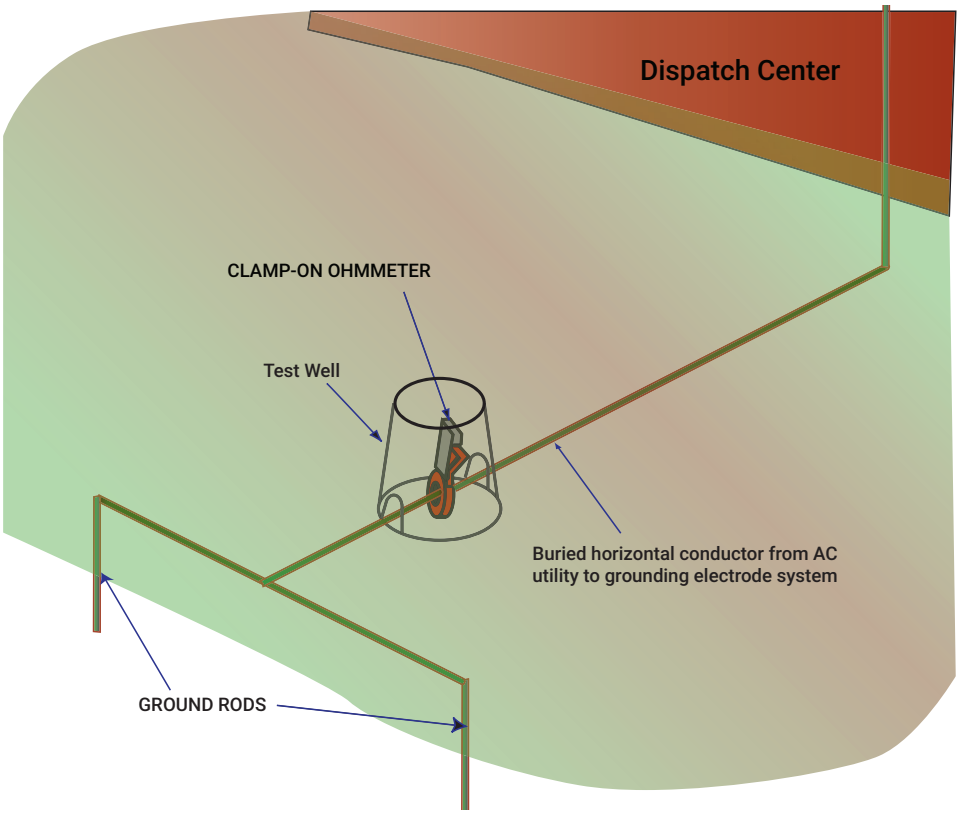


Figure D-16. Clamp-on Ohmmeter Placement For Parallel Grounding Electrode System (Site without a Tower)

D.5.3.4 Multi-Bonded Complex Grounding Electrode System Testing

For a site using a multi-bonded complex grounding electrode system (typical at a communications site), perform the test as follows:

IMPORTANT: This test requires the site grounding electrode system to be bonded to the electric utility neutral conductor and may require all non-balanced (phase-to-neutral) loads within the site to be switched off or transferred to a backup power source.

NOTE: The neutral conductor is used for this measurement because it is typically the only point at the site where all site grounding connections are combined onto a single conductor and downstream to the meter. As such, measuring at this point allows the clamp-on ohmmeter to "view" all the various connections as one single grounding electrode.

1. Follow the steps described in "Site AC Power Disconnect Requirements" on page D-23.
2. Disconnect any other utility connections to the grounding electrode system, such as the telephone service provider ground.

WARNING: Lethal voltages may be present. Only qualified personnel SHALL open an electrical panel to attempt a ground resistance measurement.

3. Have the electric utility neutral conductor exposed by a qualified electrician at the point of entry into the site (before it makes any bond to the site), ensuring that it has no secondary path to the site via a conduit or other connection.

NOTE: See the meter's User Manual to determine a meter indication, if any, showing that the meter is reading a closed loop rather than the actual grounding electrode system. The closed loop reading may be caused by a ground loop through a conduit, electrical service meter base or any other electrical panelboard. It may also indicate that another utility is connected, such as a water pipe or the telephone service provider ground. A very low reading (such as < 0.5 ohms) may also indicate a closed loop reading.

NOTE: In many cases, the first neutral-ground bonding point is not at the building electrical service panel, instead it is in the meter box where the neutral is bonded to the meter chassis (and metallic conduit). In this situation, if a measurement is attempted at the electrical service panel, the meter displays an erroneous closed-loop reading instead of a reading of the grounding electrode system (see Figures D-17, D-18 and D-19 for examples and testing options). If the electrical service enters the building in a PVC conduit, this situation typically does not apply. As such, a grounding electrode system resistance reading can be made in the electrical service panel. Consultation with an engineering firm is recommended.

4. Depending on the location of the first neutral-ground bonding point, attach the clamp-on ohmmeter around the neutral conductor as shown in Figures D-17, D-18 and D-19.

WARNING: Lethal voltages may be present. Only qualified personnel SHALL open an electrical panel to attempt a ground resistance measurement.

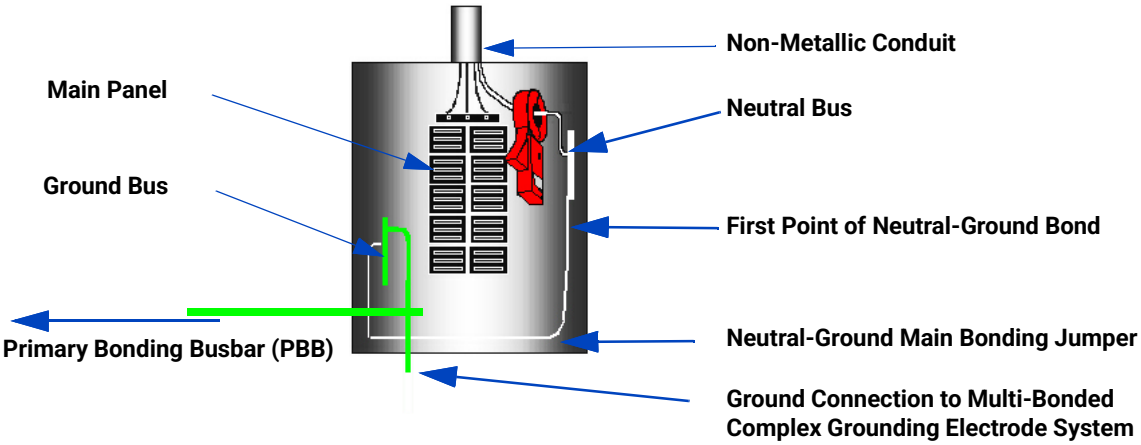


Figure D-17. Clamp-on Ohmmeter Placement For Multi-Bonded Complex Grounding Electrode System (Neutral-Ground Bond at Service Panel)

5. Set the meter to the Amps scale and verify no significant current on the neutral conductor.

NOTE: Unbalanced current flow (current on the neutral conductor) may affect the ability of the meter to achieve an accurate reading. Therefore, arrange for any non-balanced (phase-to-neutral) loads within the site to be electrically de-energized so there is no current flow on the neutral conductor. The easiest way to accomplish this is to completely de-energize the AC power to the site. Any current on the neutral conductor (even if less than 3 - 5 amps) may result in a false reading.

6. Set the meter to the Ohms scale and note the reading. If no noise or other errors are indicated on the meter, this is the resistance of the grounding electrode system under test.

7. Record the reading on a photocopy of the clamp-on ohmmeter/ammeter test worksheet on page D-37. A digital photograph showing the meter location and displayed resistance value is also recommended.

Neutral bonding inside the meter box and metallic conduit makes it impossible to take a reading in the building. Reading must be taken on the electric utility side of this bond.

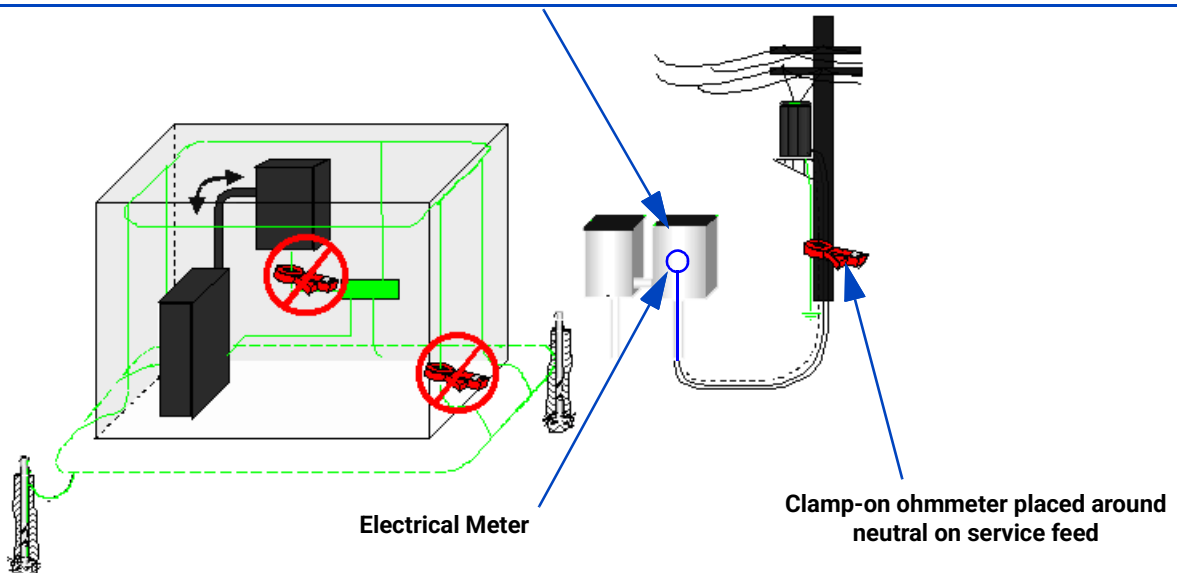


Figure D-18. Clamp-on Ohmmeter Placement for Multi-Bonded Complex Grounding Electrode System (Underground Service)

WARNING: Measurements at these locations SHALL only be made under the direct supervision of the electric utility.

WARNING: Appropriate fall restraint and fall arrest techniques SHALL be observed when climbing or using any personnel lift. Applicable national and local codes SHALL be followed.

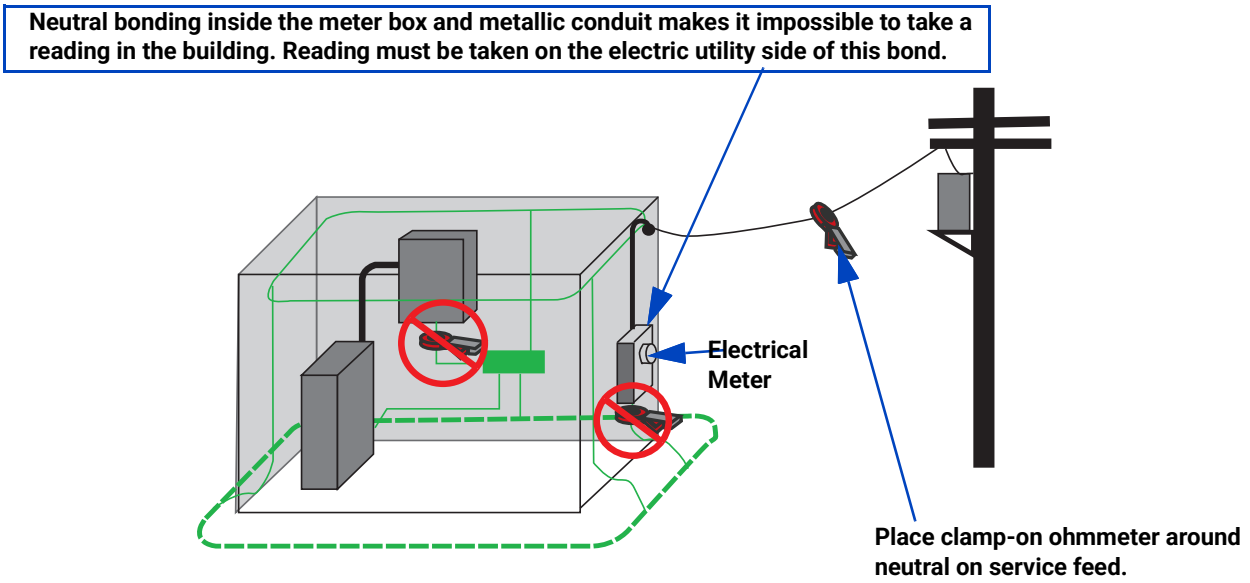


Figure D-19. Clamp-on Ohmmeter Placement For Multi-Bonded Complex Grounding Electrode System (Overhead Service)

WARNING: Measurements at these locations SHALL only be made under the direct supervision of the electric utility.

WARNING: Appropriate fall restraint and fall arrest techniques SHALL be observed when climbing or using any personnel lift. Applicable national and local codes SHALL be followed.

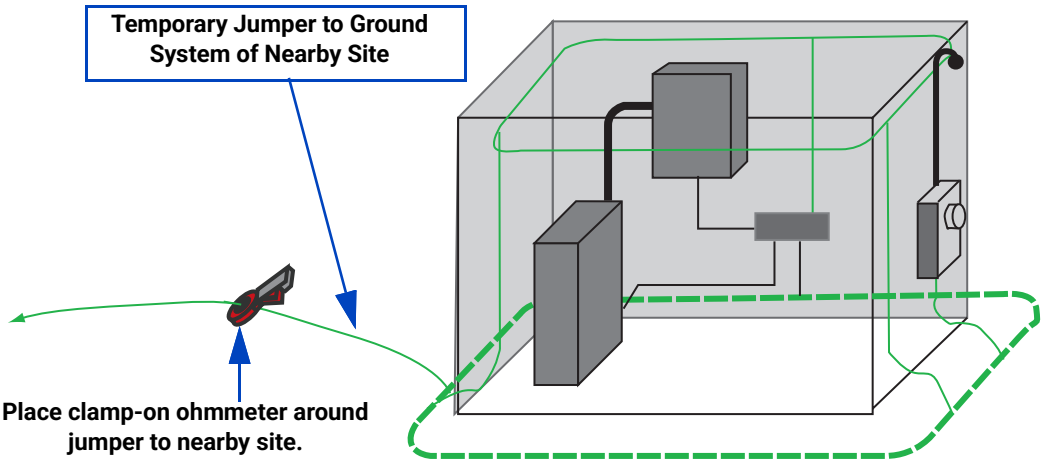


Figure D-20. Clamp-on Ohmmeter Placement For Multi-Bonded Complex Grounding Electrode System (Before AC Utility is Connected)

D.5.4 Clamp-on Ohmmeter Bonding Continuity Testing

Testing for conductive loops at a site (external and internal) helps validate an adequately installed grounding and bonding system. Because the clamp-on ohmmeter works by inducing a low-frequency test current (usually between 1 kHz and 3.4 kHz), from a known voltage source, into a conductive loop, most conductive loops at a communications site can be measured with a clamp-on ohmmeter. See Figure D-12 for loop examples. The meter operator must determine and understand which loop they are measuring. The placement of the meter determines the loop being tested. An experienced operator can determine how to measure the most common loops at a communications site.

All bonding connections **shall be** verified during installation. Table D-6 provides guidance on the expected measured values at some common test locations. It is assumed that the site is properly grounded and bonded, and equipment (including coaxes) is installed and plugged into an AC power receptacle. This table is for general guidance only and is not indicative of all sites.

Table D-6. Common Ground Test Locations and Typical Measured Values

Clamp-on Ohmmeter Test Location	Typical Value *	Notes
External Ground Busbar (EGB) grounding electrode conductor	< 0.2 ohms	The primary loop is through the grounding electrode system, to the tower structure, to the grounded coaxes, to the EGB and returning to the EGB grounding electrode conductor. A secondary loop may also exist through the grounded coaxes, to the lightning protection unit, to the Primary Bonding Busbar (PBB), to the grounding electrode system and returning on the EGB grounding electrode conductor.
Bottom Tower Ground Busbar (TGB) grounding electrode conductor	< 0.2 ohms	The primary loop is through the grounding electrode system, to the EGB grounding electrode conductor, to the EGB and returning to the TGB through the grounded coaxes. Other secondary loops may exist.
Tower leg grounding electrode conductor (each tower leg conductor should be tested)	< 0.2 ohms	The primary loop is through the tower grounding electrode conductor, to the tower ground ring, to the tower structure via another tower grounding electrode conductor and returning through the tower structure. Testing the tower leg grounding electrode conductors helps to validate the existence of a tower ground ring. Higher resistance values may indicate bonding problems or the lack of a tower ground ring. Higher resistance values that vary at each tower leg and have resistance values for a typical ground rod for the given soil further indicate that no tower ground ring is present.
Ice bridge support post grounding conductor	< 0.5 ohms	The primary loop is through the grounding electrode system, to another ice bridge support post and returning to the support post under test via the ice bridge structure.
Externally mounted HVAC unit bonding conductor	< 0.5 ohms	The primary loop is completed via the HVAC AC power source grounding conductor (safety ground).
Remote fuel tank bonding conductor (with non-conductive fuel line)	High	There is not typically a complete conductive loop. If a high resistance reading is encountered, install a temporary test jumper from the tank to a reliable ground point (such as an EGB). The measured value should drop to < 0.5 ohms if the tank bonding connection is adequate. Remove the temporary test jumper.
*** Some clamp-on ohmmeters are not capable of reading below 0.7 ohms. See the meter's User Manual for complete details.**		

Table D-6. Common Ground Test Locations and Typical Measured Values (continued)

Clamp-on Ohmmeter Test Location	Typical Value *	Notes
Remote fuel tank bonding conductor (with conductive fuel line)	< 0.5 ohms	The primary loop is completed through the conductive fuel line if the fuel line is bonded to the site. If a high resistance reading is encountered, install a temporary test jumper from the tank to a reliable ground point (such as an EGB). The measured value should drop to < 0.5 ohms if the tank bonding connection is adequate. Remove the temporary test jumper.
Fence post grounding conductor	Variable	The primary loop is typically through the mechanical connections of the fence fabric, returning via another grounded fence post. If a high reading is encountered, install a temporary test jumper from the fence post being measured to a reliable ground point (such as an EGB). The measured value should drop to < 0.5 ohms if the fence post bonding connection is adequate. Remove the temporary test jumper.
Gate post grounding conductor	Variable	The primary loop is typically through the mechanical connections of the fence fabric, returning via a grounded fence post. If a high reading is encountered, install a temporary test jumper from the gate post being measured to a reliable ground point (such as an EGB). The measured value should drop to < 0.5 ohms if the gate post bonding connection is adequate. Remove the temporary test jumper. A drop in resistance reading is typically observed when the gate is closed and latched.
Generator bonding conductor	< 0.2 ohms	The primary loop is completed via the AC power grounding conductor (safety ground).
Guy anchor point grounding conductor (meter must be placed below all guy wire bonding points)	Variable - the resistance of the anchor point isolated ground rod. This value will vary based on site soil resistivity.	The primary loop is typically from the ground rod, through the earth, returning to the meter via the utility ground, the site grounding electrode system, and the tower structure (including guy wires).
Miscellaneous isolated metallic objects (vent covers, metallic roof flashing, metallic siding, hand rails, and so on)	High	There is not typically a complete conductive loop for several miscellaneous metallic objects (internal and external). If a high resistance reading is encountered, install a temporary test jumper from the object to a reliable ground point (such as an EGB or PBB). The measured value should drop to < 0.5 ohms if the object bonding connection is adequate. Remove the temporary test jumper.
Primary Bonding Busbar (PBB) grounding electrode conductor	< 0.2 ohms	The primary loop is through the PBB grounding electrode conductor, to the grounding electrode system, to the EGB grounding electrode conductor, to the EGB and returning via the grounded coaxial cables.
Rack Bonding Busbar (RBB) grounding conductor	< 0.2 ohms	The primary loop is typically completed through the internal grounding and bonding system and the equipment AC power source grounding conductor (safety ground). Other secondary loops may exist.
*** Some clamp-on ohmmeters are not capable of reading below 0.7 ohms. See the meter's User Manual for complete details.**		

Table D-6. Common Ground Test Locations and Typical Measured Values (continued)

Clamp-on Ohmmeter Test Location	Typical Value *	Notes
Secondary Bonding Busbar (SBB) grounding conductor	< 0.2 ohms	The primary loop is typically completed through the internal grounding and bonding system and the equipment AC power source grounding conductor (safety ground). Other secondary loops may exist.
Equipment bonding conductors	< 0.2 ohms	The primary loop is typically completed through the internal grounding and bonding system and the equipment AC power source grounding conductor (safety ground). Other secondary loops may exist, such as through the grounded equipment rack.
*** Some clamp-on ohmmeters are not capable of reading below 0.7 ohms. See the meter's User Manual for complete details.**		

D.6 Combining Soil Resistivity Testing with Clamp-On Ohmmeter

Providing site soil resistivity readings and clamp-on ohmmeter readings to an engineering firm is sometimes the only method available for grounding electrode system resistance verification. Typically, the engineering firm enters the supplied data into a specialized computer program that determines grounding electrode system resistance for the site. The typical data required is as follows (consult with the engineering firm for specific requirements):

- The results obtained from a soil resistivity test
- Individual grounding electrode system component testing data from the clamp-on ohmmeter
- Detailed grounding electrode system *as-built* drawings for the site

Table D-7 is a worksheet for recording fall-of-potential test data.

Table D-8 is a worksheet for recording clamp-on ohmmeter test data.

Table D-7. Fall-of-Potential Test Worksheet

Distance from Grounding Electrode System Grid		Test Data
%	**ft (m)**	**Ohms (Ω)**
1%		
5%		
10%		
20%		
30%		
40%		
50%		
60%		
70%		
80%		
90%		
99%		
Test completed by:		
Date:		
Client / Project:		
Site Location/ID:		
Site Type classification: ❑ Light Duty ❑ Standard Duty ❑ Extra Duty		
Ground Resistance Tester		
Model:		
S/N:		
Calibration date:		
Soil Description:		
Ambient Conditions		
Temperature:		
Present conditions (dry, rain, snow):		
Date of last precipitation:		
Notes:		

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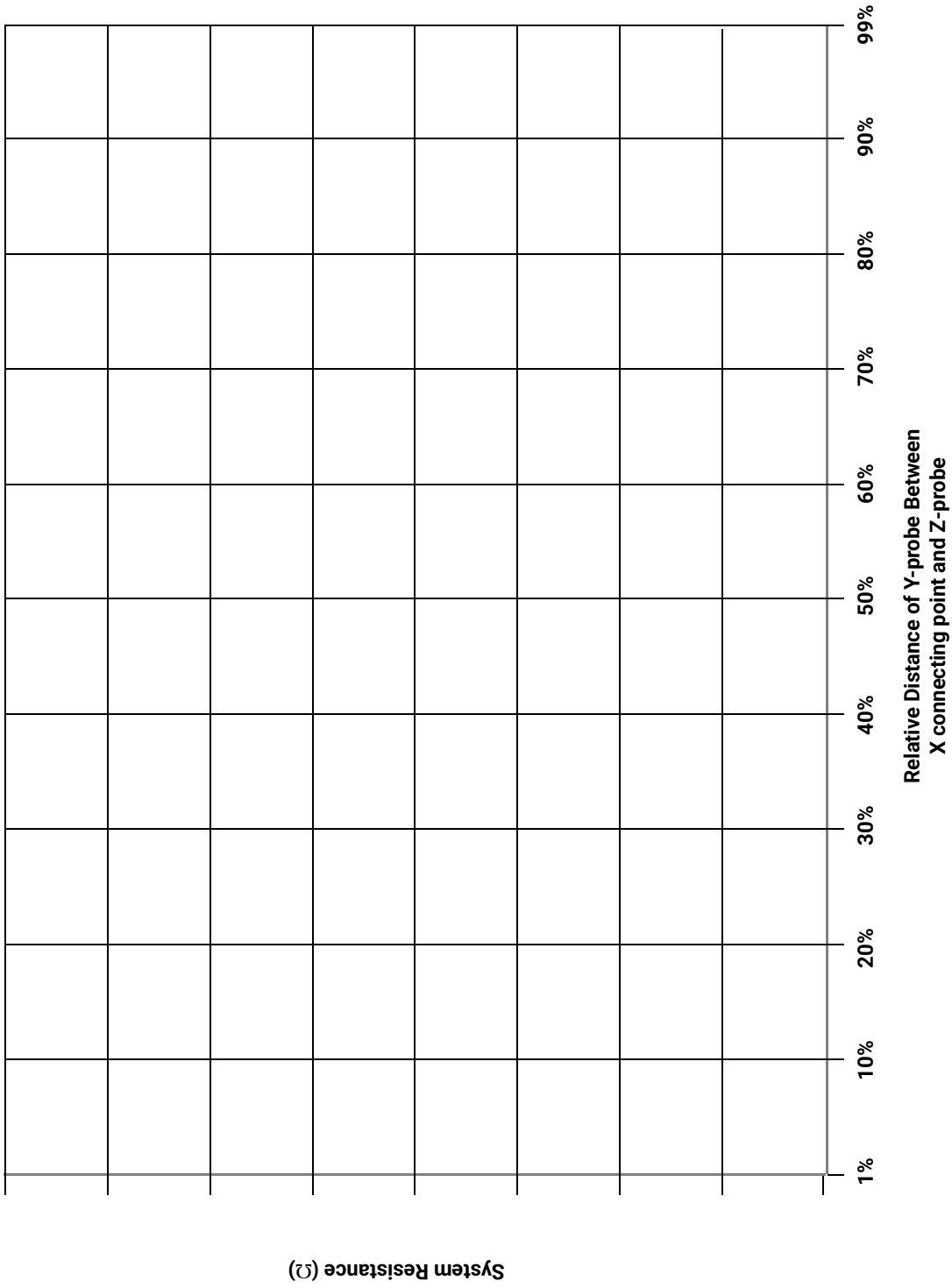


Figure D-21. Fall-of-Potential Test Graph Form

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Table D-8. Clamp-On Ohmmeter/Ammeter Test Worksheet

Points Tested	Ohms	Amps
Test Point 1:		
Test Point 2:		
Test Point 3:		
Test Point 4:		
Test Point 5:		
Test Point 6:		
Test Point 7:		
Test completed by:		
Date:		
Client / Project:		
Site Location / ID:		
Site Type classification: ❑ Light Duty ❑ Standard Duty ❑ Extra Duty		
Ground Resistance Tester		
Model:		
S/N:		
Calibration date:		
Soil Description:		
Ambient Conditions		
Temperature:		
Present conditions (dry, rain, snow):		
Date of last precipitation:		
Notes:		

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APPENDIX

E

Mobile Installation Standards and Techniques

E.1 Introduction

The information contained in this appendix has been prepared for use by persons installing mission critical two-way mobile radio equipment and associated accessories in vehicles. It has been prepared according to current engineering principles and generally accepted practices. These guidelines are intended to supplement, but not to be used in place of, detailed instructions from the manufacturers of mission critical mobile equipment. Because it is not possible to cover all possible installations of mission-critical mobile equipment, Motorola Solutions, Inc. cannot be held responsible for incidental or consequential damages arising from the use of the information contained herein.

This Appendix contains information on the following topics:

- “Referenced Publications for Mobile Installations” on page E-2
- “Safety Requirements for Mobile Installations” on page E-2
- “Mobile Installer Training and Certification” on page E-4
- “Vehicle Considerations” on page E-5
- “Planning for Mobile Installations” on page E-5
- “Transceiver Preventive Maintenance and Inspection” on page E-6
- “Pre-Install and Post-Install Checklist” on page E-6
- “Tools for Mobile Installation” on page E-7
- “Installation of Mobile Equipment” on page E-8
- “Power Wiring for Mobile Installations” on page E-16
- “Joining Conductors for Mobile Installations” on page E-26
- “Bonding Requirements for Mobile Installation” on page E-29
- “Conductor Tapping and Soldering” on page E-30
- “Electrical Tape and Heat Shrink Tubing” on page E-31
- “Antenna Installation and Testing” on page E-32
- “Effective Receiver Sensitivity Testing” on page E-42
- “Radio Transmit Noise Testing” on page E-46
- “Installation of Miscellaneous Equipment” on page E-47
- “Motorcycle Installations” on page E-49
- “Marine Installations” on page E-51
- “Aircraft Installations” on page E-52
- “Example of Installation Checklist” on page E-52



IMPORTANT: The information contained in this appendix is intended to supplement the equipment installation manual provided by the manufacturer. The specific equipment installation manual **shall** be followed.

E.2 Referenced Publications for Mobile Installations

The following publications were used in this Appendix and should be referred to for more information.

- Chrysler Corporation: Radio Communication Equipment Installation Recommendations
- FCS1362:2022: UK Code of Practice for the Installation of Mobile Radio and Related Ancillary Equipment in Land Based Vehicles
- ETA International (ETA®): Mobile Communications & Electronics Installer
- Ford Motor Company: Mobile Radio Installation Guidelines
- IEEE CH2944-7/91/0000/0866 Vehicle mobile radio installation guidelines
- General Motors: Radio Telephone / Mobile Radio Installation Guidelines
- General Motors Upfitter Integration, UI Bulletin #119: Info - Radio Telephone/Mobile Radio (Transceiver) Installation and Troubleshooting Guidelines; All GM Passenger Cars and Trucks, Model Years 2000 and beyond. Revision date August 14, 2014
- Motorola Solutions, Inc.: APX™ Mobiles Installation Manual (part number 6878215A01)
- Motorola Solutions, Inc.: RF Energy Exposure Training and Product Safety Information for Mobile Two-Way Radios installed in Vehicles or as Fixed Site Control Stations (part number 6881095C99)
- National Institute of Justice: Guide to Test Methods, Performance Requirements, and Installation Practices for Electronic Sirens Used on Law Enforcement Vehicles (NIJ Guide 500-00)
- SAE J1128_202508: Surface Vehicle Standard - Low Voltage Primary Cable
- SAE J1849: Surface Vehicle Standard - Emergency Vehicle Sirens
- SAE J378:201802: Surface Vehicle Standard - Marine Propulsion System Wiring

E.3 Safety Requirements for Mobile Installations



WARNING: Ensure adequate ventilation when running the vehicle.



WARNING: The installer SHALL receive proper training regarding the safety hazards of the following: supplemental restraint systems (airbags) and related equipment (see FCS1362:2022), high voltage in electric and/or hybrid vehicles, and compressed gas vehicles.



CAUTION: Before installing any electrical equipment, check the vehicle manufacturer's user manual and/or dealership for warnings and/or recommendations.

The following safety requirements **shall** be followed:

- To help ensure suitable and safe conditions for the installer, installation work **shall** take place in a suitable dry and well illuminated location and/or facility, as practicable (see FCS1362:2022, section 2.4.1).
- The installer **shall** read all equipment instruction manuals prior to installation.
- The installer **shall** receive proper training regarding the safety hazards associated with supplemental restraint systems (airbags) and associated equipment.
- The installer **shall** receive proper training regarding the safety hazards associated with high voltage in electric and/or hybrid vehicles.

NOTE: The high voltage (up to 900 volts) cables in hybrid and electric vehicles are typically orange or blue in color (Figure E-1 is an example). Check with the specific vehicle manufacturer's documentation. See FCS1362:2022 section 2.9.1 for more information.

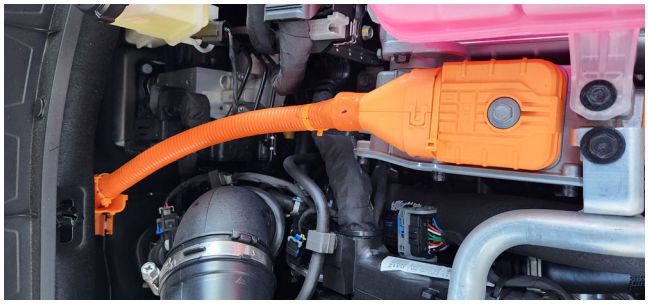


Figure E-1. Hybrid Vehicle High Voltage Cables Example

- The installer **shall** receive proper training regarding the safety hazards associated with compressed gas vehicles.
- The installer **shall** ensure the safety of the vehicle has not been compromised as a result of the mobile radio equipment installation (see FCS1362:2022).
- The installer **shall** ensure the safety of the vehicle has been maintained once work to fit the equipment has been completed (see FCS1362:2022).
- The installer **shall** take due consideration to ensure that safety is not compromised by any customer demands (see FCS1362:2022).
- Any modification to the vehicle **shall** be performed in such a way that it does not create a condition where danger is likely to be caused to the driver, passengers, or other road users (see FCS1362:2022).
- Before drilling or using self-drilling/tapping screws, check for vehicle system components (for example: batteries, wiring, fuel lines, brake lines, air conditioning lines, and so on) that may be damaged.
- There **shall** be no rough, sharp, or protruding edges that could be impacted by the vehicle's occupants in a collision (see FCS1362:2022).
- Excess lengths of any cable ties **shall** be cut flush with its locking mechanism to avoid leaving sharp and potentially dangerous projections (FCS1362:2022).
- The controls, displays, and cabling, including any microphone/handset lead of the installed equipment, **shall not** obscure nor obstruct instruments, vehicle controls or the swept area of the windscreen (windshield); neither should their operation distract or impede the driver (see FCS1362:2022).
- If the driver is the prime user of the equipment, all necessary controls should be positioned within reach of the driver but not in such a way that the driver's attention is distracted from the road or that the view of the road is obscured. See FCS1362:2022 for more information.
- The installer **shall** follow all equipment installation requirements as specified by the equipment manufacturer.
- The installer **shall** follow all installation and safety requirements published by the vehicle manufacturer related to aftermarket mobile radio equipment installations.
- Appropriate tools **shall** be used during installation, and the tools **shall** be used appropriately. See “Tools for Mobile Installation” on page E-7.
- Appropriate safety equipment (for example: safety glasses and gloves) **shall** be used during installation.
- Installers **shall** remove metallic rings and other jewelry that can come in contact with vehicle voltages.
- Appropriate hearing protection **shall** be used when running a vehicle siren.
- See FCS1362:2022 for additional safety information.

E.3.1 Requirements for Compliance with RF Energy Exposure Safety Standards

CAUTION: See the specific transceiver manufacturer instruction manual (or equivalent) for information regarding Radio Frequency (RF) energy exposure safety standards and warnings.

To ensure compliance with radio frequency (RF) Energy Safety Standards:

- Install only manufacturer approved antennas and accessories.
- Install equipment according to the manufacturer's instructions.
- Install the antenna(s) according to “Antenna Installation” on page E-33 and the radio’s Installation Manual.
- Provide any Operator’s Manual, Product Safety and RF Safety Booklets provided with the radio to the end user.

See FCS1362:2022, section 2.8 for more information.

E.3.2 Vehicle Battery Disconnect Recommendations

Before beginning mobile radio and electronics installations, Motorola Solutions recommends disconnecting the negative battery cable from the battery (12V battery systems).

If removing a seat that contains airbags, seat belt pre-tensioners, or other Supplemental Restraint System (SRS), the vehicle battery should be disconnected for safety. Before unplugging connectors associated with the seat wiring, time must be allowed after disconnecting the battery to ensure that any capacitors in the airbag or SRS circuitry have fully discharged. Check with the vehicle manufacturer’s guidelines.

All disconnected wiring must be reconnected prior to restoring the vehicle battery or turning the ignition on.

See FCS1362:2022 for more information.

E.4 Mobile Installer Training and Certification

Mission Critical Mobile Installers **shall** be properly trained in mobile installations, including the following: Land Mobile Radio (LMR), basic electricity, basic electronics, vehicle mechanics, safety, and other applicable disciplines (for example: emergency lighting and sirens). A Mobile Installer **shall** be certified in mobile installations by an industry recognized certification organization. Such certifications include, but are not limited to, the following:

- ETA International (ETA®): Mobile Communications and Electronics Installer
- Certification Systems Technology Company™: Mobile Electronics Certified Professional (MECP)

Additional certification from the Automotive Service Excellence (ASE®) in Electrical/Electronic Systems (A6) is recommended.

In addition to the certifications listed above, one or both of the following certifications are recommended for marine installers:

- National Marine Electronics Association (NMEA®): Marine Electronics Installer
- American Boat & Yacht Council (ABYC®): Marine Electrical

E.5 Vehicle Considerations

Adding emergency equipment (e.g., lights, sirens, and communications equipment) increases the current demand on the vehicle's charging system. To ensure adequate charging capacity, the vehicle's alternator must be adequately sized to accommodate the additional current draw. Vehicles ordered specifically for emergency operations typically have an alternator designed to meet the additional demand.

If the vehicle was not ordered as an emergency vehicle with a higher-capacity alternator, ensure the emergency equipment does not exceed the capacity of the vehicle's charging system. This may require the assistance of an Installation Engineer or vehicle dealership. If the charging system is determined to be inadequate, a higher-capacity alternator will be required.

E.6 Planning for Mobile Installations

NOTE: The following information primarily applies to projects and/or fleet installations. As applicable, the information should be used as general guidance for all installations.

Mission critical land mobile radio installations **shall** be properly planned, engineered, and documented. The customer **shall** approve the final installation plan. Mission-critical installation planning should include all members of the project team as follows (as applicable):

- Customer representative with decision making authority
- Project manager
- Project system engineer
- Project field engineer or system technologist
- Project maintenance technician and/or system manager
- Project installation contractor

Installation planning **shall** be documented for each vehicle type (for example: Police, Fire, Public Works, and so on), for each vehicle make/model (for example: Ford Explorer, Chevy Tahoe, Dodge Charger, Ladder Truck, Engine, Aid Unit, and so on). The installation documentation **shall minimally** include the following:

- Radio transceiver mounting location
- Radio control head mounting location
- Radio microphone mounting location
- Radio speaker mounting location
- Siren speaker mounting location
- Antenna mounting location
- Radio power and earth/ground connection locations
- Radio cable routing
- Third-party audio interface (for example: headset or PA) requirements
- Existing equipment removal and/or relocation requirements
- Power distribution and fuse locations

IMPORTANT: Ensure the antenna type and mounting location match the engineered system design. Changing the antenna type and/or mounting location without engineering approval can negatively impact the mobile radio's intended coverage footprint and/or can violate licensing limitations.

E.6.1 Vehicle Protection

The Mobile Installer **shall** exercise due care to avoid vehicle damage. Such care includes, but is not limited to, the following (see FCS1362:2022, section 2.4.3):

- Wearing nothing sharp that can scratch a vehicle or cause damage to the interior.
- Using a fender cover where applicable.
- Using drop cloths or blankets on seats.
- Avoid putting tools in back pockets that could gouge or tear the interior of the vehicle.
- Ensuring no grease, oil, or dirt is present on hands, clothing, shoes, and so on when getting in a vehicle.

E.7 Transceiver Preventive Maintenance and Inspection

Prior to installation, the radio transceiver **shall** be tested for proper operation according to the manufacturer's recommendations and jurisdictional requirements (for example: frequency, modulation, power output, and receiver sensitivity). All applicable measurements **shall** be documented. See FCS1362:2022, section 3.3 for more information.

Inspection should include a firmware upgrade (if applicable) as needed according to the manufacturer's instructions (such as Product Service Bulletins or Technical Notifications). The inspection **shall** be made by an appropriately certified and/or licensed technician.

All test equipment used for the transceiver preventive maintenance **shall** be in known good working order and **shall** be within national and/or factory calibration standards. The test equipment calibration records **shall** be maintained and made available as requested.

IMPORTANT: The transceiver output power **shall** be set according to the manufacturer's requirements and according to the system design requirements. Some specific system designs may call for a transmitter power output of something less than the maximum rated output power. Exceeding the specific system design rated power may be in violation of licensing limitations and/or may create undesired RF interference at the system infrastructure receivers.

NOTE: Receiver sensitivity should be recorded in dBm.

E.8 Pre-Install and Post-Install Checklist

Mission critical installations **shall** be planned and documented as described in “Planning for Mobile Installations” on page E-5. A pre-install and post-install checklist **shall** also be included.

The pre/post-install checklist should minimally include the following (see FCS1362:2022 and Section E.23 for example forms):

- A basic outline of the vehicle for quick indication of non-functioning lights, damage to the vehicle, and equipment location.
- A checklist pass/fail should include the following: running lights, headlights, dash lights, interior lights, LED lights and bars, strobes, sirens, wig-wags, vehicle horn, reverse lights, alley lights, brake and turn signal lights, gun release, RADAR, existing radios, intercom, and so on.
- Room for additional comments.
- Radio receiver sensitivity.
- Radio effective receiver sensitivity (see “Effective Receiver Sensitivity Testing” on page E-42).

- Radio transmit power output.
- Antenna VSWR or Return Loss (see “Antenna VSWR Testing” on page E-39).
  - Forward and reflected power.
- Voltage at radio transmitter when radio is keyed.

An example form is located at the end of this Appendix in “Example of Installation Checklist” on page E-52.

E.9 Tools for Mobile Installation

All installation tools and equipment used **shall** be functional, suitably maintained, and calibrated (if required). All measurement devices and meters should be regularly checked for accuracy. If accurate electrical measurements are required, the relevant test equipment **shall** be regularly checked and calibrated against a recognized national standard according to the manufacturer's requirements.

IMPORTANT: The appropriate tool **shall** be used, and the tool **shall** be used according to the manufacturer's instructions.

The suggested installation tools and equipment include, but are not limited to, the following (see FCS1362:2022 and ETA® International publication, *Mobile Communications & Electronics Installer*):

- A good quality general tool kit including screwdrivers, spanners, socket set, pliers, and so on
- Any specialist tools relative to the type of vehicle and products undergoing installation
- Correct equipment and tools for removal of panels and trim should be used as appropriate
- VSWR meter (see “Antenna VSWR Testing” on page E-39)
- Antenna analyzer (see “Antenna VSWR Testing” on page E-39)
- Coax strippers
- RF connector ratchet crimp tool
- Wire strippers
- DC connector ratcheting crimp tool (see “Electrical Ring Terminals, Lugs, Splices, and Similar Devices” on page E-27)
- Digital Voltmeter (DVM)
- Measuring tape
- Power drill kit
- Hole saw kit
- Hole saw specifically designed for antenna mounts (typically contain a collar to prevent damage to vehicle headliner)
- Portable soldering iron
- Heat gun (required for heat shrink materials and connectors)
- Vehicle trim removal tools
- Radio removal keys
- Specialized screw or security driver bits
- Seat, panel, and fender covers to protect the vehicle during installation procedures (see “Vehicle Protection” on page E-6)
- Storage for any parts, screws, or hardware (fixings) removed during installation for later reassembly

WARNING: DO NOT use old-style test lights (test probes) on vehicles with supplemental restraint systems (airbags). Inadvertently testing the wrong wire with the test light can deploy the airbag system, possibly resulting in injury or death to the installer and severe damage to the vehicle. Airbag-safe test lights are commercially available.

IMPORTANT: When crimping RF connectors (such as mini-UHF), the appropriate, manufacturer-approved, crimping tool **shall** be used. DO NOT attempt to crimp RF connectors with the wrong crimper, or other improper tools (such as pliers).

IMPORTANT: When crimping wire connectors and lugs, the appropriate, manufacturer-approved, crimping tool **shall** be used. DO NOT attempt to crimp connectors and lugs with the wrong crimper, or other improper tools (such as pliers).

E.10 Installation of Mobile Equipment

This section provides general guidelines and requirements for installation of mobile equipment:

- See “Safety Requirements for Mobile Installations” on page E-2.
- An equipment location **shall** be selected that provides a solid mounting point that does not interfere with the vehicle operator controls and provides adequate ventilation.

WARNING: DO NOT mount any transceiver, microphone, speaker, or any other item in the deployment path of the airbag system.

- The equipment and associated cables **shall not** be subject to damage during use.
- Ventilation for the equipment **shall** be maintained (see manufacturer installation instructions).
- Equipment **shall not** be located where it is subject to water damage.
- Equipment **shall not** be located where it is subject to heat damage.
- Connections to the equipment **shall** be easily accessible for maintenance purposes.
- If radio equipment is installed under the instrument panel, ensure there is no interference with the operation of the foot controls. Mount the control head or front panel (especially the microphone cable) so that it is clear of the steering wheel and column controls and passenger airbag.
- If screws penetrate the floor, the underbody projections **shall** be sealed. This will help keep moisture out of the carpet and insulation, and will forestall rust in this area.

WARNING: Under no circumstances SHALL installed equipment be left loose in the vehicle. All equipment SHALL be securely mounted. See FCS1362:2022, section 2.5 for more information.

IMPORTANT: Local jurisdictional regulations regarding windshield (windscreen) obstruction **shall** be followed.

E.10.1 Mounting Systems for Mobile Electronics

Numerous third-party mounting systems are available for mounting mobile electronics in emergency vehicles. Some of the benefits of the mounting systems are as follows:

- Safe and secure mounting of mobile electronics.
- Convenient mounting of mobile electronics.
- Space saving mounting of mobile electronics.
- Fold away design for space savings and convenient servicing of the equipment.

Mounting systems are available for several applications, such as the following:

- Passenger compartment area center console (see Figure E-2)
- Trunk sliding tray (see Figure E-3)
- Trunk fold away (see Figure E-4)
- Sport Utility Vehicle (SUV) rear fold away (see Figure E-5)

Motorola Solutions, Inc. does not endorse specific mobile electronics mounting systems. Requirements for mobile electronics mounting systems are as follows:

- The mounting system **shall** be designed for the application.
- The mounting system **shall** be designed for the specific vehicle.
- The mounting system **shall** be installed according to the manufacturer's requirements.



Figure E-2. Example of Center Console Mounting System

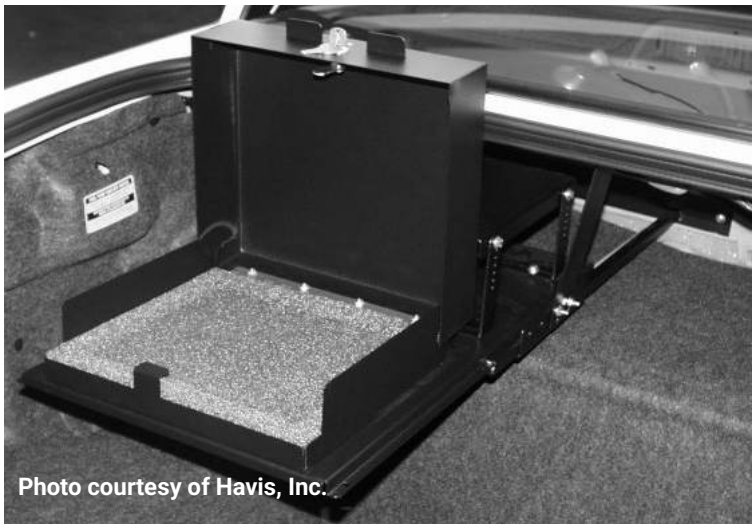


Figure E-3. Example of Sliding Trunk Mount System



Figure E-4. Examples of Trunk Fold-away Mounting System



Figure E-5. Example of SUV Fold Away Mounting System

E.10.2 Securing Hardware for Mobile Installation

Hardware to secure equipment may include the following (see FCS1362:2022, section 2.6.1.2):

- Screws or bolts with locking nuts or plain nuts with shake-proof washers are the preferred hardware for securing equipment, particularly where the equipment is heavy and/or where the equipment may be subjected to vibration.
  - This method may not always be practicable unless both sides of the holding surface are accessible.
- Rivet nuts offer a stronger solution than self-drilling/tapping screws. Rivet nuts come in various types and provide a blind nut or a threaded stud. See Figure E-6 for an example.
  - Rivet nuts often require special tools for fitting.
- Self-drilling/tapping screws are acceptable where a strong and secure surface is available to screw in to, and the back of the screw does not protrude into an accessible area leaving a sharp point that may cause injury or damage. See Figure E-7 for an example.
  - Be aware that self-drilling/tapping screws can work loose.
  - Self-drilling/tapping screws are not recommended for heavy loads.
  - Self-drilling/tapping screws are not recommended for equipment mounted to the underside of a shelf (or equivalent).
- Rivets provide a more permanent mounting. Therefore, consideration **shall** be given regarding the servicing needs of the equipment.
  - Not generally suitable for use for this reason.

Precautions **shall** be taken on all of the above to avoid the hardware working loose with vibration. The use of shake proof washers, locking nuts or flat nuts is recommended.

Corrosion resistant fastenings (for example, stainless steel nuts and bolts) should always be used in areas exposed to the elements.

WARNING: The shortest practicable screw or bolt SHALL be used to help prevent unintended contact with vehicle components (for example: EV batteries, wiring, fuel lines, or brake lines).

WARNING: To reduce risk of injury, installed hardware SHALL NOT be left with sharp protrusions.



Figure E-6. Example of Rivet Nut



Figure E-7. Example of Self-Drilling Screws

E.10.3 Routing, Protection and Securing of Conductors and Cabling

E.10.3.1 Routing of Conductors and Cabling for Mobile Installations

- Where practicable, all cables and conductors should pass under carpets and through trim or moldings in such a way as to ensure that any panels do not trap, crush, or distort the cable when refitted. Use sleeving or cable protection and cable ties where required. See FCS1362:2022, section 4.3.1 for more information.
  - Cables and conductors installed under carpets **shall** be routed away from areas of normal foot traffic, as practicable.
- Cable and conductor lengths **shall** provide sufficient slack for equipment to be easily tested and maintained while still connected.
- Cables and conductors **shall** be routed and supported so they avoid the following (see FCS1362:2022, section 4.3.3):
  - Sharp edges
  - Continual bending
  - Stress or strain
  - Abrasion
  - Extreme temperature
  - Sharp bends
  - Creating a hazard or distraction to the occupants of the vehicle
  - Running parallel to power cables in electric/hybrid vehicles, as practicable
  - Running in parallel with equipment's antenna cables, as practicable
- Route and secure all under-hood wiring away from heat and mechanical hazards, such as exhaust manifolds and moving parts (including the steering shaft, throttle linkage, fans, and so on).
  - The use of split loom or similar is required. This is important for aesthetics, as it ensures against wire chafing and protects against heat and oil damage.
  - Split loom installed in the engine space **shall** be rated for the temperature.
- Avoid routing cables and conductors near vehicle moving parts (for example: steering column, pedals, controls, and so on). See FCS1362:2022, section 4.3.3 for more information.
- Maintain as great a distance as practicable between mobile radio power conductors and the vehicle's electronic modules and wiring.
- If practicable, avoid running power conductors in parallel with vehicle wiring over long distances.
- Avoid routing the antenna cable (coax) in parallel with vehicle wiring over long distances, as practicable.
- Use caution when routing wires between the passenger and engine compartments to avoid chafing or pinching of wires.

E.10.3.2 Protection of Conductors and Cabling for Mobile Installations

NOTE: High-temperature split loom that is rated up to 149° C (300° F) is readily available. UV-rated split loom is readily available.

- Cabling open to the elements, such as power conductors installed in the engine area for connection to the battery, **shall** be protected using split loom (or equivalent) (FCS1362:2022). See Figure E-8 for an example.



Figure E-8. Example of Split Loom

- Cabling easily accessible within the passenger area **shall** be protected using split loom (or equivalent) (FCS1362:2022).
- Under-hood cabling and conductors **shall** be protected from damage and **shall** be installed in split loom (or equivalent).
- Split loom (or equivalent) used in the engine area, or other high temperature areas, **shall** be rated for the temperature.
- Split loom (or equivalent) normally exposed to UV **shall** be UV-rated.
- Grommets **shall** be used for aesthetics, safety, and cable protection whenever cabling passes through a firewall, bulkhead, or other partition. See Figure E-9 for an example.



Figure E-9. Example of Grommet Use

- Penetrations through the firewall **shall:**
  - Use grommets for cable protection (see Figure E-9).
  - Be sealed from dirt, fumes, and water. Sealing the firewall penetration may help reduce the amount of sound transmitted from the engine area to the passenger area.

E.10.3.3 Securing of Conductors and Cabling for Mobile Installations

- Cabling and conductors **shall** be secured as required to keep them in place and provide adequate strain relief.
- Cabling and conductors **shall not** be secured to movable parts under the dash, in the trunk, or in the engine compartment (for example: brake pedal, steering column, and so on).
  - Secure wires to a trunk lid arm only if mounting equipment to the trunk lid (such as antennas). Ensure there are no kinks where routing cables and leave slack if they must flex.
- Wiring **shall** be supported at intervals not greater than 45 cm (18 in.). See SAE J378:201802 for more information. Wiring routed under carpets, trim, or moldings is considered supported.

E.10.4 Cable Labeling for Mobile Installations

All cables **shall** be legibly labeled as to function and destination at each end, as practicable. Fuse holders **shall** be labeled as to the fuse size and associated equipment. Some labeling examples are as follows:

- APX Radio 700 MHz Antenna
- APX Radio VHF Antenna
- APX Radio GPS Antenna
- APX Radio 20A

See Figure E-10 for an example.



Figure E-10. Example of Coax Cable Labeling

E.10.5 Speaker Installation

- The speaker **shall** be installed according to the radio manufacturer's instructions. See Figure E-11 for an example.
- The speaker **shall** be mounted out of the way so that it will not be kicked or knocked around by the vehicle occupants.
- The speaker **shall** be positioned to provide an unobstructed audio path to the user (see FCS1362:2022, section 4.4.4).
- The speaker **shall** be positioned to ensure any vehicle occupant is not likely to suffer discomfort from excessive audio levels (see FCS1362:2022, section 4.4.4).

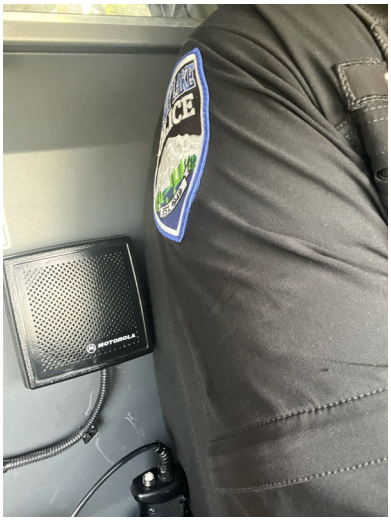


Figure E-11. Example of Speaker Installation in Police SUV

E.10.6 Microphone Installation

- The microphone **shall** be installed according to the radio manufacturer's instructions. See Figure E-2 and Figure E-12 for examples.
- The microphone hang-up clip **shall** be mounted within reach of the operator(s) and close enough to the control head to prevent cable strain.
- The microphone hang-up clip **shall** be mounted in a location that will prevent the microphone cable from interfering with normal vehicle operations and/or controls.



Figure E-12. Example of Microphone Installation

NOTE: Some radio microphone models require grounding of the microphone hang-up clip for Hang-up Box (HUB) operation to work correctly.

E.10.7 Equipment Installation in Vehicles with Airbags

Most modern vehicles are equipped with driver and passenger airbags, seat belt pretensioners, and other Supplementary Restraint Systems (SRS). These safety items are activated in the event of a collision. SRS components can be located in the steering wheel, under the dashboard fascia, sides of seats, front pillars, and side ceiling. The vehicle instruction manual and, if necessary, the vehicle manufacturer **shall** be consulted regarding the location of airbags and their deployment in the event of a collision. Care **shall** be taken during installation to avoid any possibility of inadvertently triggering the airbag or SRS equipment.

Airbags will affect the equipment installation location and associated cabling. The equipment and its cabling **shall not** impede the airbag deployment and operation.

If removing a seat containing side impact airbags, seatbelt pretensioners or other SRS, disconnect the vehicle battery as a safety precaution. Before unplugging seat wiring connectors, time must be allowed after the battery is disconnected to ensure any capacitors in the SRS circuitry have fully discharged. Check with the vehicle manufacturer's guidelines and/or dealer. All disturbed seat wiring **shall** be reconnected prior to restoring the vehicle battery or turning the ignition on. See FCS1362:2022, section 2.9.2.2, for more information.

WARNING: DO NOT mount any transceiver, microphone, speaker, or any other item in the deployment path of the airbag system.

WARNING: DO NOT use old-style test lights (test probes) on vehicles with supplemental restraint systems (airbags). Inadvertently testing the wrong wire with the test light can deploy the airbag system, possibly resulting in injury or death to the installer, and/or severe damage to the vehicle. Airbag-safe test lights are commercially available.

E.11 Power Wiring for Mobile Installations

NOTE: The recommendations and requirements contained within this section are based on a vehicle with a 12V negative ground power system. Other vehicle power system configurations may exist. In such cases, consultation with an Installation Engineer is recommended.

IMPORTANT: A 12 volt tap must not be taken from the batteries of a vehicle that has a supply greater than 12 volts. If a vehicle has a supply greater than 12 volts, then either the equipment **shall** be rated for the higher voltage, or a suitable regulator or converter **shall** be used that will provide the nominal supply voltage for which the equipment is designed. See FCS1362:2022, section 4.6.6 for more information.

- The power cable supplied by the radio manufacturer **shall** be used, where practicable.
- If the power cable must be extended, total voltage drop **shall** be considered. See “Power Conductors for Mobile Installations” on page E-20.
- Transceiver (+) power (red) connections should be made to one of the following:
  - To the battery directly, using appropriate hardware. See Figure E-13.
  - To an adequate power distribution center. Consult the vehicle manual and/or dealership to determine the power distribution center ampacity rating.
  - To the positive jump-start post, if present. See Figure E-14.
  - To the vehicle power disconnect switch, if applicable.
  - To the vehicle filtered battery distribution center (available on some emergency vehicles for the purpose of supplying power to the mission critical systems).
- The power conductor (+) **shall** be appropriately fused as close to the source as practicable. A weatherproof fuse holder is recommended.

- Transceiver (-) ground (black) should be connected to a convenient solid chassis ground point as close as practicable to the point where the battery-to-body connection is made (FCS1362:2022).
  - A factory-installed negative jump-start post is a good example. See Figure E-15.
  - **Do not** connect the ground (black) conductor directly to the battery's negative terminal.
- **Do not** fuse the ground (-) lead. If the ground-side fuse were to open, the entire supply current would be conducted by the coax shield. This could cause the coax to overheat with possible resulting damage.
- The radio power conductor (+) and ground (-) should be run together along their length as practicable to reduce induced noise (FCS1362:2022). The conductors can be twisted together for increased immunity to induced noise. See Figure E-16.
- Splices in the power cable **shall** be avoided, where practicable.
  - If required, splices **shall** be limited to one per power conductor, as practicable. If more than one splice is required, suitable solder splices (such as soldered compression butt splice) **shall** be used. See “Joining Conductors for Mobile Installations” on page E-26.
  - If required, splices **shall** be made at an easily accessible and conspicuous location.
  - Splices **shall not** be made in areas susceptible to physical damage and/or moisture intrusion.
- Cigarette lighter or “Power Point” receptacles **shall not** be used as power sources for mission critical equipment.
- Where low-power switched power sources are required (such as for radio ignition sense), do not tap into sources such as cigarette lighters and AM/FM radio. A vehicle-manufacturer-provided spare Ignition or Accessory source on the fuse block should be used instead. Install an in-line fuse holder with the proper size fuse for the equipment.

CAUTION: Do not fuse the transceiver ground (negative) conductor. If the ground-side fuse were to open, the entire supply current would be conducted by the coax shield or other alternative current return path. This could cause the coax to overheat with possible resulting damage.

CAUTION: Do not connect the ground (black) conductor directly to the battery's negative terminal.

IMPORTANT: If a high-power switched source is required, do not attempt to use the vehicle fuse block (see the vehicle documentation). A switching relay to control a direct connection to the vehicle battery (or equivalent) is required in these applications.

IMPORTANT: Except under engineering supervision, do not reuse existing radio power conductors or cables.

NOTE: Some vehicles (large buses, tractor-trailers, firefighting apparatus, and so on) may not have a source of clean DC power, and may require a DC power filter to filter out noise. Consultation with a technician and/or Installation Engineer may be required. See Figure E-17 for an example.

NOTE: In some heavy commercial vehicles, and in vehicles with tilting cabs where the cab may be isolated from the chassis by rubber mountings, a ground point is typically provided by the vehicle manufacturer within the cab to provide battery to cab grounding. Generally, this is located within the main fuse box. It is recommended that this point be used for installations in this instance. See FCS1362:2022 for more information.

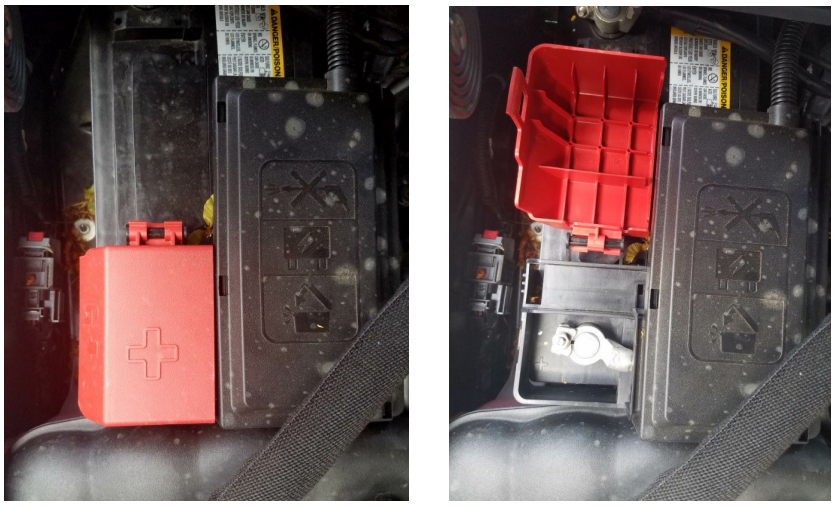


Figure E-13. Example of Vehicle Battery with External Terminal

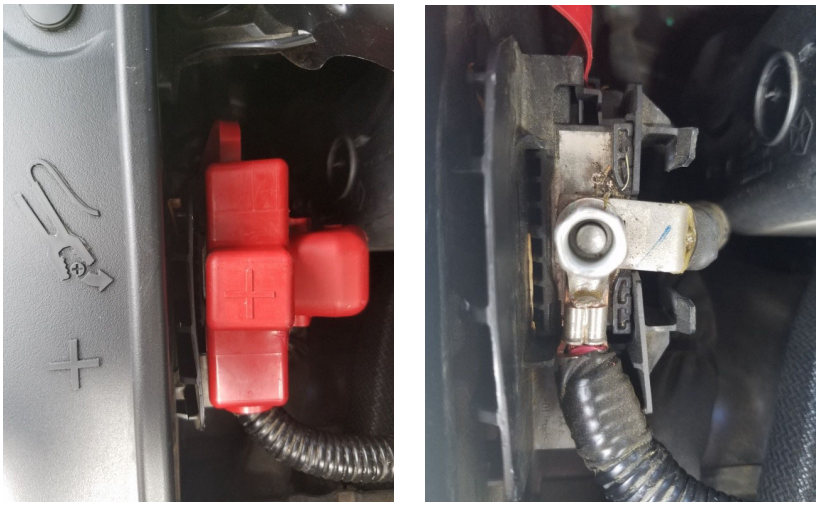


Figure E-14. Example of Vehicle Positive Jump Start Post

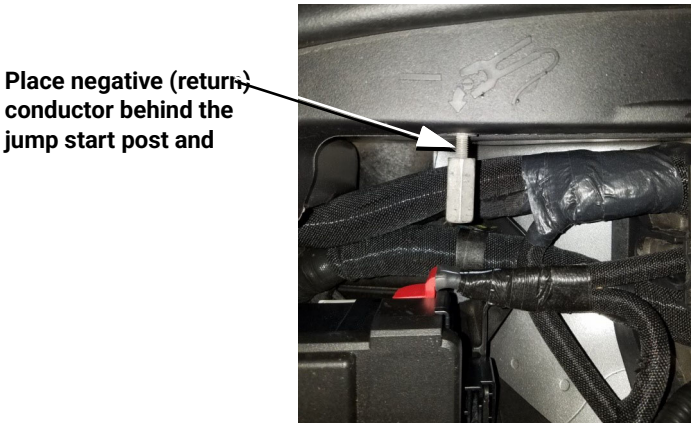


Figure E-15. Example of Vehicle Negative Jump Start Post



Figure E-16. Example of Power Conductors Twisted Together for Increased Noise Immunity



Figure E-17. Example of a Commercially Available DC Power Filter

IMPORTANT: Where a 24 volt or higher supply is used on an isolated return vehicle system, a suitable DC converter, providing DC isolation (no DC continuity between battery and output) **shall** be used. See FCS1362:2022, section 4.6.7.1, for more information.

E.11.1 Power Wiring Considerations for Electric-Powered And Hybrid Vehicles

WARNING: Hazardous high voltage is present from the large battery banks in electric-powered and hybrid vehicles (see FCS1362:2022, section 2.9.1 for more information). All vehicle-manufacturer-provided safety precautions SHALL be followed when working on electric-powered and hybrid vehicles.

Equipment installed in electric-powered and hybrid vehicles **shall** use the appropriate manufacturer-provided voltage and ground sources. Such sources may be busbars provided by the vehicle manufacturer. Check with the vehicle manufacturer or vehicle instruction manual for the location of the power and ground connection points for the communications and emergency equipment.

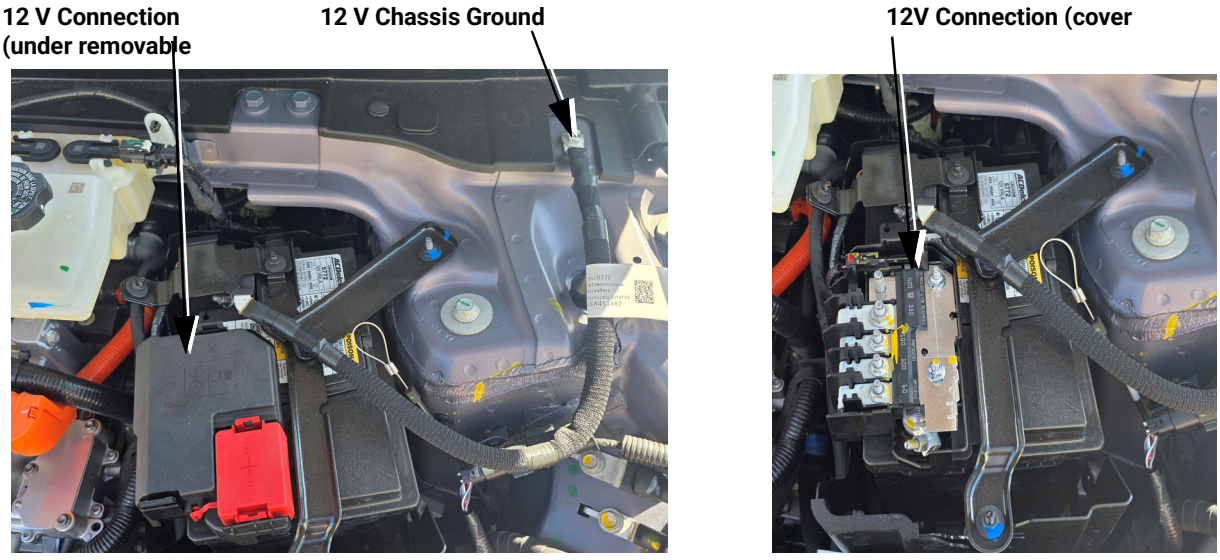


Figure E-18. Example of Plug-in Electric Vehicle Connections

E.11.2 Power Conductors for Mobile Installations

Power conductors used in mission critical mobile installations **shall** be appropriate for the application. The conductors **shall** be resistant to the following (as applicable): abrasion, battery acid, diesel fuel, gasoline, moisture, oil, sunlight, and so on (see SAE J1128).

Power conductors used in mission critical applications **shall** be rated as appropriate for the application:

- Conductors used in automotive applications **shall** be stranded automotive grade.
- Conductors used in marine applications **shall** be stranded marine grade.
  - Marine grade conductors are commonly tinned to provide additional corrosion resistance.
  - Conductors used in marine applications **shall** be UL 1426 (or equivalent) listed as required by jurisdictional regulations.

There are two main categories of automotive conductors:

- Polyvinyl chloride (PVC), which has three main types, as follows:
  - General Purpose Thermoplastic Insulated (GPT): Used for general circuit wiring. Rated to 80° C (176° F).
  - Thin Wall Thermoplastic Insulated (TWP): Lead-free thin wall wire. Rated to 105° C (221° F).
  - Heavy Duty Thermoplastic Insulated (HDT): Heavy wall wiring. Rated to 80° C (176° F).
- Cross-Linked (X), which has three main types, as follows:
  - General Purpose Cross Linked Polyolefin Insulated (GXL): Thin wall, the most common type, works with most standard automotive connectors. Rated to 125° C (257° F).
  - Special Purpose Cross Linked Polyolefin Insulated (SXL): Standard wall. Rated to 125° C (257° F).
  - Thin Wall Cross Linked Polyolefin Insulated (TXL): Extra thin wall, best for applications that require minimal size and weight. Rated to 125° C (257° F).

E.11.2.1 Selecting Conductor Size

The power cable supplied by the equipment manufacturer **shall** be used where practicable. If a power cable must be extended for a specific installation (such as in a large fire apparatus), the conductor used **shall** be the appropriate type and **shall** be appropriately sized for an acceptable voltage drop (see “Equipment Power Conductors Voltage Drop” on page E-20).

If the power conductor being extended must be increased in size in order to maintain an acceptable voltage drop (see “Equipment Power Conductors Voltage Drop” on page E-20), the splice **shall** be made as close to the equipment as practicable. The splice **shall** be made at an easily accessible and conspicuous location. The extended and/or larger conductor **shall** be fused the same as the original power cable, according to the equipment manufacturer’s requirements. The fuse holder **shall** be clearly labeled as to the fuse size and protected equipment (for example: APX radio, 20A).

E.11.2.2 Equipment Power Conductors Voltage Drop

Motorola Solutions recommends a maximum voltage drop of 5% from the battery (source) to the mission critical equipment (at full load). The total length of the positive and negative conductors **shall** be considered. If the specific equipment manufacturer requirements are less than 5% voltage drop, the manufacturer requirements **shall** be followed.

NOTE: A voltage drop of 5% in the power supply conductors from a 13.8 V source would result in a delivered voltage to the load (equipment) of 13.11 V at full load current. Voltage drop calculations other than 5% may require the assistance of an engineer. An online calculator is available at: http://www.calculator.net/voltage-drop-calculator.html.

Table E-1 provides the minimum copper conductor size for a given current and total power conductor length (positive and negative) that will provide 5% or less voltage drop to the load.

Table E-1. Minimum Copper Equipment Power Conductor Size (AWG) for Given Current and Length

	Current Flow in Amps												
	5A	**10A**	**15A**	**20A**	**25A**	**30A**	**40A**	**50A**	**60A**	**70A**	**80A**	**90A**	**100A**
10 ft	18	18	16	14	14	12	12	10	10	8	8	8	8
15 ft	18	16	14	12	12	10	10	8	8	8	6	6	6
20 ft	18	14	12	12	10	10	8	8	6	6	6	4	4
25 ft	16	14	12	10	10	8	8	6	6	6	4	4	4
30 ft	16	12	10	10	8	8	6	6	4	4	4	4	2
40 ft	14	12	10	8	8	6	6	4	4	2	2	2	2
50 ft	14	10	8	8	6	6	4	4	2	2	2	1	1
60 ft	12	10	8	6	6	4	4	2	2	2	1	1	1/0
70 ft	12	8	8	6	6	4	2	2	2	1	1/0	1/0	1/0
80 ft	12	8	6	6	4	4	2	2	1	1/0	1/0	2/0	2/0
90 ft	10	8	6	4	4	4	2	1	1	1/0	2/0	2/0	3/0
100 ft	10	8	6	4	4	2	2	1	1/0	1/0	2/0	3/0	3/0

NOTE: Recommended conductor sizes are in American Wire Gauge (AWG). Maximum voltage drop of 5% is based on a 13.8 V supply.
NOTE: If a listed conductor size is not commercially available, the next larger size conductor **shall** be used.

NOTE: Distance and/or current values exceeding those listed in the tables in this Appendix may require the assistance of an engineer.

NOTE: SAE conductors are 5% to 12% smaller than equivalent AWG, with current capacity typically 7% less than AWG conductors.

E.11.2.3 Power Distribution Unit

Where a Power Distribution Unit (PDU) or distribution busbar (see Figure E-19) is installed in an area of the vehicle, such as in the trunk or passenger compartment equipment console, the conductor supplying the PDU or busbar **shall** be sized for an acceptable voltage drop based on 125% of the expected maximum current draw. See “Power Distribution Unit Power Conductors” on page E-23 for PDU conductor voltage drop information.

NOTE: Consultation with an engineer may be required to determine the maximum current draw of the connected equipment. The calculated maximum current draw should be based on the actual current draw of the connected equipment, not their associated fuse sizes. An Installation Engineer may calculate the conductor size differently than what is shown in this section, based on 100% of non-continuous loads plus 125% of continuous loads. However, Motorola Solutions recommends not exceeding the recommended maximum voltage drop (see “Power Distribution Unit Power Conductors” on page E-23).



Figure E-19. Example of Power Distribution Unit

IMPORTANT: It is recommended to use a PDU for radio equipment and other sensitive electronics, and a separate PDU for other types of emergency equipment (for example: light-bars, flashers, gun locks, strobe lights, and so on).

When selecting the conductor size, perform the following actions:

1. Determine the maximum expected current draw from the PDU, based on the connected equipment. The PDU maximum current rating, and future equipment connections should be considered.
2. Multiply the current value in Step 1 by 1.25.
3. Determine the required total conductor length (positive and negative conductors).
4. Select the minimum conductor size according to “Power Distribution Unit Power Conductors” on page E-23, based on the current value calculated in Step 2, and the conductor length for the given installation in Step 3.
5. Determine the temperature rating of the proposed conductor.
6. Determine if the conductor will be installed, partially or completely, in the engine space.
7. Using “Power Conductor Ampacity and Fuse Rating” on page E-24 and Table E-3, determine if the conductor size selected in Step 4 meets the allowable current for the selected conductor (temperature rating) and installation location (inside or outside engine spaces).
8. If the conductor allowable current does not permit the current value from Step 2, increase the conductor size and/or conductor temperature rating as required.
9. Fuse the conductor according to the current value in Step 2.

Example 1:

1. PDU is rated for 80A.
2. 80A * 1.25 = 100A.
3. The total conductor length is 50 feet.
4. According to Table E-2, the minimum conductor size for the given current in Step 2 (100A), and the total conductor length in Step 3 (50 ft) is #2/0 AWG.
5. The proposed conductors have a temperature rating of 80° C (176° F).

6. A portion of the conductors will be installed in the engine space. Therefore, the “Inside Engine Spaces” column of Table E-3 will be used.
7. Table E-3 permits 222A for the proposed #2/0 AWG conductor.
8. In this example, no conductor size and/or temperature rating increase is required since the current in Step 2 (100A) does not exceed the allowable current permitted in Step 7 (222A).
9. The positive conductor (for negative ground vehicles) is fused at the Step 2 current value (100A) as close to the source as practicable.

Example 2:

1. PDU is rated for 80A.
2. 80A * 1.25 = 100A.
3. The total conductor length is 10 feet.
4. According to Table E-2, the minimum conductor size for the given current in Step 2 (100A), and the total conductor length in Step 3 (10 ft) is #6 AWG.
5. The proposed conductors have a temperature rating of 80° C (176° F).
6. A portion of the conductors will be installed in the engine space. Therefore, the “Inside Engine Spaces” column of Table E-3 will be used.
7. Table E-3 permits 78A for the proposed #6 AWG conductor.
8. In this example, the current from Step 2 (100A) exceeds the allowable current permitted in Step 7 (78A). Therefore, the conductor size and/or temperature rating must be increased using one of the following options (see Table E-3):
   - 105° C (or higher) rated #6 AWG
   - 80° C (or higher) rated #4 AWG
9. The positive conductor (for negative ground vehicles) is fused at the Step 2 current value (100A) as close to the source as practicable.

E.11.2.4 Power Distribution Unit Power Conductors

Motorola Solutions recommends a maximum voltage drop of 3% from the battery (source) to the Power Distribution Unit (PDU), at full load (see American Boat and Yacht Council standards for more information). The total length of the positive and negative conductors **shall** be considered.

When using a power distribution system, the use of a distributed ground bar is recommended. The conductor feeding the ground bar (-) should be sized the same as the conductor feeding the PDU (+). The conductor feeding the ground bar must be factored into the conductor size calculations (see examples in “Power Distribution Unit” on page E-21.

NOTE: A voltage drop of 3% in the PDU power supply conductors from a 13.8 V source would result in 13.39 V delivered to the PDU at full load current. Voltage drop calculations other than 3% may require the assistance of an engineer. An online calculator is available at http://www.calculator.net/voltage-drop-calculator.html.

Table E-2 provides the minimum copper conductor size for a given current and total power conductor length (positive and negative) that will provide 3% or less voltage drop to the PDU.

Table E-2. Minimum Copper Power Distribution Unit Conductor Size (AWG) for Given Current and Length

	Current Flow in Amps												
	5A	**10A**	**15A**	**20A**	**25A**	**30A**	**40A**	**50A**	**60A**	**70A**	**80A**	**90A**	**100A**
10 ft	18	16	14	13	12	11	10	9	8	7	7	6	6
15 ft	17	14	12	11	10	9	8	7	6	6	5	5	4
20 ft	16	13	11	10	9	8	7	6	5	4	4	3	3
25 ft	15	12	10	9	8	7	6	5	4	3	3	2	2
30 ft	14	11	9	8	7	6	5	4	3	3	2	2	1
40 ft	13	10	8	7	6	5	4	3	2	1	1	1/0	1/0
50 ft	12	9	7	6	5	4	3	2	1	1/0	1/0	2/0	2/0
60 ft	11	8	6	5	4	3	2	1	1/0	1/0	2/0	2/0	3/0
70 ft	10	7	6	4	3	3	1	1/0	1/0	2/0	3/0	3/0	4/0
80 ft	10	7	5	4	3	2	1	1/0	2/0	3/0	3/0	4/0	4/0
90 ft	9	6	5	3	2	2	1/0	2/0	2/0	3/0	4/0	4/0	300 kcmil
100 ft	9	6	4	3	2	1	1/0	2/0	3/0	4/0	4/0	300 kcmil	350 kcmil

NOTE: Recommended conductor sizes are in American Wire Gauge (AWG). Maximum voltage drop of 3% is based on a 13.8 V supply.
NOTE: If a listed conductor size is not commercially available, the next larger size conductor **shall** be used.

NOTE: Distance and/or current values exceeding those listed in the tables in this Appendix may require the assistance of an engineer.

NOTE: SAE conductors are 5% to 12% smaller than equivalent AWG, with current capacity typically 7% less than AWG conductors.

E.11.2.5 Power Conductor Ampacity and Fuse Rating

Conductor ampacity is commonly defined as the maximum amount of electric current a conductor can carry before sustaining immediate or progressive deterioration. Also described as the current-carrying capacity a conductor can continuously carry while remaining within its temperature rating. Conductor ampacity primarily depends on its insulation temperature rating.

The temperature rating of power conductors **shall** be considered and selected for the application. Motorola Solutions recommends a minimum conductor temperature rating of 80° C (176° F).

NOTE: Automotive-rated conductors with a minimum temperature rating of 80° C (176° F) are readily available.

NOTE: Conductors installed inside engine spaces have a lower ampacity due to the increased ambient temperature. Conductor insulation temperature must not exceed its rating. Ambient temperature and conductor temperature increase due to current flow (I^2R) are both conductor insulation temperature factors. Table E-3 considers ambient temperature and current flow.

Power conductors **shall** be fused according to the conductor ampacity (current carrying capacity) rating. Table E-3 provides the maximum allowable current for conductors under 50 V, based on the temperature rating of the conductor and the installation location (inside or outside engine spaces). Power conductors **shall** be fused no greater than that allowed in Table E-3.

Table E-3. Maximum Allowable Current for Conductors Under 50 Volts

Temperature Rating of Conductor Insulation										
Conductor Size		80°C (176° F)		90°C (194° F)		105°C (221° F)		125° C (257° F)		200°C (392° F)
AWG	Metric (mm^2)	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside or Inside Engine Spaces
18	(0.8)	15	11.7	20	16.4	20	17.0	25	22.3	25
16	(1)	20	15.6	25	20.5	25	21.3	30	25.7	35
14	(2)	25	19.5	30	24.6	35	29.8	40	35.6	45
12	(3)	35	27.3	40	32.8	45	39.3	50	44.5	55
10	(5)	50	39.0	55	45.1	60	51.0	70	62.3	70
8	(8)	70	54.6	70	57.4	80	68.0	90	80.1	100
6	(13)	100	78.0	100	82.0	120	102	125	111	135
4	(19)	130	101	135	110	160	136	170	151	180
2	(32)	175	138	180	147	210	178	225	200	240
1	(40)	210	163	210	172	245	208	265	235	280
0	(50)	245	191	245	200	285	242	305	271	325
00	(62)	285	222	285	233	330	280	355	316	370
000	(81)	330	257	330	270	385	327	410	384	430
0000	(103)	385	300	385	315	445	378	475	422	510



Figure E-20. Example of Automotive Grade Mobile Radio Power Cable

E.12 Joining Conductors for Mobile Installations

Suitable methods of joining conductors include the following (see FCS1362:2022 and “Electrical Ring Terminals, Lugs, Splices, and Similar Devices” on page E-27 for more information):

E.12.1 Soldering

- Soldering typically requires more skill than crimping; therefore, it is subject to more mistakes.
- Soldered joints **shall** employ a mechanical aspect to give strength to the joint prior to soldering. Such as the following:
  - Non-insulated crimp butt connector
  - Wrapping one conductor around the other (see “Conductor Tapping and Soldering” on page E-30 and Figure E-29)
- Solder the conductors using industry accepted techniques. See Figure E-30 for an example of a completed solder connection.
- The soldered joint **shall** be sealed with one of the following:
  - Heat shrink tubing.
  - Self-amalgamating tape. See “Conductor Tapping and Soldering” on page E-30 and “Electrical Tape and Heat Shrink Tubing” on page E-31 for more information.
  - Insulation tape, which is then wrapped in a cloth tape. This will keep the insulation tape in place over time but still provide excellent insulation. See FCS1362:2022 for more information.
  - See “Electrical Tape and Heat Shrink Tubing” on page E-31 for more information.

IMPORTANT: Soldering, particularly with gas powered irons, may not be appropriate in certain environments. Caution **shall** be taken where a gas soldering iron has a hot air vent, which could easily cause damage to the insulation of other cables or the environment around the area of use. See FCS1362:2022 for more information.

E.12.2 Crimped (Butt) Connectors

- Crimped butt connectors are an acceptable method provided the correct size connector is chosen and the correct ratchet tool is used.
- Crimped butt connectors are only suitable for use inside a vehicle where the connector is not exposed to the elements. Crimped butt connectors **shall not** be used under vehicle carpet that is exposed to normal foot traffic.
- See “Electrical Ring Terminals, Lugs, Splices, and Similar Devices” on page E-27 for more information.

E.12.3 Heat Shrink Butt Connectors

- Heat shrink butt connectors come in two types, crimp and solder.
- They have a heat shrink outer casing, making them acceptable in areas where the connector may be exposed to the elements.
- Crimp versions **shall** be crimped before the outer casing is shrunk.
  - The correct crimp tool **shall** be used.
  - See “Electrical Ring Terminals, Lugs, Splices, and Similar Devices” on page E-27 for more information.
- Solder versions are self-contained with pre-fluxed solder within a transparent heat shrinkable tube.
  - Can be completed with just a heat gun.
  - Combine a soldered, strain relieved, encapsulated termination for weatherproofing and can be used on sensitive low-temperature wires such as PVC.
  - See Figure E-25 for an example.

E.12.4 Electrical Ring Terminals, Lugs, Splices, and Similar Devices

Electrical ring terminals, lugs, splices, and similar devices (electrical connection devices) used in mission critical applications **shall** be appropriate for the application (see Figure E-21).



Figure E-21. Examples of Electrical Connection Devices

The requirements and recommendations for electrical connection devices are as follows:

- Electrical connection devices **shall** be UL listed (or equivalent), Canadian Standards Association (CSA) certified, or have the CE (European Conformity) marking.
- Electrical connection devices **shall** be suitable for the type of conductor:
  - Solid
  - Stranded
- Electrical connection devices **shall** be suitable for the size of the conductor.
- Electrical connection devices **shall** be suitable for use in industrial, automotive, and other high-vibration electrical applications (see product documentation).
- Consumer-grade electrical connection devices **shall not** be used.
- Electrical conductors **shall** be prepared in such a way that no bare wire is exposed once the electrical connection device is attached.

- Electrical conductors **shall not** be damaged during preparation or stripping of insulation. Care **shall** be taken to ensure all conductor strands are intact and undamaged.
- Plastic auto electrical snap-lock splicing connectors that cut into the cable's insulation (the insulation displacement connector) should not be used as a connection method (FCS1362:2022, section 2.6.2). See Figure E-22 for examples.

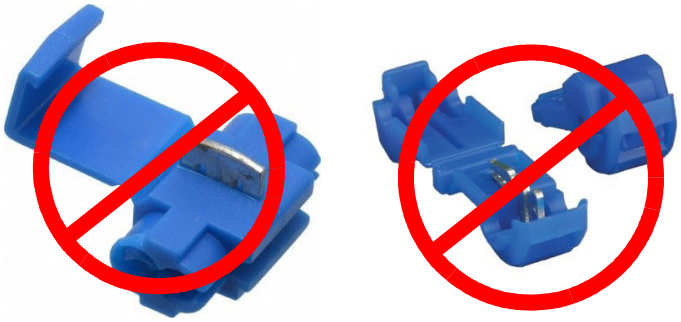


Figure E-22. Examples of Unacceptable Insulation Displacement Connectors

- Electrical connection devices used in marine applications **shall** be suitable for marine applications. See Figure E-23 for examples. Marine application devices typically have the following characteristics:
  - Constructed from tinned-copper for improved corrosion resistance.
  - Contain an adhesive-lined heat shrink insulator to seal connection from vibration and to provide improved strain relief.



Figure E-23. Examples of Marine-Grade Electrical Connection Devices

- Butt connectors exposed to the elements (for example: installed under the hood, or installed under the vehicle carpet and exposed to foot traffic) **shall** be heat shrink-type butt connectors (or marine grade). See Figure E-24 and Figure E-25 for examples.



Figure E-24. Example of Heat Shrink Crimped Butt Connector



Figure E-25. Example of Heat Shrink Solder Butt Connector

- Only manufacturer-approved crimping devices **shall** be used (see product documentation).
- Ring lugs should be used where practicable as opposed to spade lugs. Ring lugs have a larger contact area and are more secure.
- Electrical connection devices should have a brazed seam to protect the barrel from splitting during crimping. Proper crimping techniques **shall** be used to help prevent splitting of the barrel.
  - The connection device **shall** be inserted into the tool so the seam is within the round portion of the crimping tool (as applicable).
  - See Figure E-26 for an example.
  - See the specific crimper instructions.



Figure E-26. Example of Crimping Technique

- The crimping tool used **shall** be the approved tool by the electrical connection device manufacturer (see electrical connection device instructions).
  - A controlled cycle (ratcheting) crimping tool is recommended for consistent quality crimps. See Figure E-27 for an example of a controlled cycle crimping tool.



Figure E-27. Example of Controlled Cycle (Ratcheting) Crimper

E.13 Bonding Requirements for Mobile Installation

The following requirements apply where attaching a lug to a bonding surface, such as attaching an equipment ground (-) conductor to the vehicle chassis:

- Paint, enamel, lacquer, and other non-conductive coatings **shall** be removed from surface areas where connections are made to ensure good electrical continuity.
- Bonding surfaces **shall** be cleaned to remove dirt, corrosion, and oxidized material on the connection surface area.
- The use of a piloted bonding brush is recommended for cleaning the bonding surface. See Figure E-28 for an example of a piloted bonding brush.
- After bonding to a factory-painted surface, the area **shall** be thoroughly cleaned and coated with an approved corrosion inhibiting paint (or equivalent). See FCS1362:2022, section 2.11.3 for more information.

IMPORTANT: DO NOT install a washer of any kind between a lug and the bonding surface.

NOTE: Using a star washer does not alleviate the requirement to remove non-conductive coatings from attachment surfaces. Star washers should only be used as a lock washer.



Figure E-28. Example of Piloted Bonding Brush

E.14 Conductor Tapping and Soldering

Conductors must sometimes be tapped into a vehicle wiring system conductor. Such applications may be one or more of the following:

- Radio ignition sense conductors are required and an ignition switched power point is not readily available at the vehicle fuse box or other location.
- Vehicle horn conductor is required for radio accessory features, such as audible alert and/or siren features (“horn ring”).
- Vehicle lights conductor is required for radio accessory features, such as visual alert.

Since plastic auto electrical snap-lock splicing connectors (insulation displacement connectors) are not recommended (see “Electrical Ring Terminals, Lugs, Splices, and Similar Devices” on page E-27), soldering may be required (see FCS1362:2022).

Soldered joints **shall** employ a mechanical aspect to give strength to the joint prior to soldering; for example, by wrapping one conductor around the other (see Figure E-29).

Soldering **shall** be performed only by trained personnel. The following general process **shall** be followed (see FCS1362:2022):

1. Cut approximately 20 mm (0.8 in.) of insulation from the tapped conductor (red in Figure E-29).
2. Tin the tapped conductor.
3. Twist the tap conductor (yellow in Figure E-29) around the exposed tapped conductor approximately three times.



Figure E-29. Example of Wrapping Tap Conductor Around Tapped Conductor Prior to Soldering

4. Solder the conductors using industry-accepted techniques. See Figure E-30 for an example of a completed solder connection.
5. Clean the joint as needed and remove any sharp elements such as protruding wires.

6. Seal the joint with self-amalgamating tape, or insulation tape that is then wrapped in a cloth tape. Insulation tape is prone to losing its adhesive properties over time and through exposure to moisture and varying temperatures. See “Electrical Tape and Heat Shrink Tubing” on page E-31 and Figure E-32.



Figure E-30. Example of Completed Solder Connection

E.15 Electrical Tape and Heat Shrink Tubing

Electrical tape and similar products used **shall** be appropriate for the application. The general requirements and recommendations are as follows:

- Electrical tape **shall** be listed (for example, CSA or UL).
- Electrical tape **shall** be commercial-grade, professional-grade, or heavy duty-grade as defined by the manufacturer.
  - Consumer-grade or economy-grade tape **shall not** be used.
- Heat shrink tubing **shall** be listed (for example, CSA or UL). See Figure E-31 for examples.



Figure E-31. Examples of Heat Shrink Tubing

NOTE: Heat shrink tubing is readily available in many colors, sizes, and shrinking ratios.

- Heat shrink tubing is the preferred method of insulating as it provides excellent insulation and does not react adversely to moisture or typical seasonal temperature changes (FCS1362:2022).
  - Non-adhesive heat shrink tubing can be used inside a vehicle.
  - An adhesive-lined heat shrink tubing **shall** be used if the joint is exposed to the elements and/or in marine applications.
- The appropriate manufacturer-recommended heat source **shall** be used to shrink the tubing.
  - Typically a heat gun is used for this purpose.
  - An open flame is not recommended.
- Self-amalgamating (self-bonding or self-fusing) tape **shall** be designed for use as an electrical tape as defined by the manufacturer.
- Soldered joints on tapped conductors **shall** be insulated with self-amalgamating tape, or insulation tape that is then wrapped in a cloth tape. See “Conductor Tapping and Soldering” on page E-30 and Figure E-32.



Figure E-32. Example of Self-Amalgamating Tape

E.16 Antenna Installation and Testing

This section provides antenna installation requirements and guidelines. Instructions provided by the transceiver and antenna manufacturer **shall** be followed.

E.16.1 Coaxial Cable (Coax)

- The coax supplied by the radio manufacturer **shall** be used, where practicable.
- The coax used **shall** be commercial grade and designed for mission critical applications.
  - A minimum 95% shield is recommended.
  - Low loss as required by the frequency in use (consult with the system engineer).
- Stranded center conductor coax is recommended.
  - Solid center conductor coax should not be used in mobile installations. Solid center conductors are susceptible to breakage due to repeated flexing in mobile applications.
- The coax from the radio to the antenna **shall** be free of splices and/or extensions. The appropriate length of cable **shall** be used for the application.
- The appropriate connector **shall** be used for the type of coax used (see manufacturer's specifications).
- Marine grade coax **shall** be used in marine installations.
  - Marine grade coax is designed for UV and salt environments.
  - Marine grade coax center conductor and outer shield are tinned for corrosion resistance.
  - Marine grade coax typically has a white outer jacket.

IMPORTANT: Except under engineering supervision, DO NOT reuse existing coaxial cables.

E.16.2 Antenna Installation

NOTE: The information in this section is primarily taken from the *APX Mobiles Installation Manual*.

IMPORTANT: Ensure the installed antenna type and mounting location match the engineered system design. Changing the antenna type and/or mounting location without engineering approval can negatively affect the mobile radio's ability to transmit and/or receive on the intended system.

IMPORTANT: Antennas **shall** be tuned according to manufacturer instructions, as applicable.

Motorola Solutions recommends the following sequence for antenna system installation:

1. **External installation:** Check the requirements of the antenna supplier and install the vehicle antenna external to a metal body vehicle in accordance with those requirements.
2. **Roof top:** For optimum performance and compliance with RF Energy Safety standards, mount the antenna in the center area of the roof.
3. **Trunk lid:** On some vehicles with clearly defined, flat trunk lids, the antennas of some radio models (see restrictions below) can also be mounted on the center area of the trunk lid. For vehicles without clearly defined, flat trunk lids (such as hatchback autos, sports utility vehicles, and pickup trucks), mount the antenna in the center area of the roof.
4. Before installing an antenna on the trunk lid:
   - Be sure that the distance from the antenna location on the trunk lid will be at least 85 cm (33 in.) from the front surface of the rear seat-back to assure compliance with RF Energy Safety standards.
   - Ensure that the trunk lid is grounded by connecting grounding straps between the trunk lid and the vehicle chassis, as required.
5. Mounting restrictions for certain radio models.
   - For all VHF and UHF models, the ¼ wave antenna should be mounted only in the center area of the roof, not on the trunk lid, to assure compliance with RF Energy Safety standards.
6. Ensure that the antenna cable can be easily routed to the radio. Route the antenna cable as far away as possible from any vehicle electronic control units and associated wiring.
7. Check the antenna location for any electrical interference.
8. Ensure that any transmitting radio antennas on the vehicle are separated from each other by at least 0.9 m (3 ft.), as practicable. See Figure E-33.
9. The minimum distance between the antenna and the radio/accessories should be at least 91.44 cm (3 ft.).
10. The minimum distance between the antenna and the fuel filler cap **shall** be 30 cm (12 in.), as practicable to reduce the risk of the radiated electric field being a source of ignition (FCS1362:2022, section 4.2.3.2).

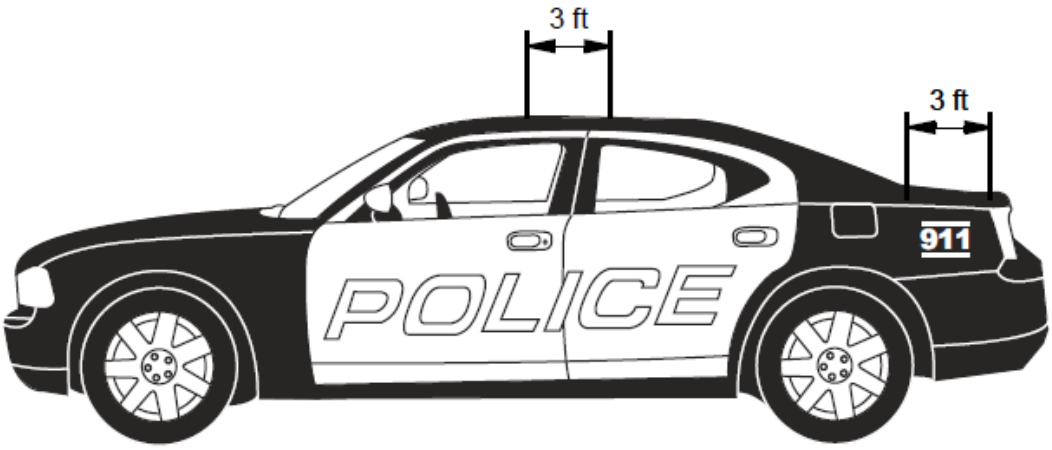


Figure E-33. Separation of Multiple Antennas

IMPORTANT: Except under engineering supervision, DO NOT reuse existing antennas and/or coaxial cables.

NOTE: Any two metal pieces rubbing against each other (such as seat springs, shift levers, trunk and hood lids, exhaust pipes, and so on) near the antenna can cause receiver interference.

NOTE: See FCS1362:2022, Appendix C for example antenna radiation patterns for common antenna installation locations.

E.16.3 Antenna Installations on Non-Metallic Surfaces

Many emergency vehicles, motorcycles, and marine vessels contain fiberglass or other non-metallic body parts (including the roof). Antennas mounted in these locations require special consideration to ensure proper antenna performance. Options for installations on non-metallic surfaces include (but are not limited to) the following:

- Antenna specifically designed for no ground plane installations.
- Foil ground plane tape designed specifically for mobile installations (see Figure E-34).
  - The foil tape is typically self-adhesive for ease of installation.
  - The foil tape is effective for uneven surfaces.
  - The foil tape is installed on the underside of the mounting surface (for example, a fiberglass roof).
  - The tape should be arranged so that at least four strips are equally spaced around a common intersecting point, as practicable. The intersecting point is the antenna mounting hole. See Figure E-35 for an example.
  - The coax mount grounding hardware **shall** make good electrical contact with the sections of foil tape.
  - The minimum length of the foil tape from the center intersection point to each end (radius of circle) should be equal to or greater than the ¼ wavelength of the desired frequency. See Table E-4 and the graph in Figure E-37 for example lengths at given frequencies.
- Metallic ground plate designed for mobile installations.
  - The ground plate is mounted in a similar fashion as described above for foil tape.
  - Metallic ground plate is ideal for smooth and even surfaces.
  - The radius of the plate should be sized the same as described for foil tape. See Table E-4 and the graph in Figure E-37.
  - See Figure E-36 for an example of a ground plate.
- Other engineered ground plane.



Figure E-34. Example of Foil Ground Plane Tape

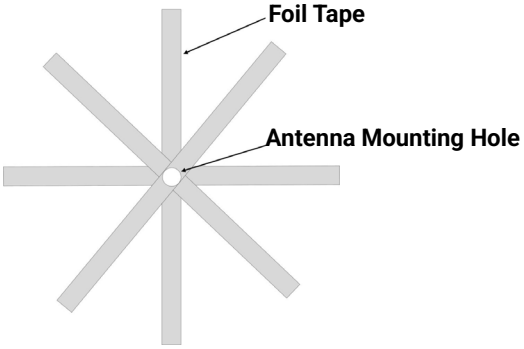


Figure E-35. Example of Minimum Recommended Foil Tape Installation Pattern



Figure E-36. Example of Metallic Ground Plane Plate

Table E-4. Frequency versus ¼ Wavelength

Frequency	Approximate ¼ Wavelength
27 MHz	2.8 m (109 in.)
50 MHz	1.5 m (59 in.)
100 MHz	0.75 m (29.5 in.)
150 MHz	0.5 m (19.7 in.)
170 MHz	0.44 m (17.4 in.)
430 MHz	0.174 m (6.9 in.)
450 MHz	0.167 m (6.6 in.)
700 MHz	0.107 m (4.2 in.)
800 MHz	0.094 m (3.7 in.)
900 MHz	0.083 m (3.3 in.)

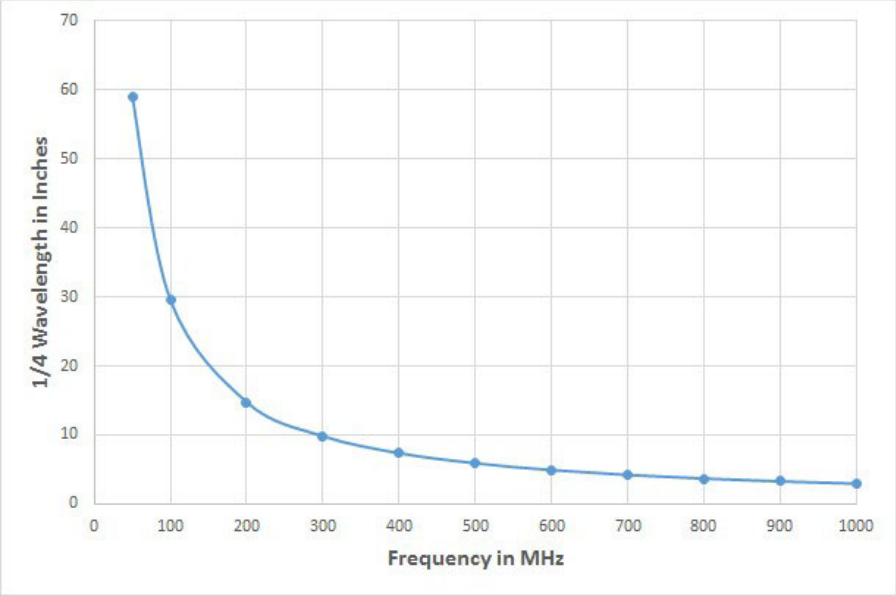


Figure E-37. Frequency versus ¼ Wavelength

NOTE: The wavelength of any given frequency can be calculated using the following formula: wavelength in meters = 300 / frequency in MHz. The wavelength is cut in half for every doubling of the frequency.

An example calculation for 156.8 MHz is as follows:

- Wavelength in meters = 300 / 156.8 MHz = 1.91 m (75.2 in.)
- ¼ wavelength = 1.91 m / 4 = 0.48 m (18.8 in.)

E.16.4 Mini-UHF Connection

NOTE: The information in this section is primarily taken from the *APX Mobiles Installation Manual*.

The mini-UHF connector is a common connector for Land Mobile Radio (LMR) and is covered in this subsection (see Figure E-38). The mini-UHF connector **shall** be installed according to manufacturer instructions, using manufacturer-approved crimping tool. A ratcheting crimp tool is recommended (see Figure E-39).



Figure E-38. Examples of Mini-UHF Connectors



Figure E-39. Example of Mini-UHF Ratcheting Crimp Tool (Motorola Solutions Part Number 6680388A26)

To ensure a secure connection of an antenna cable's mini-UHF plug to a radio's mini-UHF jack, their interlocking features must be properly engaged. If they are not properly engaged, the system will loosen. Using a tool (pliers or wrench) will not overcome a poor engagement, and is not recommended.

IMPORTANT: Applying excessive force with a tool can cause damage to the antenna jack or the connector (for example: stripping threads, deforming the collar or connector, or causing the connector to twist in the housing opening and break).

The mini-UHF connector tool (Motorola Solutions part number HLN6695) is designed to securely tighten the antenna plug-radio jack connection without damaging either the plug or the jack.

Motorola Solutions recommends the following sequence to ensure proper attachment of the system (see Figure E-40 and Motorola Solutions Inc. publication 6878215A01 *APX Mobiles Control Head Installation Manual*).

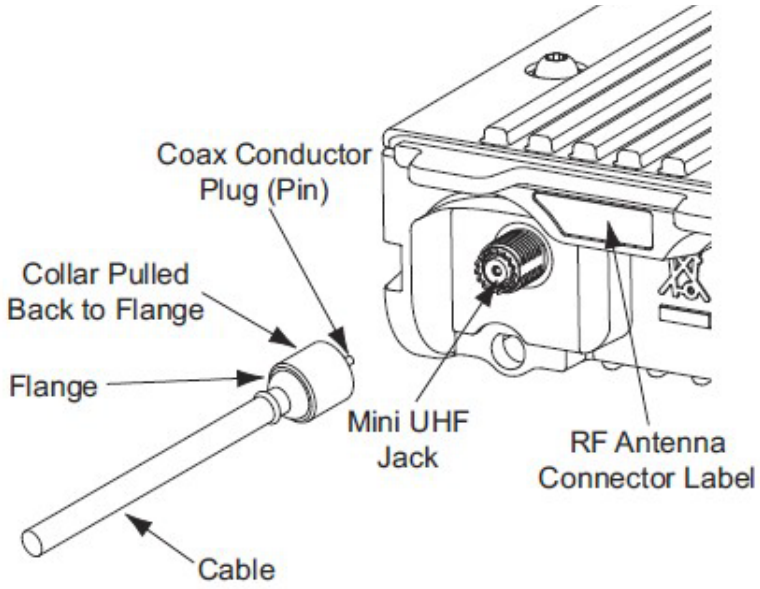


Figure E-40. Example of Mini-UHF Connection

1. Ensure that there is sufficient slack in the antenna cable.
2. Ensure that the collar of the antenna cable plug is loose and does not bind.
3. Ensure that the mini-UHF jack is tight in the radio housing.
4. Slide the collar back against the flange. Insert the antenna cable plug's pin fully into the radio jack, but do not engage the threads.
5. Ensure that the plug's and jack's interlocking features are fully seated. Check this by grasping the crimp on the cable jack, rotating the cable, and noting any movement. If the features are seated correctly, there should be **no** movement.
6. Finger-tighten the antenna cable plug's collar onto the radio's jack.
7. Give a final tug, by hand, to the collar, and tighten by hand as firmly as possible.
8. Slip the mini-UHF connector tool over the coaxial cable, using the gap between the tool's legs (see Figure E-41). Then, slide the tool up onto the plug's knurled collar. Squeeze the two straight legs of the tool firmly together between your thumb and index finger and turn clockwise (as shown) to tighten the collar (¼ turn or less). When you feel the tool slipping on the collar, the connection has been sufficiently tightened. The tool can also be used to loosen a tight collar.

IMPORTANT: DO NOT use pliers or any other device to grip the tightening tool. It has been designed to enable you to achieve the proper torque on the collar without excessive tightening. Excessive tightening of the collar can damage the connector and the radio.

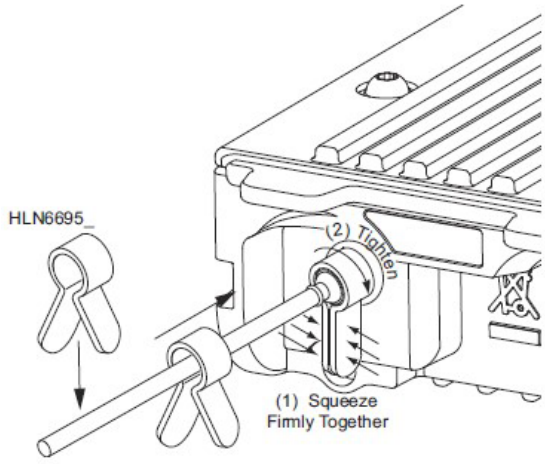


Figure E-41. Mini-UHF Connector Torque Tool

E.16.5 Antenna VSWR Testing

As part of the mobile radio installation, antennas **shall** be tested for Voltage Standing Wave Ratio (VSWR) or Return Loss (RL) (see FCS1362:2022 for more information). VSWR or RL testing may be completed using a through-line directional wattmeter (for example, Bird Technologies® APM-16) or a cable and antenna analyzer.

The antenna VSWR or RL **shall** meet the manufacturer's specifications (see the antenna specification sheet). Typical mobile antenna VSWR specifications are 1.5:1 (RL = 14 dB) or 2.0:1 (RL = 9.54 dB).

IMPORTANT: VSWR testing of digital format radios (for example: DMR, MOTOTRBO, P25 or TETRA) requires the use of an average reading power meter. An analog wattmeter will not provide accurate results unless the radio can be put in an analog test mode.

IMPORTANT: Antennas **shall** be tuned according to manufacturer instructions, as applicable.

NOTE: The preferred method of testing an antenna is to use a cable and antenna analyzer (frequency domain reflectometer or vector network analyzer). The cable and antenna analyzer allows a technician to easily see how the antenna is operating across the entire customer frequency spectrum.

NOTE: A VSWR of 1.5:1 or an RL of 14 dB is equivalent to 4% reflected power. A VSWR of 2.0:1 or an RL of 9.54 dB is equivalent to 11% reflected power.

When testing the antenna VSWR or RL, the following **shall** be followed:

- All vehicle doors, trunk, and hood **shall** be closed.
- All antennas, lightbars, and other metallic objects **shall** be installed on the vehicle. Metallic objects (including antennas other than the antenna under test) can impact the VSWR/RL measurement.
- Adapters **shall** be avoided as practicable. The wattmeter **shall** have the appropriate connectors installed.
- If using a wattmeter, the vehicle battery **shall** be fully charged or the vehicle **shall** be running during the test. Ensure adequate ventilation or test outdoors.
- The wattmeter or cable and antenna analyzer **shall** be in known good working condition and **shall** be within factory calibration tolerances.

- If VSWR testing is made using a directional wattmeter, the measured forward power output **shall** match the power recorded in "Transceiver Preventive Maintenance and Inspection" on page E-6. If the power does not match within ± 5%, a technician **shall** be engaged to troubleshoot the problem.

IMPORTANT: When testing the antenna VSWR using a wattmeter, it is important to check multiple frequencies across the customer frequency spectrum. This is to help ensure antenna match on all customer frequencies.

NOTE: Analyzers are suitable for analog and digital systems, whereas the traditional analog power meter is only suitable for analog systems (see FCS1362:2022).

E.16.5.1 Wattmeter and Test Accuracy Considerations

Wattmeter tests have forward and reflected power measurement accuracy limitations that must be considered. Wattmeters may specify their accuracy using different methods, and often specify a measurement accuracy based on one of the following:

- A percentage of the reading (for example, ± 5% of the measured value)
- A percentage of the full scale (for example, ± 5% of the full scale)
- A dB value of the reading (for example, ± 0.4 dB of the measured value)
- A combination of one or more of the above (for example, ± 4% of the measured value and ± 1% of full scale).

Examples

A wattmeter with an accuracy specification of ± 5% of the measured value:

- Measuring a 100-watt radio would have an accuracy range of 95 - 105 watts (± 5% of 100).
- Measuring a 50-watt radio would have an accuracy range of 47.5 - 52.5 watts (± 5% of 50).
- Measuring a 35-watt radio would have an accuracy range of approximately 33 - 37 watts (± 5% of 35).
- Measuring a 15-watt radio would have an accuracy range of approximately 14 - 16 watts (± 5% of 15).

A wattmeter with an accuracy specification of ± 5% of the full scale:

- Measuring a 100-watt radio using a 100-watt element would have an accuracy range of 95 – 105 watts (± 5% of full scale). In this example, 5% of the full range is 5 watts.
- Measuring a 50-watt radio using a 100-watt element would have an accuracy range of 45 – 55 watts (± 5% of full scale). In this example, 5% of the full range is 5 watts.
- Measuring a 50-watt radio using a 50-watt element would have an accuracy range of 47.5 – 52.5 watts (± 5% of full scale). In this example, 5% of the full range is 2.5 watts.
- Measuring a 35-watt radio using a 50-watt element would have an accuracy range of 32.5 – 37.5 watts (± 5% of full scale). In this example, 5% of the full range is 2.5 watts.
- Measuring a 15-watt radio using a 25-watt element would have an accuracy range of 13.75 – 15.25 watts (± 5% of full scale). In this example, 5% of the full range is 1.25 watts.

A wattmeter with an accuracy specification of ± 0.4 dB of the measured value:

- Measuring a 100-watt radio would have an accuracy range of approximately 91 – 110 watts (± 0.4 dB of the measured value).
- Measuring a 50-watt radio would have an accuracy range of approximately 46 – 55 watts (± 0.4 dB of the measured value).
- Measuring a 35-watt radio would have an accuracy range of approximately 32 – 38.5 watts (± 0.4 dB of the measured value).
- Measuring a 15-watt radio would have an accuracy range of approximately 13.5 – 16.5 watts (± 0.4 dB of the measured value).

A wattmeter with an accuracy specification of ± 4% of the measured value and ± 1% of the full scale:

- Measuring a 100-watt radio using a 100-watt element would have an accuracy range of 95 – 105 watts (± 5 watts). In this example, 4% of the measured value is 4 watts, and 1% of the full scale is 1 watt (4 + 1 = 5 watts).
- Measuring a 50-watt radio using a 100-watt element would have an accuracy range of 47 – 53 watts (± 3 watts). In this example, 4% of the measured value is 2 watts, and 1% of the full scale is 1 watt (2 + 1 = 3 watts).
- Measuring a 50-watt radio using a 50-watt element would have an accuracy range of 47.5 - 52.5 watts (± 2.5 watts). In this example, 4% of the measured value is 2 watts, and 1% of the full scale is 0.5 watts (2 + 0.5 = 2.5 watts).
- Measuring a 35-watt radio using a 50-watt element would have an accuracy range of approximately 33.1 – 36.4 watts (± 1.9 watts). In this example, 4% of the measured value is 1.4 watts, and 1% of the full scale is 0.5 watts (1.4 + 0.5 = 1.9 watts).
- Measuring a 15-watt radio using a 25-watt element would have an accuracy range of approximately 14 – 16 watts (±1 watt). In this example, 4% of the measured value is approximately 0.6 watts, and 1% of the full scale is 0.25 watts (0.6 + 0.25 = 0.85 watts or ≈ 1 watt).

E.16.5.1.1 Wattmeter Element and Frequency Selection

For a wattmeter to provide an accurate power reading, the correct frequency range must be selected. Depending on the wattmeter model, the frequency range is set by software, or a frequency-specific element is installed.

When measuring reflected power, use the lowest power-rated element (or power selection) that will provide a measurement that is in the middle range of the meter movement (approximately 50 – 80% of full scale). Due to accuracy limitations, higher power elements (or power settings) cannot provide the required accuracy at lower power levels.

IMPORTANT: To prevent wattmeter damage when measuring reflected power, start with a high-power element (or power selection) to ensure excessive high reflected power does not damage the meter movement. Then, reduce the element power rating (or power setting) as needed to achieve a meter movement of approximately 50–80% of full scale.

E.16.5.1.2 Test Cable Requirements

The test cable used between the radio and wattmeter **shall** be of high quality, in known good condition, and the loss for the given frequencies must be known. Cable loss can be measured using a vector network analyzer.

IMPORTANT: The loss of the test cable must be accounted for in the measurement. For example, if the test cable has a known loss of 0.5 dB and the transmitter power output is 100 watts, the value measured at the wattmeter would be 0.5 dB less than the actual, or 89 watts. Several dB calculator apps are available that can be used to determine the expected power based on the cable loss, such as the Rohde & Schwarz dB Calculator app.

E.17 Effective Receiver Sensitivity Testing

Effective receiver sensitivity is a measure of how well a receiver performs under actual operating conditions. Effective receiver sensitivity may be degraded by nearby noise sources. Examples are, but not limited to, emergency lights, high-intensity LED lights, mobile data computers, strobe lights, transmitters, vehicle charging systems, vehicle ignition systems, Wi-Fi hotspots, wireless broadband cards, and so on.

Mission-critical land mobile radio installations **shall** be tested for effective receiver sensitivity. In large projects and/or fleet installations, testing of a small sample of each vehicle/installation type is required. Examples of vehicle/installation types include:

- Police Department Patrol 2026 Ford Explorer
- Police Department Patrol 2025 Ford Explorer
- Police Department Patrol Chevrolet Tahoe
- Police Department Traffic Dodge Charger
- Fire Department Ladder Truck
- Fire Department Engine
- Fire Department Medic Unit

Testing should include as many frequencies across the customer frequency band as practicable. For trunking radios, testing should be included on the available test channels (see the radio maintenance manual).

IMPORTANT: Testing may not be possible on active channels. Normal channel activity could appear as degradation during the test.

Effective receiver sensitivity testing requires the use of a capacitive coupler, commonly known as an Iso-T. Testing for receiver degradation and effective sensitivity is detailed in the following steps and summarized in Table E-5:

1. Ensure the vehicle battery is fully charged. Turn vehicle off and turn off all other vehicle systems, except the radio under test.
2. Measure and record the basic sensitivity (in dBm) of the receiver as described in “Transceiver Preventive Maintenance and Inspection” on page E-6. See Figure E-42.
3. Configure the test setup as shown in Figure E-43. The communications analyzer (signal generator) is connected to the capacitively coupled (isolated) port.
4. Adjust the signal generator for 12 dB SINAD or 5% Bit Error Rate (BER). Record the value (in dBm).
5. Configure the test setup as shown in Figure E-44. The 50 ohm termination is replaced with the vehicle antenna.
6. Adjust the signal generator as required for 12 dB SINAD or 5% BER (the same method used in Step 4). Monitor the 12 dB SINAD or 5% BER for at least 60 seconds to help ensure that no intermittent interference exists. Record the value (in dBm).
7. Calculate the amount of receiver degradation (in dB) by subtracting the value recorded in Step 4 from the value recorded in Step 6. This value should be a positive number or zero.
8. Calculate the effective receiver sensitivity (in dBm) by adding the amount of receiver degradation (in dB) from Step 6 to the basic receive sensitivity value recorded in Step 2. Record the results.
9. Start the vehicle and all vehicle systems (for example: lightbars, LED running lights, data terminals, video recording system, sirens, RADAR devices, and so on).
10. Repeat steps 5 through 8 and record the results as required.

11. Report the findings to the system engineer and/or system manager.

Table E-5. Example of Receiver Degradation Calculation

Step Number	Example Value	Notes
2	-120 dBm	Typical value.
4	-90 dBm	50 ohm load is connected. The Iso-T “isolated” port and 6 dB attenuator have an isolation of 30 dB.
6	-89 dBm	The vehicle antenna is connected in place of the 50 ohm load.
7	-89 dBm - -90 dBm = 1 dB Mathematically rewritten as: -89 dBm + 90 dBm = 1 dB	The amount of receiver degradation is calculated as follows: Step 4 value subtracted from Step 6 value. In this example, 1 dB of receiver degradation is measured from the external environment (not vehicle systems).
8	-120 dBm + 1 dB = -119 dBm	The effective receiver sensitivity is calculated as follows: Step 2 value + Step 7 value. Effective Sensitivity = Basic sensitivity + receiver degradation. -120 dBm + 1 dB = -119 dBm
6	-87 dBm	The vehicle antenna is connected in place of the 50 ohm load. The vehicle is running and all vehicle systems are on.
7	-87 dBm - -90 dBm = 3 dB Mathematically rewritten as: -87 dBm + 90 dBm = 3 dB	The amount of receiver degradation is calculated as follows: Step 4 value subtracted from Step 6 value. In this example, 3 dB of receiver degradation is measured from the external environment and vehicle systems.
8	-120 dBm + 3 dB = -117 dBm	The effective receiver sensitivity is calculated as follows: Step 2 value + Step 7 value. Effective Sensitivity = Basic sensitivity + receiver degradation. -120 dBm + 3 dB = -117 dBm

IMPORTANT: Any degradation in receiver sensitivity **shall** be reported to the system engineer and/or system manager.

NOTE: Measurement of receiver degradation and/or effective receiver sensitivity **shall** be performed by a qualified technician.

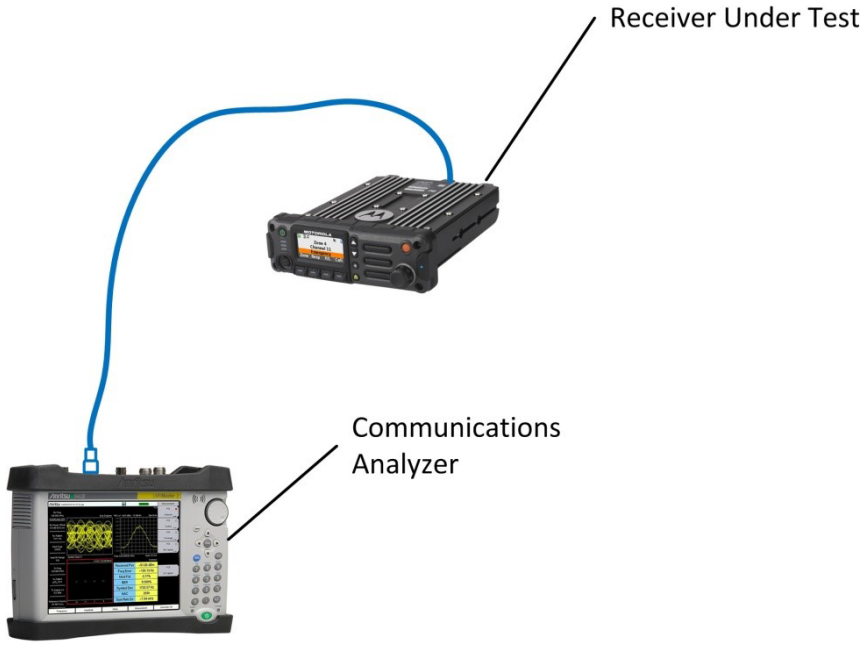


Figure E-42. Configuration for Measurement of Basic Receiver Sensitivity

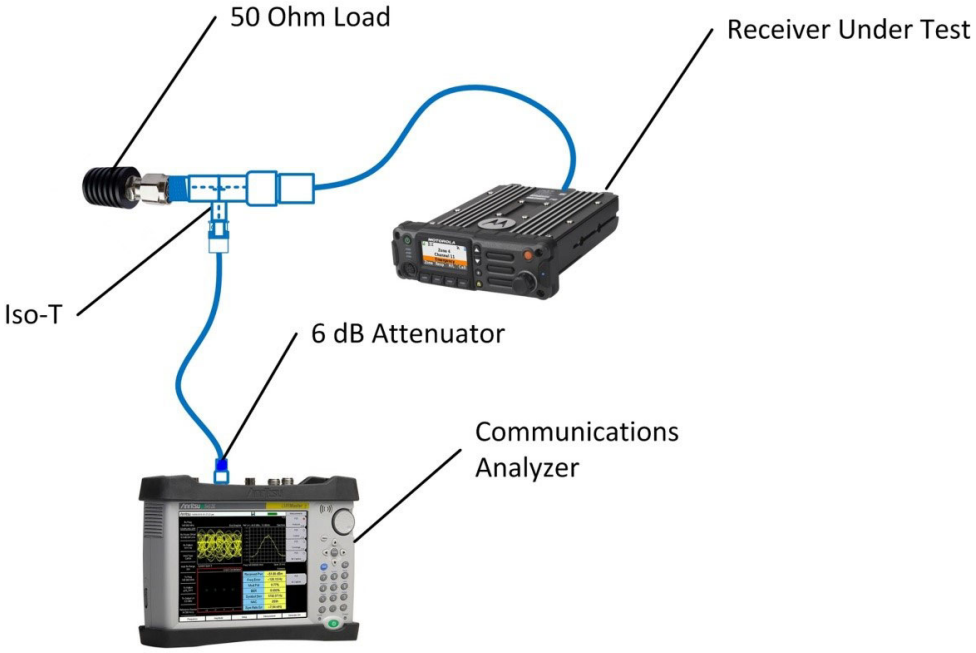


Figure E-43. Configuration for Measurement of Effective Receiver Sensitivity with 50 Ohm Load

NOTE: The 6 dB attenuator shown in Figure E-43 and Figure E-44 helps provide impedance matching between the isolated port of the Iso-T and the communications analyzer. Impedance matching improves accuracy and repeatable results.

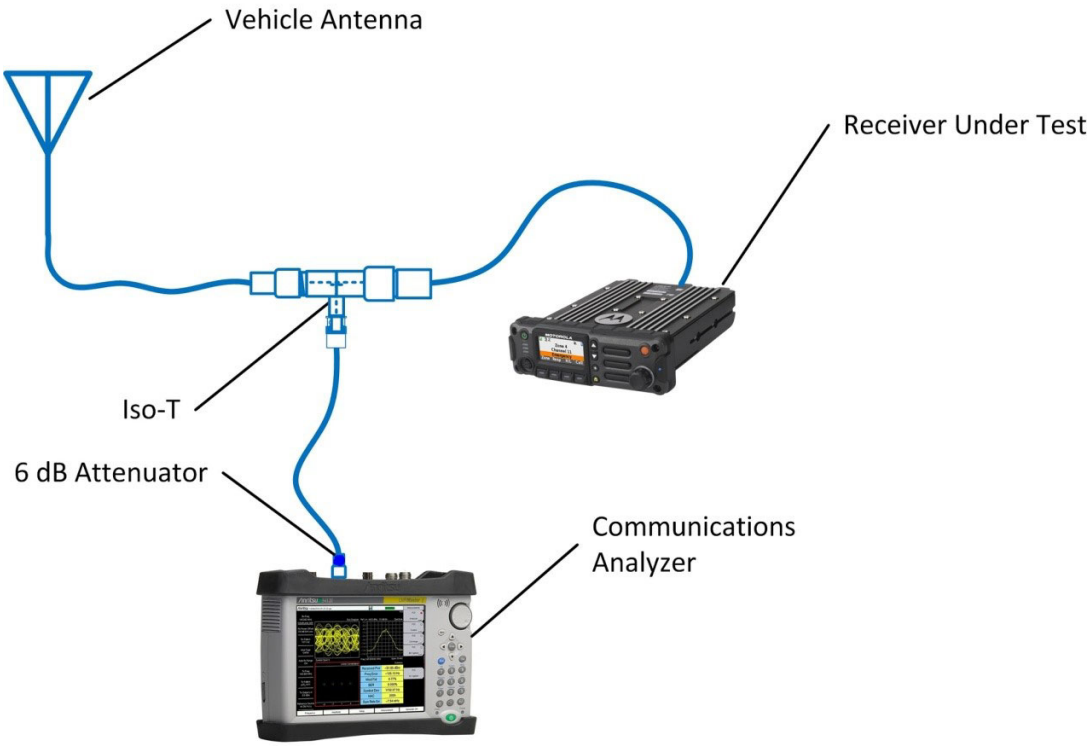


Figure E-44. Configuration for Measurement of Effective Receiver Sensitivity with Vehicle Antenna

Table E-6 provides a general summary of receiver degradation impact. Actual system coverage impact may vary on a per system basis. The measured receiver degradation **shall** be reported to the system engineer and/or system manager.

Table E-6. Summary of Impact of Receiver Degradation

Receiver Degradation	Impact of Findings
0 dB to 3 dB	This amount of degradation is generally considered normal.
3 dB to 5 dB	This amount of degradation is generally considered significant and may impact system coverage. Consult with the system engineer. Troubleshooting for the degradation source is required.
5 dB to 10 dB	This amount of degradation is generally considered high and will degrade system coverage. Consult with the system engineer. This level of degradation must be resolved or reduced to an acceptable level.
Greater than 10 dB	This amount of degradation is generally considered severe and will significantly degrade system coverage. Consult with the system engineer. This level of degradation must be resolved or reduced to an acceptable level.

E.18 Radio Transmit Noise Testing

Perform the TX noise test using a convenient customer channel (such as a lesser used TAC channel) as follows:

NOTE: For digital systems (for example: DMR, MOTOTRBO, P25, or TETRA), this test may require the radio to be put in an analog test mode.

1. Connect the radio directly to the high-power input port of the communications analyzer (see Figure E-45).
2. Start the vehicle engine and turn on vehicle systems (for example: data terminals, LED running lights, lightbars, RADAR devices, sirens, strobe lights, video recording system, and so on).

WARNING: Ensure adequate ventilation when running the vehicle.

3. Monitor the radio's transmit (Tx) channel with the communications analyzer.
4. With the engine running, key the radio and listen to the communications analyzer speaker for noise (alternator, engine, lightbar motors, strobes, and so on).
5. With the vehicle in park, rev the engine to approximately 1500 RPM (see FCS1362:2022) and listen for noise on the communications analyzer. If noise is present, troubleshoot the root cause and correct as needed.

IMPORTANT: The testing described in this section should also be completed with the vehicle siren running to help ensure the siren audio is not excessively coupled to the radio microphone. This test requires significant acoustical isolation from the receiver. As such, it may be more practical for a remotely located technician to monitor an over-the-air transmission using a customer subscriber unit. Obtain necessary customer permissions as needed when testing on an active channel.

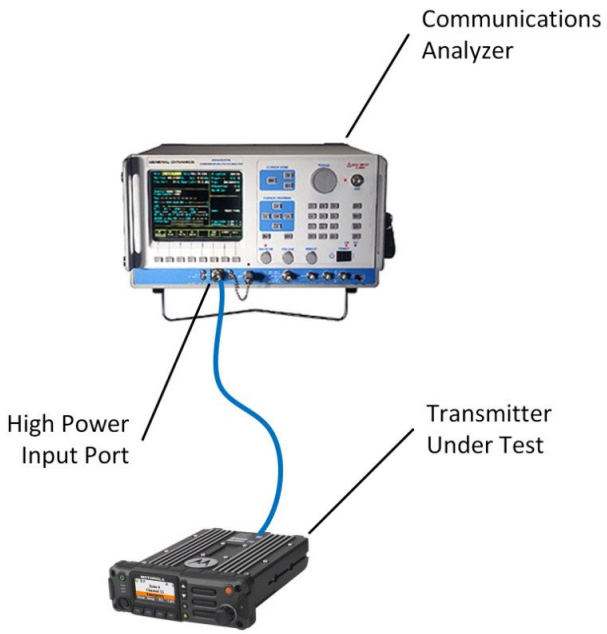


Figure E-45. Example of Configuration for Transmitter Noise Test

E.19 Installation of Miscellaneous Equipment

Emergency vehicles often contain equipment and electronics beyond the two-way radio. Such equipment may be one or more of the following:

- Computers
- Lightbars
- RADAR systems
- Relays
- Sirens
- Strobe lights
- Video recording systems

The installation of other miscellaneous equipment should follow the general guidelines and requirements provided in this Appendix. The specific installation instructions from each equipment manufacturer **shall** be followed.

E.19.1 Power and Ground Sources

- See “Power Wiring for Mobile Installations” on page E-16.
- For vehicles with a Power Distribution Unit (PDU), it is recommended to use a PDU for radio equipment and other sensitive electronics, and a separate PDU for other types of emergency equipment such as lightbars, flashers, gun locks, strobe lights, and so on.
- For vehicles with a PDU ground, it is recommended to use one ground for radio equipment and other sensitive electronics, and a separate ground for other types of emergency equipment (for example: lightbars, flashers, gun locks, strobe lights, and so on).

E.19.2 Relays

For vehicles that use electromechanical relays to control external devices (for example: lights, motors, switch boxes, and so on), these relay circuits should be isolated as practicable from the mobile radio equipment (and other electronics). Diode suppression should also be used across the relay coil to minimize the noise produced by the collapsing magnetic field (see Figure E-46).

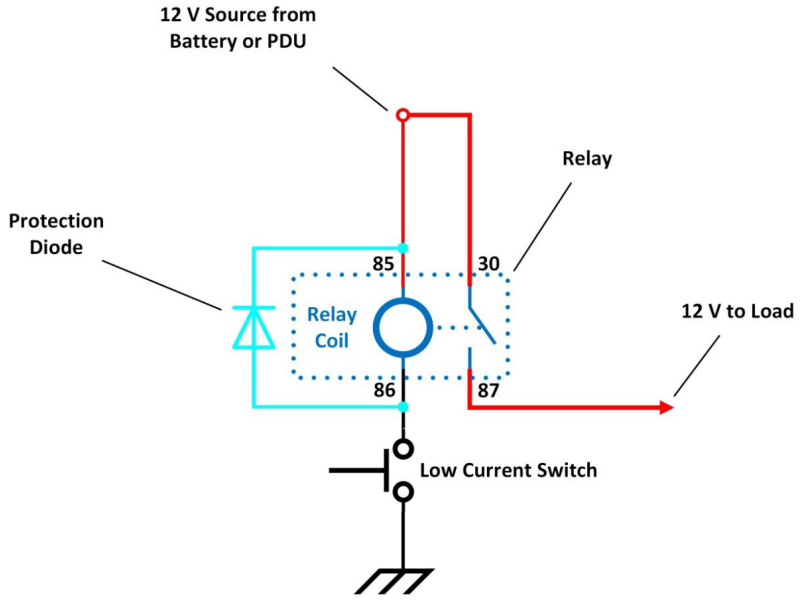


Figure E-46. Example of Relay Diode Wiring

NOTE: The numbers 30, 85, 86, and 87 in Figure E-46 represent the typical automotive relay terminal numbering standard.

E.19.3 Sirens

In addition to the specific instructions provided by the siren manufacturer, the following **shall** be observed:

- The siren speaker **shall** be positioned with the sound-projecting opening pointing forward, parallel to the ground, and not obstructed by structural components of the vehicle such as the radiator (NIJ Guide 500-00 and SAE J1849). See Figure E-47 for examples.
  - Mounting the siren under the hood and behind the radiator will result in a reduction of sound pressure levels at locations away from the vehicle and is not recommended (NIJ Guide 500-00 and SAE J1849).
- The siren speaker should be mounted as far from the vehicle occupants as practicable, preferably in the front grille area (NIJ Guide 500-00 and SAE J1849). See Figure E-47 for examples.
- Installation of two speakers, such as in high-power output applications, requires the speakers to be wired in phase (see Figure E-47). When connecting two speakers in parallel, wire similar speaker terminals together to ensure maximum loudness and prevent “dead spots.” For example, if the terminals are marked “1” and “2”, connect the terminals marked “1” together and connect those wires to one speaker lead. Connect the terminals marked “2” together and connect those wires to the other speaker lead (see Figure E-48).



Figure E-47. Examples of Siren Installations

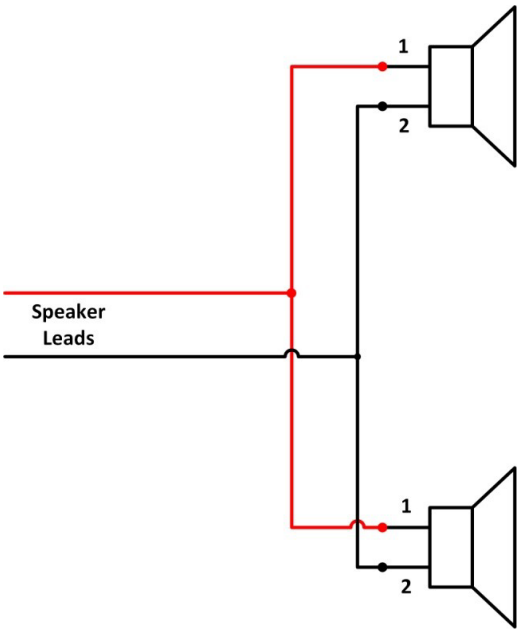


Figure E-48. Example of Two Siren Speakers Wired in Phase for High Power Output Applications

E.19.4 Strobe Lights

In addition to the specific instructions provided by the strobe light manufacturer, the following **shall** be observed:

- Strobe lights **shall** be installed according to manufacturer instructions.
- Strobe light cables **shall** maintain as much separation as practicable from vehicle and radio cabling/wiring.
- Strobe light cable shields **shall** be grounded according to manufacturer instructions.
- Strobe lights **shall** use a separate Power Distribution Unit (PDU) from sensitive electronic equipment (such as computers and radios).
- Strobe lights **shall** use a separate PDU ground (-) distribution point from sensitive electronic equipment (such as computers and radios).

NOTE: Light Emitting Diode (LED) technology lights are increasingly replacing strobe lights.

E.20 Motorcycle Installations

Motorcycle installations can be much more complicated than typical vehicle installations; therefore, only installers trained and experienced with motorcycle applications **shall** perform such installations.

In addition to the specific instructions provided by each equipment manufacturer, the following **shall** be observed:

- Equipment installed on motorcycles **shall** be rated for such installations and **shall** be appropriately weather-resistant as required.
- Equipment **shall** be installed according to manufacturer instructions.
- Equipment **shall** be installed in weather-resistant enclosures as applicable (see manufacturer instructions).
- Forward components (for example: control head, microphone, and speaker) **shall not** interfere with visual or physical access to controls and instruments.
- Forward components **shall not** interfere with the handling of the motorcycle.
- All components **shall** be securely mounted to withstand the constant vibration experienced on a motorcycle.
- Hardware used in motorcycle installations **shall** be stainless steel (or equivalent) to help prevent corrosion.
- Cabling **shall** be protected using a split loom (or equivalent) as necessary. See “Protection of Conductors and Cabling for Mobile Installations” on page E-12.
- Cabling **shall** be run so that it does not interfere with motorcycle operation. See “Routing of Conductors and Cabling for Mobile Installations” on page E-12.
- Cabling **shall** be routed away from motorcycle components that become hot during operation of the motorcycle. See “Routing of Conductors and Cabling for Mobile Installations” on page E-12.
- Cabling **shall** be secured using nylon cable ties (or equivalent) at frequent intervals as required to prevent damage caused by motorcycle vibration.
- Equipment positive (+, red) conductors **shall** connect directly to the battery or other adequate motorcycle manufacturer-provided power points. See the motorcycle manual and/or contact the dealer for information.
- Equipment requiring an ignition sense voltage **shall** terminate to an adequate fuse box ignition point. See the motorcycle manual and/or dealer for location recommendations and current draw limitations. If the current draw limitations on the motorcycle are inadequate, an ignition relay may be required.
- Equipment negative (-, black) conductors **shall** be connected to an adequate chassis ground point on the motorcycle. See the motorcycle manual and/or contact the dealer for more information. **Do not** connect the black conductor directly to the negative battery post.

NOTE: See “Antenna Installations on Non-Metallic Surfaces” on page E-34 for information regarding antenna installations with limited and/or no ground plane.

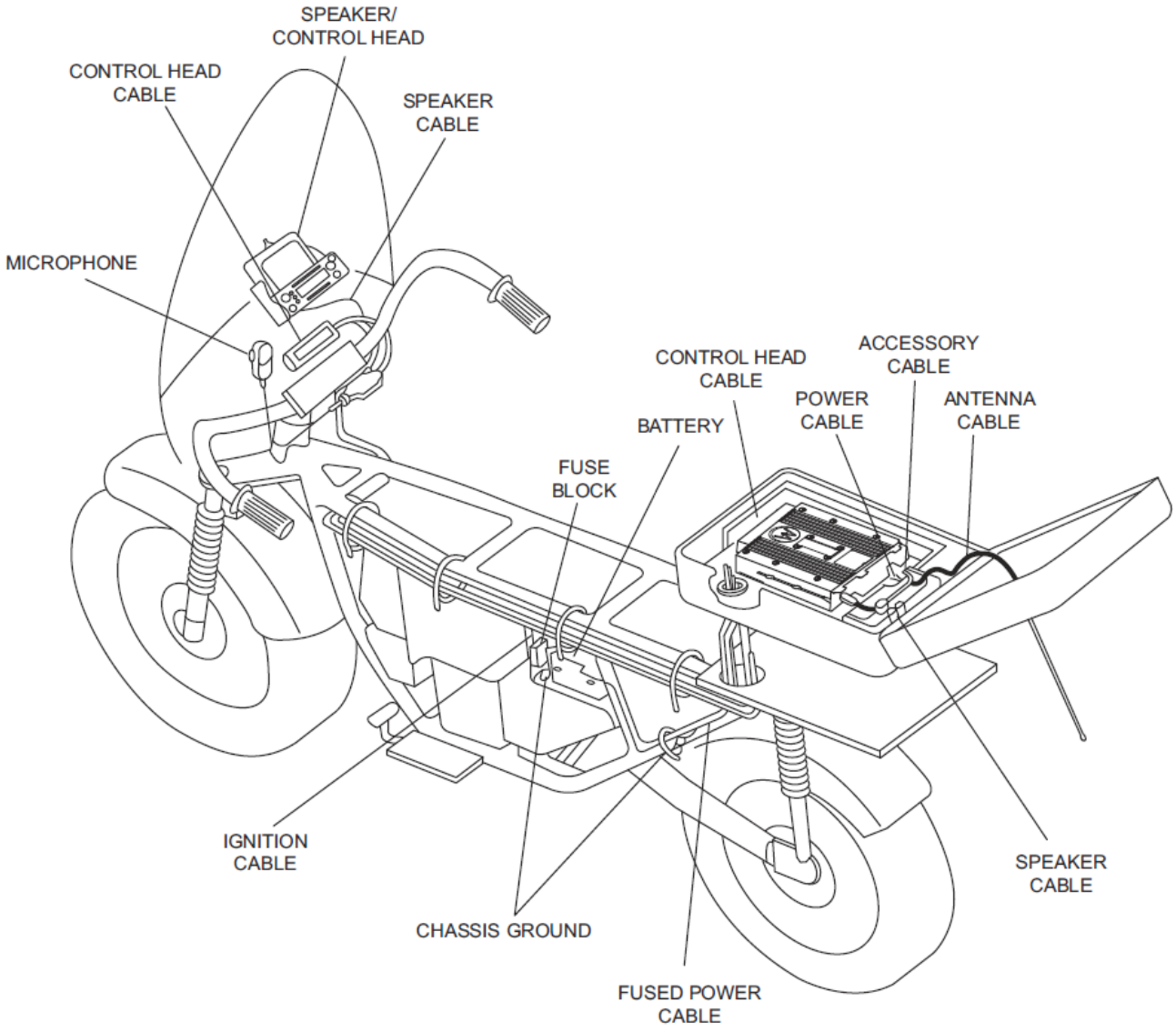


Figure E-49. Example of Motorcycle Radio Installation

E.21 Marine Installations

The information in this section applies to land mobile radios installed in marine applications, such as Police or Fire Department boats. Marine radios used for marine applications **shall** follow applicable installation requirements of the authority having jurisdiction. See “Mobile Installer Training and Certification” on page E-4 for certification requirements and recommendations.

While under operation, a marine vessel can be subject to extreme vibration. Careful attention **shall** be given to proper mounting techniques and securing of equipment and associated cabling/wiring.

Installation of mission critical two-way radio equipment and associated devices, such as lightbars and sirens, **shall not** impede the functionality of other marine vessel equipment (for example, other radios and RADAR) or any functions pertaining to the operation of the vessel.

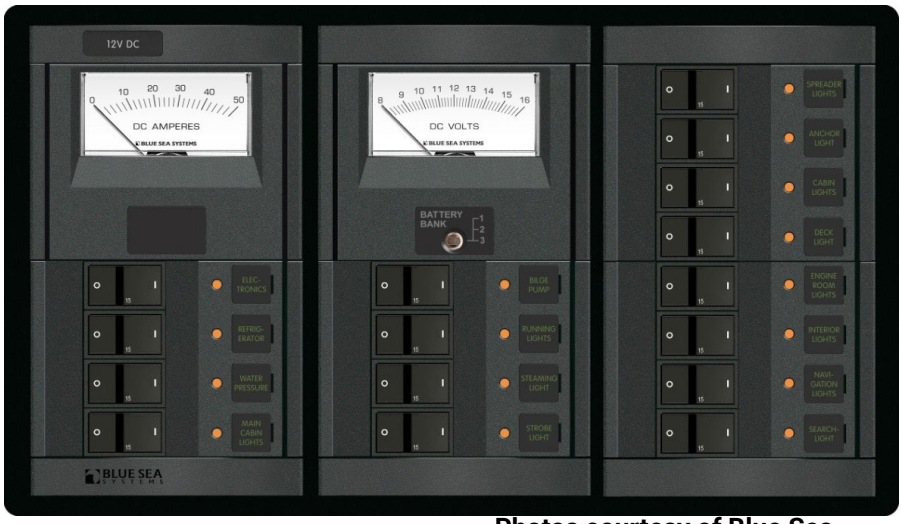
In addition to the specific equipment manufacturer instructions, the following **shall** be observed:

- Antennas and other equipment **shall** be installed away from the RADAR antenna as much as practicable, as required by the RADAR manufacturer.

NOTE: See “Antenna Installations on Non-Metallic Surfaces” on page E-34 for information regarding antenna installations with limited and/or no ground plane.

- Equipment power connections (positive) **shall** be made to an adequate marine vessel-provided 12V power distribution point (+).
  - Equipment **shall** be fused according to manufacturer requirements.
  - See Figure E-50 for an example.
- Equipment power return (negative) **shall** be made to an adequate marine vessel-provided power return bus (-).
- Power conductors **shall** be marine grade (see “Power Conductors for Mobile Installations” on page E-20).
- Mounting hardware **shall** be corrosion resistant (such as stainless steel). See “Securing Hardware for Mobile Installation” on page E-11.
- Electrical connection devices used in marine applications **shall** be suitable for marine applications. Marine application devices typically have the following characteristics:
  - Constructed from tinned-copper for improved corrosion resistance.
  - Contain an adhesive-lined heat shrink insulator to seal connection from vibration and to provide improved strain relief.
  - See “Electrical Ring Terminals, Lugs, Splices, and Similar Devices” on page E-27 for more information.
- Mechanical electrical connections should use a conductive antioxidant compound.
  - The antioxidant compound **shall** be designed for electrical connections.
  - The antioxidant compound **shall** be approved for marine applications (see manufacturer instructions).
- Marine grade coax **shall** be used.
  - Marine grade coax is designed for UV and salt environments.
  - Marine grade coax center conductor and outer shield are tinned for corrosion resistance.
  - Marine grade coax typically has a white outer jacket.
- The use of marine grade antennas is recommended. Standard vehicle antennas are highly prone to corrosion from salt air.

NOTE: Refer to standards from the National Marine Electronics Association and the American Boat & Yacht Council for more details.



Photos courtesy of Blue Sea

Figure E-50. Example of Marine 12V DC Power Distribution Panel

E.22 Aircraft Installations

The following paragraph applies to aircraft installations in the United States. Installations outside of the United States **shall** follow the requirements of the local jurisdiction.

Installations in aircraft carry additional requirements and responsibilities which are beyond the scope of this Appendix. However, persons performing these installations should hold an Airframe and Powerplant (A&P) Certification, and work **shall** be inspected by an Airframe and Powerplant Certificate Holder with Inspection Authorization (A&P-IA) or a certified repair station. Equipment installed in aircraft **shall** have an approved STC (Supplemental Type Certificate) or FAA Field Approval for the aircraft in which the equipment is to be installed.

E.23 Example of Installation Checklist

NOTE: A customer-specific checklist may need to be created for unique installation requirements.

Installation Checklist			
Date			
Customer			
Project			
Vehicle Make		License/Vehicle Number	
Vehicle Model		Mileage	
Radio Model		Radio ID #	

Installation Checklist (continued)			
Radio SN		Radio Asset #	
Radio Firmware			

Vehicle Condition
* Note any existing physical damage on “Existing Vehicle Damage Form” at the end of this document.

	Pre	Post
Low - Beams		
Hi-Beams		
Brake Lights		
Left Signal		
Right Signal		
Hazard Lights		
Fog Lights		
Reverse Lights		
Running Lights		
Air Conditioning		
Seat Belt Operation		
SRS (Air Bag)		
Engine Compartment Light		
Check Engine Light		
Interior Trim		

	Pre	Post
Door Locks		
Power Windows		
Wipers Front		
Wipers Rear		
Power Mirrors		
Power Seats		
AM / Radio		
Clock		
Interior Light		
Trunk Light		
Instrument Lights		
Roof Lining		
12 VDC Power Ports		
Horn		
Fluid Leaks		

Vehicle Condition Items Not Listed on Previous Page

	Pre	Post

Accessories

Installation Checklist (continued)					
	Pre	Post		**Pre**	**Post**
Light bar			Spotlight		
Headlight Flasher			Gun Release		
Corner Strobes			P/A		
Siren			Air Horn		
Siren Park Kill			Horn/Ring		
Take Downs			Map Light		
Alley Lights			Pump Panel Lights		
Ignition Bypass			Radio Power-up - No Key		
Existing Radios					
RADAR			Radio Off With Key		
Accessories Items Not Listed Above				**Pre**	**Post**

Installation Information	
Equipment	**Equipment Location**
Transceiver	
Control Head	
Microphone	
Speaker	
Antenna	
Other Equipment	**Equipment Location**

Installation Checklist (continued)					
Power Cable Gauge		AWG			
Antenna Model			Antenna Frequency		MHz

Radio Testing			
Wattmeter Model		Wattmeter SN	

TX Forward Power		Watts	TX Reflected Power		Watts
Voltage Drop During Transmit		VDC			

VSWR = (1 + sq. root (P(r)/P(f))) / (1 – sq. root (P(r)/P(f)))			VSWR (< 1.5:1)

Communications Service Monitor Model		SN	

Radio Receiver Basic Sensitivity		dBm
Radio Receiver Effective Sensitivity		dBm

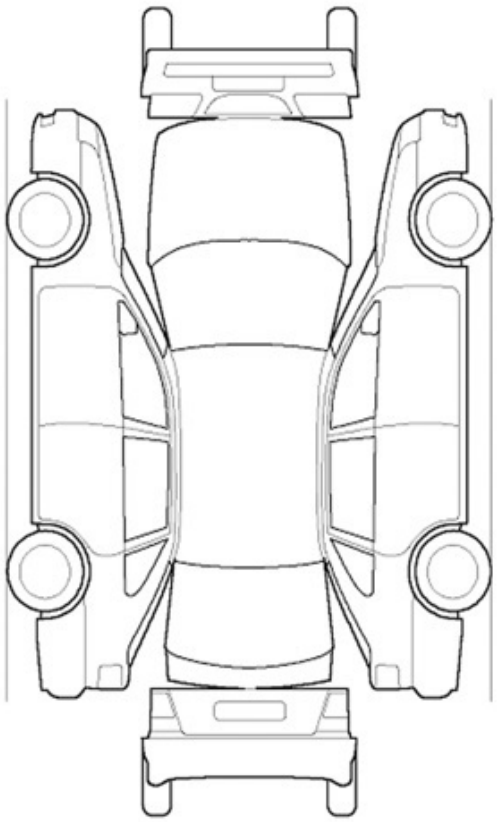
Radio Check					
	Pass	Fail		Pass	Fail
Channel Name:					
Outbound Voice Heard Clearly			Inbound Voice Heard Clearly		
Channel Name:					
Outbound Voice Heard Clearly			Inbound Voice Heard Clearly		
Channel Name:					
Outbound Voice Heard Clearly			Inbound Voice Heard Clearly		

Equipment installed correctly according to installation requirements:	Yes	No
Customer Name		

Installation Checklist (continued)						
Customer Signature						
Installer Name						
Installer Signature						
Notes						

Existing Vehicle Damage

Location(s) of Damage Observed:



Notes:

APPENDIX F

Cybersecurity Guidelines for Communication Sites

F.1 Basic Cybersecurity Guidelines

In an increasingly interconnected world, the security of communication sites is paramount. These sites, often critical infrastructure, are vulnerable to a growing array of cyber threats that can disrupt services, compromise data, and pose a risk to public safety. This appendix provides guidelines on techniques for protecting communication sites from malicious actors and cyberattacks. Motorola Solutions strongly recommends implementation of these security measures.

Network Segmentation: A fundamental principle of cybersecurity is to limit the attack surface. For RF communications systems, this involves:

- **Isolation:** Strictly isolating RF communications systems from other networks to prevent lateral movement of threats.
- **Firewall Implementation:** Utilizing robust firewalls to ensure all network access is controlled, monitored, and logged.
- **Port Management:** Disabling all unused network ports to eliminate potential entry points for attackers.
- **MAC Port Lockdown:** Implementing MAC address port lockdown to restrict network access to authorized devices only.
- **802.1X Authentication:** Employing 802.1X authentication for all network connections to ensure only authenticated and authorized devices can access the network. See IEEE 802.1X-2020 for more information.

Network Redundancy and High Availability: To help ensure continuous operation and minimize downtime, implementing the following network redundancy and high availability measures is crucial:

- **Redundant Network Paths:** Design the network with multiple, independent data transmission paths to prevent single points of failure.
- **Failover Mechanisms:** Implement automatic failover mechanisms that seamlessly switch to a backup system or path in the event of a primary system failure.
- **Load Balancing:** Utilize load balancing across multiple servers or network devices to distribute traffic, optimize performance, and ensure availability even under heavy loads.
- **Geographic Redundancy:** For critical communication sites, consider geographic redundancy, with mirrored systems in different locations to protect against regional outages or disasters.
- **Regular Testing:** Conduct regular testing of all redundancy and failover systems to verify their functionality and ensure they will perform as expected during an actual incident.

Regular Software and Firmware Updates: Maintain up-to-date software and firmware to address known vulnerabilities. Good practices include the following:

- **Inventory Management:** Maintain an accurate and up-to-date inventory of all hardware and software components within the communication site.
- **Continuous Updates:** Regularly update all software, firmware, and hardware components to patch security flaws and mitigate new vulnerabilities as they are discovered.
- **Patch Management Processes:** Implement structured patch management processes to ensure timely and efficient deployment of updates across all systems.

I**ntrusion Detection and Monitoring:** Proactive monitoring is vital for detecting and responding to malicious activity.

- **Intrusion Detection Systems (IDS)**: Deploy intrusion detection systems (IDS) to continuously monitor network traffic for suspicious patterns and unauthorized activities.

- **Endpoint Protection:** Ensure all client devices connected to the network are adequately protected with anti-malware and antivirus solutions.
- **Power Systems Monitoring:** Implement continuous monitoring of commercial power sources and backup power systems (e.g., generators, UPS) to ensure uninterrupted operation and promptly detect anomalies or outages.

Physical Security Measures: Cybersecurity extends beyond the digital realm and includes protecting the physical infrastructure by implementing the following:

- **Restricted Access:** Ensure RF communication sites are physically secure with restricted access, employing measures such as robust fencing, locked enclosures, and access control systems.
- **Surveillance:** Implement surveillance systems such as CCTV to monitor the site for unauthorized entry or activity.
- **Access Auditing:** Regularly review access logs and audit trails for all physical entry points to identify and investigate any unusual or unauthorized access attempts. This includes maintaining detailed records of who accessed the site, when, and for what purpose, to ensure accountability and to detect potential breaches.

Incident Response Planning: A well-defined incident response plan is essential for minimizing the impact of a cyberattack.

- **Tailored Plan:** Develop and maintain a robust incident response plan specifically tailored to the unique characteristics and potential threats to RF communication systems.
- **Regular Exercises:** Regularly conduct tabletop exercises and drills to test the effectiveness of the incident response plan and ensure personnel are prepared to respond swiftly and effectively to cyber incidents.

Supply Chain Security: The security of a communication site is only as strong as its weakest link, often found within the supply chain.

- **Vendor Vetting:** Thoroughly vet all suppliers and vendors to ensure they adhere to stringent cybersecurity standards and best practices.
- **Component Monitoring:** Continuously monitor third-party components for vulnerabilities that could compromise the integrity and security of RF systems.

Employee Training and Awareness: Human error remains a significant vulnerability. Robust and ongoing training is critical.

- **Ongoing Training:** Provide ongoing and comprehensive cybersecurity training to all staff involved in handling or managing RF communications systems.
- **Threat Education:** Educate personnel on recognizing common cyber threats, such as phishing attempts, social engineering tactics, and other forms of cyber deception.
- **Regular Drills:** Conduct regular simulated phishing attacks and other social engineering drills to test employee vigilance and reinforce best practices.
- **Reporting Procedures:** Establish clear and accessible procedures for employees to report suspicious activities or potential security incidents without fear of reprisal.
- **Security Culture:** Foster a strong security-aware culture within the organization, emphasizing that cybersecurity is a shared responsibility.

F.2 Additional Resources

- See NFPA 70-2026, Article 708.5, for physical security requirements related to Critical Operations Power Systems (COPS).
- See NFPA 70-2026, Article 708.7, for cybersecurity requirements for COPS.
- See APCO ANS 2.106.1-2019, section 3.2 for additional physical security recommendations.
- See APCO ANS 2.106.1-2019, section 3.13 for power systems cybersecurity requirements.
- Consult with Motorola Solutions Engineering for security assessment/hardening recommendations.

APPENDIX

G

General Conversions and Formulas

Table G-1. Conversion Formulas

Conversion Formulas
Linear Measure
miles (statute) = miles (nautical) x 1.1508
mils = in x (1×10^3)
ft = in/12
yard = ft/3
miles = ft/5280
Volume
ounce (fluid) = qt x 32
pint = qt x 2
gallon (US) = qt/4
gallon (imperial) = gallon (US) x 0.8327
gallon (US) = cu. ft x 7.477
Avoirdupois Weight
ounce = lb x 16
short ton = lb/2000
long ton (UK) = lb/2240
Temperature
°C = (°F-32)/1.8
°F = (°C·1.8) + 32
°K (Kelvin; Celsius absolute) = °C + 273.18
°R (Rankine; Fahrenheit absolute) = °F + 459.72
Angular Measurement
radians = degrees x 0.01745
revolutions = radians / 2π
Sinusoidal Waveform Measurement
rms = average x 1.11
peak = average x 1.57

Table G-1. Conversion Formulas (continued)

Conversion Formulas
peak-to-peak = average x 3.14
average = rms x 0.9
peak = rms x 1.414
peak-to-peak = rms x 2.828
average = peak x 0.637
rms = peak x 0.707
peak-to-peak = peak x 2
Power
hp = W / 746
BTU/hr = W / 0.293
Energy
BTU = KWh / (2.9306×10^{-4})
Metric Conversion Formulas
Linear Measure
cm = in x 2.54
in = centimeters x 0.3937
in = meters x 39.37
yards = meters x 1.0936
ft = kilometers x 3281
kilometers = miles (statute) x 1.6093
micron = meter / 10^{-6}
millimicron = meter / 10^{-9}
Angstrom units = meter / 10^{-10}
Area
cm^2 = sq. in / 0.155
m^2= sq. ft / 10.76
square miles = km^2 x 0.3861
km^2 = square miles x 2.59
Liquid Measure
US gallon = liter x 0.2642
fluid ounce = milliliter x 0.0338

Table G-1. Conversion Formulas (continued)

Conversion Formulas
Volume
liter = 1000 cm^3 = cu. in / 61.02
Pressure
Pa = N/m^2 = psf x 47.88
Pa = psi x 6895
atm = psf / 2116
Weight
ounce = gram x 0.03527
lb = kilogram x 2.2046
gram = ounce x 28.35
kilogram = lb x 0.4536
US short ton = 2000 lb = 0.907185 metric tonnes (metric tonne = US short ton x 0.907185) UK long ton = 2240 lb = 1.016 metric tonnes (metric tonne = UK long ton x 1.016)
metric tonne = 1000 kg = 0.9842 UK long tons (long ton = metric tonne x 0.9842) metric tonne = 1000 kg = 1.102 US short tons (US short ton = metric tonne x 1.102)
Torque
N·m = lbf·ft x 1.356
lbf·ft = N·m x 0.7376

Table G-2. Metric Equivalents of American Wire Gauge (AWG)

Area				Diameter	
AWG	c mils	inches^2	mm^2	mils	mm
28	159.8	0.000126	0.08	12.6	0.320
26	254.1	0.000200	0.128	15.9	0.404
24	404.0	0.000317	0.205	20.1	0.511
22	642.4	0.000505	0.324	25.3	0.643
19	1288	0.001012	0.653	35.9	0.912
18	1624	0.001276	0.823	40.3	1.02
16	2583	0.002028	1.31	50.8	1.29
15	3257	0.002558	1.65	57.1	1.45
14	4107	0.003225	2.08	64.1	1.63
13	5178	0.004067	2.63	72.0	1.83
12	6530	0.005129	3.310	80.0	2.05
11	8234	0.006467	4.17	90.7	2.304
10	10380	0.008155	5.261	101.9	2.588
9	13090	0.01028	6.631	114.4	2.906
8	16510	0.01297	8.367	128.5	3.264
7	20820	0.01635	10.55	144.3	3.665
6	26250	0.02062	13.30	162.0	4.115
5	33100	0.02600	16.77	181.9	4.520
4	41740	0.03278	21.15	204.3	5.189
3	52640	0.04134	26.67	229.4	5.827
2	66370	0.05213	33.63	257.6	6.543
1	83690	0.06573	42.41	289.3	7.346
1/0	105600	0.08289	53.49	324.9	8.252
2/0	133100	0.1045	67.44	364.8	9.266
3/0	167800	0.1318	85.01	409.6	10.40
4/0	211600	0.1662	107.26	460.0	11.68
	250000	0.1963	126.70	500.0	12.70
	350000	0.2749	177.39	591.6	15.03
	500000	0.3927	253.35	707.1	17.96
	750000	0.5890	380.13	866	22

Table G-3. Temperature Conversion Chart

°C	°F	°C	°F	°C	°F	°C	°F
-60	-76	-25	-13	5	41	45	113
-55	-67	-20	-4	10	50	50	122
-50	-58	-17.8	0	15	59	55	131
-45	-49	-15	5	20	68	60	140
-40	-40	-10	14	30	86	65	149
-35	-31	-5	23	35	95	70	158
-30	-22	0	32	40	104		

NOTE: °C= (°F-32) / 1.8
°F= (°C·1.8) + 32

Table G-4. Engineering Prefixes

Prefix	Symbol	Value	Example
tera	T	1×10^{12}	terahertz (THz)
giga	G	1×10^{9}	gigahertz (GHz)
mega	M	1×10^{6}	megahertz (MHz)
kilo	k	1×10^{3}	kilohertz (kHz)
centi	c	1×10^{-2}	centimeter (cm)
milli	m	1×10^{-3}	millihenry (mH)
micro	µ	1×10^{-6}	microfarad (µF)
nano	n	1×10^{-9}	nanosecond (nsec)
pico	p	1×10^{-12}	picofarad (pF)

Table G-5. Decimal Equivalent Drill Sizes

Fractional Drill Size (in.)	Decimal Equivalent (in.)	Metric Equivalent (mm)	Fractional Drill Size (in.)	Decimal Equivalent (in.)	Metric Equivalent (mm)
1/64	0.0156	0.397	33/64	0.5156	13.097
1/32	0.0313	0.794	17/32	0.5313	13.494
3/64	0.0469	1.191	35/64	0.5469	13.891
1/16	0.0625	1.588	9/16	0.5625	14.287
5/64	0.0781	1.985	37/64	0.5781	14.684
3/32	0.0938	2.381	19/32	0.5938	15.081
7/64	0.1094	2.778	39/64	0.6094	15.478

Table G-5. Decimal Equivalent Drill Sizes (continued)

Fractional Drill Size (in.)	Decimal Equivalent (in.)	Metric Equivalent (mm)	Fractional Drill Size (in.)	Decimal Equivalent (in.)	Metric Equivalent (mm)
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.1406	3.572	41/64	0.6406	16.272
5/32	0.1563	3.969	21/32	0.6563	16.669
11/64	0.1719	4.366	43/64	0.6719	17.067
3/16	0.1875	4.762	11/16	0.6875	17.463
13/64	0.2031	5.159	45/64	0.7031	17.86
7/32	0.2188	5.556	23/32	0.7188	18.238
15/64	0.2344	5.953	47/64	0.7344	18.635
1/4	0.25	6.35	3/4	0.75	19.05
17/64	0.2656	6.747	49/64	0.7656	19.446
9/32	0.2813	7.144	25/32	0.7813	19.842
19/64	0.2969	7.541	51/64	0.7969	20.239
5/16	0.3125	7.937	13/16	0.8125	20.636
21/64	0.3281	8.334	53/64	0.8281	21.033
11/32	0.3438	8.731	27/32	0.8438	21.43
23/64	0.3594	9.128	55/64	0.8594	21.827
3/8	0.375	9.525	7/8	0.875	22.224
25/64	0.3906	9.922	57/64	0.8906	22.621
13/32	0.4063	10.319	29/32	0.9063	23.018
27/64	0.4219	10.716	59/64	0.9219	23.415
7/16	0.4375	11.112	15/16	0.9375	23.812
29/64	0.4531	11.509	61/64	0.9531	24.209
15/32	0.4688	11.906	31/32	0.9688	24.606
31/64	0.4844	12.303	63/64	0.9844	25.004
1/2	0.5	12.7	1	1.0	25.4

Table G-6. Powers of 10

Unit	Name
10^{12} = 1 000 000 000 000	1 trillion (UK and US) 1 billion (France and Germany)
10^{9} = 1 000 000 000	1 billion (UK and US) 1 milliard (France and Germany)
10^{6} = 1 000 000	1 million
10^{3} = 1 000	1 thousand
10^{2} = 100	1 hundred
10^{1} = 10	ten
10^{0} = 1	one (unity)
10^{-1} = 0.1	1 tenth
10^{-2} = 0.01	1 hundredth
10^{-3} = 0.001	1 thousandth
10^{-6} = 0.000 001	1 millionth
10^{-9} = 0.000 000 001	1 billionth (US)
10^{-12} = 0.000 000 000 001	1 trillionth (US)

Table G-7. Voltage Standing Wave Ratio (VSWR) to Return Loss and Return Loss to VSWR

Return Loss (dB)	VSWR	Voltage Reflection Coefficient
1	17.391	0.891
2	8.724	0.794
3	5.848	0.708
4	4.419	0.631
5	3.570	0.562
6	3.010	0.501
7	2.615	0.447
8	2.323	0.398
9	2.100	0.355
10	1.925	0.316
11	1.785	0.282
12	1.671	0.251
13	1.577	0.224
14	1.499	0.200
15	1.433	0.178
16	1.377	0.158
17	1.329	0.141
18	1.288	0.126
19	1.253	0.112
20	1.222	0.100
21	1.196	0.089
22	1.173	0.079
23	1.152	0.071
24	1.135	0.063
25	1.119	0.056
26	1.105	0.050
27	1.094	0.045
28	1.083	0.040
29	1.074	0.035
30	1.065	0.032

Table G-8. dBm to Watts Conversion

Power (dBm)	Power (W)
-30 dBm	0.000001 W
-20 dBm	0.00001 W
-10 dBm	0.0001 W
0 dBm	0.001 W
1 dBm	0.0012589 W
2 dBm	0.0015849 W
3 dBm	0.0019953 W
4 dBm	0.0025119 W
5 dBm	0.0031628 W
6 dBm	0.0039811 W
7 dBm	0.0050119 W
8 dBm	0.0063096 W
9 dBm	0.0079433 W
10 dBm	0.01 W
20 dBm	0.1 W
30 dBm	1 W
40 dBm	10 W
50 dBm	100 W

Table G-9. dB to Ratio Conversion

dB	Amplitude ratio	Power ratio
-100 dB	10^{-5}	10^{-10}
-50 dB	0.00316	0.00001
-40 dB	0.010	0.0001
-30 dB	0.032	0.001
-20 dB	0.1	0.01
-10 dB	0.316	0.1
-6 dB	0.501	0.251
-3 dB	0.708	0.501
-2 dB	0.794	0.631
-1 dB	0.891	0.794

Table G-9. dB to Ratio Conversion (continued)

dB	Amplitude ratio	Power ratio
0 dB	1	1
1 dB	1.122	1.259
2 dB	1.259	1.585
3 dB	1.413	2 ~ 1.995
6 dB	2 ~ 1.995	3.981
10 dB	3.162	10
20 dB	10	100
30 dB	31.623	1000
40 dB	100	10000
50 dB	316.228	100000
100 dB	10^5	10^{10}

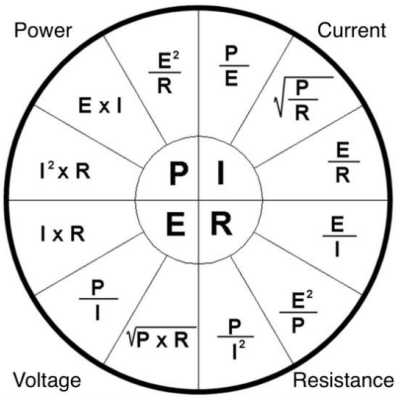


Figure G-1. Ohm's Law Wheel

APPENDIX H
Glossary

1.2/50 Voltage Wave: Voltage surge with a virtual front time of 1.2 μs and a half-value of 50 μs delivered across an open circuit.

10/1000 Voltage Wave: Voltage surge with a virtual front time of 10 μs and a half-value of 1000 μs delivered across an open circuit.

8/20 Current Wave: Current surge with a virtual front time of 8 μs and a half-value of 20 μs delivered into a short circuit.

A2LA: American Association for Laboratory Accreditation

ACI: American Concrete Institute

ADSL: Asymmetric Digital Subscriber Line

AH: Ampere Hours

AHJ: Authority having jurisdiction

Ambient Temperature: Environmental temperature as typically measured 610 mm (5 ft) above the floor in the center of an aisle

Ampere Hours: A measurement of battery current capacity relative to time, normalized to 8 hours. For example, a 320 Ah battery will deliver 40 Amperes for 8 hours.

ANSI: American National Standards Institute

Antenna: A device that permits transmission and reception of radio frequency energy through space. Also known as aerial.

Antenna Structure: Generic term describing an antenna supporting system which may be other than a tower (building, monopole, bracket, and so on).

Approved: Acceptable to the authority having jurisdiction

ARPANSA: Australian Radiation Protection and Nuclear Safety Agency

As-Built: A compilation of records that accurately represent a building or installation within a building or structure as actually constructed or configured, as opposed to how it was originally designed.

ASHRAE: American Society of Heating, Refrigerating and Air Conditioning Engineers

ASSE: American Society of Safety Engineers

ASTM: American Society for Testing of Materials

Attenuator: A passive device for controlling (attenuating) signal levels. It can be fixed, calibrated or variable. Where calibrated attenuators are used, the device is typically calibrated in dB of negative gain (loss or attenuation).

Authority Having Jurisdiction (AHJ): An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure. The local governing body. See NFPA 70-2026, Article 100, for more information.

AWG: American Wire Gauge: An American standard for identifying the thickness of electrical conductors.

Bandpass Cavity: A high Q resonant circuit designed to pass a narrow band of frequencies with very little loss while attenuating all other frequencies outside the selected bandwidth. Where used between a transmitter and the antenna transmission line, it reduces spurious signals and transmitter sideband noise that might otherwise be radiated from the transmitter and degrade the performance of a nearby receiver.

Bandwidth: The frequency spectrum space occupied by a signal of a single channel.

Base station: Station that allows simplex communications between radio units and console positions. Also: A repeater that provides the source of audio received by the console and the destination of audio transmitted from the console.

Battery: One or more electrochemical storage cells connected together to serve as a DC voltage source.

Blackout: An extended zero-voltage condition (total loss of power) lasting for minutes, hours or even days at a time. Blackouts can be caused by ground faults, accidents, lightning strikes, power company failures or other acts.

BNC: Bayonet “N” Connector

BOCA: Building Officials and Code Administrators International, Inc.

Bonding: The permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity and the capacity to safely conduct any current likely to be imposed.

Bonding jumper: A reliable conductor that ensures the required electrical conductivity between metal parts required to be electrically connected.

Boot: A protective, flexible sleeve installed around cables that pass through the wall of a communications site building.

Branch circuit: The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).

British Thermal Unit: A standard measurement of generated energy, typically as heat. (1 BTU equals 1.055 kJoules of energy.)

Brownout: A long-term under-voltage condition lasting minutes, hours or even days at a time. They are often intentionally instituted by an electric utility company when peak demand exceeds generating capacity.

BTU: British Thermal Unit

Building: For the purposes of this manual, a permanent structure capable of regular human occupancy built on a foundation that contains communications equipment and related ancillary support systems and may contain other unrelated equipment and/or facilities.

C^4I: Command, Control, Communications, Computers, and Intelligence

Cabinet/enclosure: An enclosure that houses communications equipment and ancillary systems only. It is designed such that equipment contained within can be accessed without the need for personnel to enter the cabinet.

Cable ladder: An open steel structure (painted or anodized) suspended from the ceiling that provides an orderly means of support and routing for wires and cables throughout a communications site. May be installed inside the building or vertically to guide cables on a tower. All exterior cable ladders should be constructed of galvanized metal. See Cable runway.

Cable runway: A structure provided for the routing and management of cabling. May be located below a raised floor, suspended from the ceiling, or mounted on top of equipment racks and/or cabinets. The term Cable Runway is used in this manual to include both cable ladders and cable trays.

Cable tray: A solid structure, typically constructed of aluminum or fiberglass, suspended from the ceiling that provides an orderly means of support and routing for wires and cables throughout the interior of a communications site. See Cable runway.

Caisson: A drilled cylindrical foundation shaft used to transfer a load through soft soil strata to firm strata or bedrock. The shaft is filled with either reinforced or unreinforced concrete. A caisson may either be a straight shaft or bell type of installation.

CATV: Cable Television

CCTV: Closed-Circuit Television

Cellular: A multi-site, low-power full-duplex radio system that interfaces to the public switched telephone network (PSTN).

Central Office: The main switching center of a telephone service provider or local exchange carrier (LEC).

CETma: Master Certified Electronics Technician

CETmsR56A: R56 Auditor Master Specialty Certified Electronics Technician

CFC-free: Denotes a refrigerant which does not use chlorofluorocarbons.

CFR: Code of Federal Regulations

Channel bank: A device that places multiple channels on a digital or analog carrier signal.

Channel Service Unit: A digital DCE used to terminate digital circuits (such as DDS or T-1 lines) at the customer site. It conditions the line, ensures network compliance with FCC rules and responds to loopback commands from the central office.

CO: Central Office

Combination Wave: Also called combination surge. A surge delivered by a generator which has the inherent capability of applying a 1.2/50 μs voltage wave across an open circuit and delivering an 8/20 μs current wave into a short circuit. The exact wave that is delivered is determined by the generator's fictive impedance (UL 1449 5th Edition).

Customer edge Premises Equipment (CePE): The point where the NID, microwave or broadband switch interfaces with the Network Management Plane (Site Link).

Combiner: A passive device that allows transmitters on different frequencies to use a single antenna.

Common Mode: Voltages appearing between line or neutral conductors and ground (L-G or N-G).

Communications Equipment: Electronic equipment that performs the telecommunications operations for the transmission of audio, video and data, and includes power equipment (for example, DC converters, inverters, and batteries), technical support equipment (for example, computers), and conductors dedicated solely to the operation of the equipment.

Communications Raceway: An enclosed channel of nonmetallic materials designed expressly for holding communications wires and cables, typically communications wires and cables and optical fiber and data (Class 2 and Class 3) in plenum, riser and general-purpose applications.

Console: A dispatch console is a system that interfaces to a private or public radio system, allowing the dispatcher to communicate directly with all field workers, police officers, EMS personnel, and others in order to coordinate their activities.

Conventional system: A radio system in which resources are dedicated to a specific frequency.

COPS: Critical Operations Power Systems

COW (Cell on Wheels): A standalone mobile/portable communications site

CPR: Cardiopulmonary Resuscitation

Critical Loads: Devices and equipment whose failure to operate satisfactorily jeopardizes the health or safety of personnel and /or results in loss of function, financial loss or damage to property deemed critical by the user.

CSA: 1) Canadian Standards Association. 2) Cross-sectional area (as used for cable gauge specification in metric system).

CSU: Channel Service Unit

Daisy chain: Any method of connection whereby the conductors are connected from one chassis, equipment frame or rack connection point to a second chassis, equipment frame or rack connection point and on to a third connection point, creating a series arrangement whereby the removal of the second connection point interrupts the ground path from the first chassis, equipment frame or rack. Daisy chaining of grounding conductors is not an acceptable method of connection.

Demarcation point: The telephone or utility point of presence at a facility which divides utility assets from customer assets and accordingly assigns maintenance responsibilities.

Dip: See Sag. Dip is the International Electrotechnical Commission (IEC) term for sag.

Distortion: Any deviation from the normal sine wave for an AC quantity.

Duplexer: An RF filtering system that separates the transmit and receive frequency, so that equipment can transmit and receive simultaneously on a single antenna, without affecting other equipment.

DVM: Digital Voltmeter

E-1: A time division multiplex (TDM) digital link that uses 32 time slots with a speed of 2.048Mb/s.

Earth; Earthing: Synonymous with ground; grounding.

Easement: An interest in real property which is owned by another that entitles the holder to a specific limited use or enjoyment of the owner's property.

Effective Radiated Power: The near-field radiated effective power (as opposed to peak envelope power) of a transmitting antenna. Specifies power radiated less any losses inherent in transmission lines or antenna coupling.

EGB: External Ground Busbar

EHS: Environmental Health and Safety

EIA: Electronics Industries Association

Electrolytic ground rods: Ground rods whose charge dissipation ability is enhanced by chemical reaction with the soil.

Electrical Metallic Tubing: Describes conduit tubing used specifically for housing electrical conductors. Several variations are available for specific purposes.

Electrostatic Discharge (ESD): A high voltage, low current electrical discharge caused by buildup of static charge between two surfaces.

EME: Electromagnetic Energy. Reflected or emitted electrical or magnetic waves traveling through space and Earth's atmosphere. EME ranges from just above DC to very high broadband frequency.

EMP: Electromagnetic Pulse

EMT: Electrical Metallic Tubing

Equipotential: Having the same electric potential or uniform electric potential, the same or uniform potential at every point.

ERP: Effective Radiated Power

ESD: Electrostatic Discharge

Ethernet: A Local Area Network (LAN) protocol

Exothermic welding: A process by which two pieces of metal are permanently welded using heat generated by a chemical reaction caused by combining the welding materials.

External Ground Busbar (EGB): A ground busbar that provides a bonding point for multiple grounding conductors (such as all coaxial connections) and connection to the grounding electrode system.

External grounding system test: A test that measures the effective resistance of the external site grounding system.

External site grounding ring: A ring of conductor wire surrounding an equipment enclosure, building and tower at a communications site. The grounding ring is bonded to the grounding electrodes, so that electrical charges are ultimately dissipated by the earth.

Facility: A complete site environment, including power system(s), site structure, HVAC system, antenna structure and boundary fencing (if applicable).

Failsoft: A default communication mode for trunking systems that prevents system shutdown by providing limited communications capability during a system failure. The repeaters operate in conventional mode if the central controller fails.

Fault Current: The current from the connected power system that flows in a short circuit (UL 1449 5th Edition).

Federal Aviation Administration (FAA): The US regulatory agency responsible for air traffic safety. It also governs height and marking regulations for towers and other tall structures that could pose a hazard to aircraft.

Federal Communications Commission (FCC): The US regulatory agency responsible for overseeing radiated transmissions in the United States.

Firestop: A firestop or fire-stopping is a form of passive fire protection that is used to seal around openings and between joints in a fire-resistance-rated wall or floor assembly.

Fixed Network Equipment: Permanently installed communications site infrastructure equipment.

FM: Frequency Modulation; also Factory Mutual

FNE: Fixed Network Equipment

Frequency Deviation: An increase or decrease in the power frequency from nominal. The duration of a frequency deviation can be from several cycles to several hours (IEEE STD 1100-2005 and IEEE STD 1159-2019).

Global Positioning System (GPS): A system which determines exact locations by utilizing high-precision satellite signals as its reference. The satellite signals can also be used as a timing reference.

Ground Fault Circuit Interrupter (GFCI): A type of electrical receptacle that removes power to the receptacle if a ground fault occurs in the equipment connected to the receptacle.

Grounding: The connecting of a particular leg of a circuit across multiple equipment of a power system in common. The common connection is then also electrically bonded to the soil. In this manner, the grounded portion of the circuit can serve as a common low-side connection across the system. Synonymous with earthing.

Grounding conductor: A means for bonding equipment to the site grounding electrode system.

Grounding electrode system: A buried system of ground conductors that provides a bonding point between soil grounding at the site and the neutral-ground connection of the incoming AC power. The site's PBB is bonded to this point.

Ground loop: A potentially detrimental loop formed when two or more points in an electrical system that are normally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential.

Ground test well: A buried port that allows inspection of connections to the grounding electrode system.

Gumbo: A soil composed of fine-grain clays. When wet, the soil is highly plastic, very sticky and has a soapy appearance. When dried, it develops large shrinkage cracks.

Hantavirus: A potentially deadly airborne virus spread by rodents.

Hard-wiring: The practice of direct physical connection of wiring leads directly to a junction device. An example of hard-wiring is the connection of a device's AC line directly to a junction box without the use of a receptacle and line cord.

Harmonic: Regarding power lines, an abnormality in which distortion of the normal utility sine wave occurs. Harmonics can be transmitted back into an AC power line by non-linear loads such as switching power supplies and variable speed motors. If significant enough, harmonic conditions can cause overheating in step-down and three-phase load transformers and neutral conductors.

Hazardous Material Identification System: A labeling system for identifying the location of potentially hazardous materials.

HAZMAT: Hazardous material(s)

HEMP: High-Altitude Electromagnetic Pulse

HEPA: High-Efficiency Particulate Air (or Air Filter/Arrestance). HEPA is a standard for air filters designed to trap at least 99.97% of airborne particles—including dust, pollen, mold, and bacteria—that are 0.3 microns in diameter.

Hertz (Hz): Frequency measurement unit abbreviated as Hz. One Hz equals one cycle per second.

HEMP: High-Altitude Electro Magnetic Pulse

HMIS: Hazardous Material Identification System

HVAC: Heating, Ventilation and Air Conditioning equipment

Ice bridge: A protective shield for horizontal cable runs between towers and building cable entry panels, or between two buildings, designed to prevent ice from forming and falling on the cables during winter.

IEC: International Electrotechnical Commission

IEEE: Institute of Electrical and Electronics Engineers

IGZ: Isolated Ground Zone

Intermodulation (IM): A The production, in a nonlinear element of a system (for example, amplifier), of frequencies corresponding to the sum and difference frequencies of the fundamentals and integral multiples (harmonics) of the component frequencies that are transmitted through the element (see *Newton's Telecom Dictionary*).

Internal Perimeter Bonding Bus (IPBB): A The IPBB, formerly known as the Internal Perimeter Ground (Earth) Bus (IPGB), conductors provide a suitable bonding conductor to earth for ancillary support apparatus, electrical conduits, ventilation louvers, metal door frames, and other metallic items (for example, non-electronic items) that are located throughout the shelter, building, or room.

Isolated Ground Zone: An installation configuration where grounding of equipment is electrically isolated and/or separate from general facility grounding.

Isolated Terra (IT): An electrical system where the power source is ungrounded or connected through high impedance, while electrical equipment is connected to a local earth. It ensures continuity of service during the first ground fault. It is often used to prevent EMI in sensitive data/audio systems and for safety in medical environments.

ITU: International Telecommunications Union, also known as CCITT.

IZGB: Isolated Zone Ground Bar.

Labeled: Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

LEC: Local Exchange Carrier

Let-through Voltage: Voltage (at a specified current) allowed through a surge protective device when the device is in suppression mode. Now referred to as Voltage Protection Rating (UL 1449 5th Edition).

Listed: Equipment, materials or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services and whose listing states that either the equipment, material or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

Low Pass Filter: Also referred to as “harmonic filter”. Filter that suppresses harmonic frequencies above its specified pass band. It is used with transmitters to prevent intermodulation. Most systems require this type of filter between the isolator and the antenna system to reject second and third harmonic transmitter energy.

LPG: Liquefied Propane Gas

LTV: Let-through Voltage

LVLD: Low-Voltage Load Disconnect

Master Ground Busbar (MGB): See Primary Bonding Busbar (PBB).

Maximum Continuous Operating Voltage (MCOV): The maximum continuous root mean square (rms) value of the power frequency voltage that may be continually applied to the mode of protection of an SPD (UL 1449 5th Edition).

Maximum Permissible Exposure: Defines maximum permissible exposure to radiated RF energy to personnel. Several levels exist based upon frequency, power density and time of exposure.

MCOV: Maximum Continuous Operating Voltage

Measured Limiting Voltage: A UL term for the maximum magnitude of voltage, measured at the leads, terminals, receptacle contacts, and similar locations after the application of an impulse of specified waveshape and amplitude (UL 1449 5th Edition).

Modes of Protection: Electrical paths where the SPD offers defense against transient overvoltages. Examples include Line to Neutral (L-N), line to Ground (L-G), Line to Line (L-L), and Neutral to Ground (N-G). (UL 1449 5th Edition)

Metal-Oxide Varistor: A two-terminal voltage protection device in which resistance across the device markedly decreases when the voltage across the device reaches a specified threshold.

Meter pedestal: The base structure for the electric services utility meter at communications site. Typically installed by the local utility company during communications facility construction.

MEN: Multiple Earth Neutral

Microwave: Frequencies higher than one GigaHertz (1,000,000,000 Hz) in the frequency spectrum.

MOV: Metal-Oxide Varistor

MM or MMI: Modified Mercalli Intensity scale, a measurement of the effects of an earthquake at a given location, in contrast with the seismic magnitude, which measures the inherent force or strength of an earthquake at the point where it occurred. The MMI scale measures intensity of shaking, at any particular location, on the surface.

MPE: Maximum Permissible Exposure

MSO: Mobile Switching Office

MTBF: Mean Time Between Failures

Multicoupler: An RF device that provides multiple outputs of a single RF input.

Multimeter: A test instrument capable of measuring voltage, current and resistance.

NAVLAP: National Voluntary Laboratory Accreditation Program

National Electrical Code: A consultative organization responsible for electrical practices standards. It is part of the National Fire Protection Association (NFPA).

NBB: Network-Equipment Bonding Busbar

NCRP: National Council for Radio Protection and Measurement

NEBS: Network Equipment Building Systems

NEC®: National Electrical Code®

NEMA: National Electrical Manufacturers Association

NEMP: Nuclear Electromagnetic Pulse

Network-Equipment Bonding Busbar (NBB): A bonding busbar termination point for network equipment in a cabinet or rack. The purpose of an NBB is to provide a convenient bonding termination point for two or more similar pieces of network equipment installed adjacent to one another (horizontally or vertically) within the same cabinet or rack.

Network Interface Device (NID): A device that serves as the demarcation point between the carrier's local loop and the customer's premises wiring (CePE) (Smart Jack).

Network Interface Unit: A T-1 network interface unit

Neutral Conductor: The conductor connected to the neutral point of a system that is intended to carry current under normal conditions.

Neutral Point: The common point on a wye-connection in a polyphase system or midpoint in a single-phase, 3-wire system, or midpoint of a single-phase portion of a 3-phase delta system, or a midpoint of a 3-wire, DC system. At the neutral point of the system, the vectorial sum of nominal voltages from all other phases withing the system that utilize the neutral, with respect to the neutral point, is zero potential.

NFPA: National Fire Protection Association

NID: Network Interface Device. The point where a carrier's network cabling connects to a customer's on-premises wiring, providing a demarcation point (equivalent to NIU).

NIU: Network Interface Unit. The point where a carrier's network cabling connects to a customer's on-premises wiring, providing a demarcation point (equivalent to NID).

Noise: Regarding line power, a power line abnormality that collectively refers to various kinds of high frequency impulses that ride on the normal sine wave of AC electrical power. Noise can range from a few millivolts to several volts in amplitude and can create erratic behavior in any electronic circuit. RF noise, if present over power lines, is one of the more troublesome. This noise can be generated by lightning, radio transmissions, or computer power supplies.

Nominal Discharge Current (I_n): Peak value of the current, specified by the manufacturer, through the SPD having a current waveshape of 8/20µs where the SPD remains functional after 15 surges (UL 1449 5th Edition).

Nominal System Voltage: A nominal value assigned to designate a system of a given voltage class in accordance with ANSI/NEMA C84.1-2020 (R2025) and UL 1449 5th Edition.

Nomograph: An arrangement of axes in which a variable is determined by a line which intersects known points on associated axes.

Non-Linear Load: Steady-state electrical load that draws current discontinuously or whose impedance varies throughout the cycle of the input AC voltage waveform (IEEE STD 1159-2019).

Normal Mode: Voltage between line and neutral (L-N) and line to line (L-L) conductors.

Notch Filter: A band-reject cavity filter designed with a high Q resonant circuit to attenuate a narrow band of frequencies while allowing all other frequencies to pass through with only a slight loss of signal strength.

NRTL: Nationally Recognized Test Laboratory

Objectionable Current: Any current flow over conductors not designed to normally carry current. For example, an equipment grounding conductor is not intended to carry current, except during a fault condition.

Ohm-cm: The resistance in ohms (Ω) of one cubic centimeter of soil, measured from opposite sides of the cube. Pronounced “ohm centimeter,” not “ohms per centimeter.” (Ω-cm)

Ohm-m: The resistance in ohms (Ω) of one cubic meter of soil, measured from opposite sides of the cube. Pronounced “ohm meter,” not “ohms per meter.”

Operating Temperature: Temperature within an equipment case, with the equipment operating at a given capacity or load.

OSHA: Occupational Safety and Health Administration: United States federal government regulatory agency responsible for standards regarding personnel safety at commercial and industrial sites.

Panelboard: A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices and equipped with or without switches for the control of light, heat or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition or other support; and accessible only from the front.

PANI: A method of bonding conductors to the PBB in a specific order, depending on their origin.

Passive Intermodulation (PIM): Intermodulation that occurs in passive devices (for example, cables, connectors, antennas, lightning protectors, and so on) that are subjected to two or more high power signals. When two or more RF signals encounter a nonlinearity, they create new signals; these new signals may cause interference. Sources of nonlinearity may include loose metal-to-metal contacts (for example, poorly terminated RF connectors), metal flakes or shavings inside RF connectors, rusty or corroded surfaces, contaminated surfaces (for example, dirt, dust, moisture or oxidation), nonlinear metals (for example, nickel, steel, ferrite). PIM may also be created at nearby metallic objects in the path of the transmit antenna (for example, rusty bolts, roof flashing, vent pipes, guy wires, and so on).

PBB: Primary Bonding Busbar.

Permanently Connected (PC): An SPD provided with terminals or leads for field connection to wiring systems in accordance with NFPA 70-2026.

PIM: Passive Intermodulation

Plenum: A compartment or chamber to which one or more air ducts are connected and that forms part of the air distribution system.

PME: Protected Multiple Earth

Practicable: Capable of being done, effected, or put into practice, with the available means; feasible.

Point of entrance: The point of emergence through an exterior wall, a concrete floor slab or from a rigid metal conduit or an intermediate metal conduit effectively bonded to a grounding electrode system.

Power over Ethernet (PoE): Several standardized or ad-hoc systems which pass electrical power along with data on twisted pair Ethernet cabling. Typically -48 VDC, but may be a higher voltage depending on the cable used for the application.

Primary Bonding Busbar (PBB): The single grounding point inside an equipment enclosure to which all other interior ground wires are ultimately bonded. There is one Primary Bonding Busbar per building or equipment area at a communications site. Formerly known as Master Ground Busbar (MGB).

Protected Multiple Earthed systems (PME): AC System (TN-C-S), or a continuous metallic earth conductor from the star point of the supply transformer to the earthing terminal of the installation, it runs in parallel with the installation neutral, which is at the same potential. The neutral and earth conductors are kept separate within the installation. The main earthing terminal is bonded to the incoming combined earth and neutral conductor by the electrical utility. (With a slight difference, PME is also known as Multiple Earth Neutral (MEN).

Pulse method: A method for tower guy wire tensioning.

PSTN: Public Switched Telephone Network

QA/QC: Quality Assurance/Quality Control

R56: The Motorola Solutions committee responsible for enacting standards related to communication site construction and installation practices. R56 also refers to the literature distribution number formerly used for this manual, Standards and Guidelines for Communications Sites (PN 68P81089E50).

Rack: A standard equipment rack used for supporting communications equipment installed in an existing Building or Shelter.

Rack Bonding Busbar (RBB): A single busbar to which all equipment ground wires are bonded within a single equipment rack. Also known as Rack Ground Busbar.

Rack Ground Busbar (RGB): A single busbar to which all equipment ground wires are bonded within a single equipment rack.

Return Loss (RL): Similar to VSWR, but measured in dB. Return Loss is the loss of power in the signal returned (reflected) by an impedance mismatch in the transmission line (coax). The mathematical range is from 0 dB (open or short) to infinity (perfect match).

RF: Radio Frequency.

RFDS: RF Distribution System

RFP: Request For Proposal

RF Distribution System: A system that combines RF signals so that multiple transmitters and receivers tuned to different frequencies can use a single antenna.

RGB: Rack Ground Busbar

RH: Relative Humidity

Rho (ρ): The Greek letter **ρ** used to represent soil resistivity

RMS: Root-Mean-Square

R-Value: A standardized rating system of thermal insulation effectiveness. Higher values denote greater insulating effectiveness.

SAD: Silicon Avalanche Diode

Safety climb: Equipment that is attached to a tower to safely enable tower climbing.

Safety Data Sheet: A manufacturer-provided ingredient and safety hazard description of materials classified as hazardous or containing hazardous elements. It also includes information for handling spills or chemical reactions.

Sag: A root mean square (RMS) reduction in the AC voltage, at the power frequency, for durations from a half cycle to a few seconds (IEEE STD 1100-2005). A multi-cycle, under-voltage condition that can be caused by ground faults, undersized power systems, lightning or a sudden start-up of a large electrical load. The IEC terminology for sag is “dip.”

SBB: Secondary Bonding Busbar

SDS: Safety Data Sheet.

Secondary Bonding Busbar (SBB): A Secondary Bonding Busbar, previously referred to as a Sub System Ground Busbar (SSGB), is a busbar used as a convenient extension of the Primary Bonding Busbar (PBB).

Seismic rating: Any of several standardized systems of rating an area's probability and intensity of seismic activity based on geological and empirical data. This publication recognizes the International Building Code (IBC) Seismic Design Category rating system, which incorporates site-specific characteristics for Specific Ground Motion, Soil Type, and Building Importance (Risk Category). This results in more stringent seismic building requirements for essential facilities, such as hospitals.

Separately Derived System: An electrical source, other than a service, having no direct connection(s) to circuit conductors of any other electrical source other than those established by grounding and bonding connections. (NFPA 70-2026)

Service Entrance: The point at which the utility enters a facility and the utility ground rod is attached.

Shelter: A Permanent structure built on a foundation that contains communications equipment and related ancillary support systems and may contain other unrelated equipment and/or facilities. A Shelter **shall** be suitable for temporary human occupancy during equipment installation, maintenance and use.

Short Circuit Current Rating (SCCR): The suitability of an SPD for use on an AC power circuit that is capable of delivering not more than a declared rms symmetrical current at a declared voltage during a short circuit condition (UL 1449 5th Edition).

Silicon Avalanche Diode: A two-terminal voltage protection device in which resistance across the device markedly decreases when the voltage across the device reaches a specified threshold.

Simple Network Management Protocol (SNMP): An application-layer protocol for monitoring and managing network devices on a local area network (LAN) or wide area network (WAN). The purpose of SNMP is to provide network devices, such as routers, servers and printers, with a common language for sharing information with a network management system.

SME: Subject matter expert

Soil Resistivity (Ω): A measure of how much a volume of soil will resist an electric current (IEEE 81-2025). The electrical resistance between opposite faces of a unit cube of material; the reciprocal of conductivity (ASTM G57). Soil Resistivity (Ω) is measured in Ω-cm or Ω-m.

SPD: Surge Protective Device

SPD Disconnector: Device(s) internal or external, required for disconnecting an SPD from the power system. Devices may provide overcurrent (fuse or circuit breaker) and/or thermal response protection.

STP: Shielded Twisted Pair: a twisted pair cable protected against electromagnetic interference by a foil or thin mesh shield.

Surge: A transient fast wave of current, potential or power in an electric circuit. For this standard, surges do not include Temporary Over Voltages (TOV) consisting of an increase in power frequency voltage lasting for several cycles (UL 1449 5th Edition).

Surge Protective Device (SPD): A device composed of at least one non-linear component and intended for limiting surge voltages on equipment by diverting or limiting surge voltages; and capable of repeating these functions as specified. SPDs were previously known as Transient Voltage Surge Suppressors (TVSS) or secondary surge arresters. (UL 1449 5th Edition).

Swell: An increase in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1.0 minute (IEEE 1100-2005 and IEEE STD 1159-2019).

Terminal Equipment (TE): Carrier-owned equipment edge or Network Control Plane of a Public Switched Telephone Network (PSTN).

Terra Neutral-Separate (TN-S): A low-voltage electrical distribution network where the neutral (N) and protective earth (PE) conductors are kept separate throughout the entire system. The source neutral is grounded, and all exposed conductive parts of the equipment are connected to the separate PE conductor.

Terra Neutral-Combined-Separate (TN-C-S): A type of grounding system where the protective earth and neutral functions are combined into a single protective earth neutral (PEN) conductor in the upstream supply network, but are separated into distinct PE and N conductors within the site installation.

Terra Terra (TT): Grounding/earthing system type with a directly grounded/earthed power source (usually the transformer neutral) and independently earthed exposed conductive parts of the installation. The installation's metalwork connects to a local earth electrode, completely separate from the supply network's earthing.

Terra Neutral-Combined (TN-C): A type of terra neutral earthing configuration where the neutral (N) and protective earth (PE) functions are combined into a single conductor throughout the entire system, known as a PEN conductor. The source is directly grounded/earthed, and all exposed conductive parts of the installation are connected to the PEN conductor.

TETRA: Terrestrial Trunked Radio

Time Division Multiplexing (TDM): A digital technique that transmits multiple independent signals over a single communication channel by dividing time into tiny, sequential segments. Each signal is assigned a specific "time slot" in which to transmit its data, ensuring that multiple streams can share the same medium without interfering with one another.

Total Harmonic Distortion (THD): The ratio of the root square value of the harmonic content to the root square value of the fundamental quantity, expressed as a percentage of the fundamental (IEEE 1100-2005).

Transient: A sub-cycle disturbance in the waveform that is evidenced by a sharp, brief discontinuity of the waveform. May be either polarity and may be additive to, or subtractive from, the nominal waveform (IEEE STD 1100-2005). See IEEE 1159-2019, section 4.4.1, for details on transient definitions, types and causes.

Transient Voltage Surge Suppressor (TVSS): A device that functions as an SPD or surge suppressor (IEEE 1100-2005). The term TVSS has generally been retired and replaced with the term SPD.

Tremie: A watertight pipe and hopper system used to pour concrete underwater or into deep, narrow excavations, ensuring the mixture reaches the bottom without washing out or mixing with water/slurry. It allows for a "bottom-up" placement that minimizes air pockets and improves structural integrity.

Triboelectric charge: Triboelectric charging occurs when two materials come in contact and are then separated, resulting in a transfer of positive or negative ions. Walking across an unprotected floor when humidity is low can create a triboelectric charge buildup in the range of 25,000 volts or more.

TVSS: See Surge Protective Device

Twisted Pair (TP): Two conductors of a single circuit that are twisted together to cancel electromagnetic interference (EMI) from external sources; for instance, crosstalk between neighboring pairs.

UTP: Unshielded Twisted Pair: Two conductors of a single circuit that are twisted together to cancel electromagnetic interference (EMI) from external sources; general purpose copper telephony cable with TP circuits wrapped in an unshielded insulated cover. UTP is for interior use only and **shall not** be used outdoors.

Voltage Protection Rating (VPR): A rating selected from a list of preferred values (see Table 7-7 on page 7-30) and assigned to each protection mode. For this standard, VPR is establish for (L-N) surges only, using a combination wave generator at a setting of 6kV/3kA. See UL 1449 5th Edition.

Voltage Limiting Type SPD: SPD with a high impedance when no surge is present, that continuously reduces impedance in response to increased surge current and voltage. Varistors and suppressor diodes are examples of components used as nonlinear devices, also called "clamping-type SPDs" (UL 1449 5th Edition).

Voltage Switching Type SPD: SPD that has a high impedance when no surge is present, that can suddenly change to a low impedance in response to a voltage surge. Common examples of components used as nonlinear devices are spark gaps, gas tubes, and silicon controlled rectifiers. These SPDs are sometimes called “crowbar-type” SPDs. (UL 1449 5th Edition), and are not approved for AC surge protection by Motorola Solutions.

VSWR: Voltage Standing Wave Ratio

Whole Body Peak (WBP): A metric in RF safety evaluations, representing the absolute maximum level of RF energy present across the vertical extent of a human body. This measurement is designed to identify the point of highest potential RF exposure within a defined area.

APPENDIX

I

R56 Compliance Checklist

I.1 Introduction

This checklist is a guide for preparing a site for mission-critical use. It does not replace a thorough R56 compliance audit by a certified R56 Auditor, nor is it an exhaustive list of all required items. All applicable codes regarding site construction and equipment installation **shall** be adhered to. Follow the installation instructions provided by the equipment manufacturers as necessary. Not all checklist items apply to all sites. Refer to this manual for details on each checklist item.

I.2 R56 Auditor Tools and Test Equipment

The following is a list of tools and test equipment recommended for checking compliance with the requirements of this manual. The recommended equipment listed is subject to change based on availability

I.2.1 Required Test Equipment

- Clamp-On Ground Resistance Tester (AEMC 3710, 3711, 6416, or 6417, or equivalent)
- Clamp-On AC DC Ammeter (Fluke 325, 374, or equivalent)
- Light Meter (Dr. Meter LX1330B Digital Illuminance/Light Meter or equivalent)
- AC Circuit Tester (Extech CT70, Ideal Technologies 64-164 Sure Test Circuit Analyzer, or equivalent)
- Temperature and Humidity Meter (Fluke 971 or equivalent)

I.2.2 Suggested Test Equipment for Troubleshooting Site Issues

- EMF meter (F.W. Bell 4180 Triple-Axis AC Gaussmeter, TriField EMF Meter Model TF2, or equivalent)
- Soil Resistivity and Fall of Potential Meter (AEMC 6472 or equivalent)
- Power quality testing (Fluke VR1710 Voltage Data Logger, or equivalent)

I.2.3 Required Equipment and Tools

- R56 manual
- Tablet or cellular telephone with a camera to run the online audit form
- Hard hat
- Tape measure, 8 m (25 ft) or longer
- Small flashlight
- Magnet on a telescoping rod
- Tool kit with basic hand tools
- Hammer, 350 to 500 g (12 to 16 oz)

I.2.4 Suggested Equipment and Tools

- Safety goggles or glasses
- Stool or step ladder
- Small table and chair

- Digital camera
- Small shovel
- Wire gauge measurement tool
- Spool of stranded wire, 15 m (50 ft) or longer, #12 AWG minimum, with heavy duty alligator clips on each end
- Binoculars

I.3 Site Checklist

Chapter 2, "Site Design and Development"

- ❒ All necessary permits, including construction and electrical, have been obtained from the authority having jurisdiction (AHJ).
- ❒ The AHJ has approved all inspections related to each required permit.

Chapter 3, "Site Building Design and Installation"

- ❒ All utility entrances to the facility are located in the same general area of the shelter and are located as close together as is practicable.
- ❒ The ceiling height meets the minimum requirements for installing equipment.
- ❒ The design and installation of the cable tray system meet the requirements.
- ❒ The floor is sealed as required.
- ❒ All transmission line entry ports, holes or openings that penetrate the outer surface of the building are sealed as required. The building is weather-tight.
- ❒ Interior and exterior lighting requirements are met.
- ❒ Appropriate heating and air conditioning are provided.
- ❒ Fire suppression equipment is installed as required.
- ❒ A First Aid kit is readily available onsite.
- ❒ Cable tray systems meet the installation requirements.
- ❒ Personal protective safety equipment is available for personnel working on or around batteries.
- ❒ A telephone, microwave link, or cellular phone is available at the site.
- ❒ Phone numbers of importance are posted.
- ❒ The minimum required signage is posted in accordance with local regulations.
- ❒ The site is free of other known Building Design and Installation safety and/or equipment reliability concerns.

Chapter 4, "External Grounding (Earthing) and Bonding"

- ❒ A grounding electrode system design document and an as-built document are available.
- ❒ The lightning exposure at the site was evaluated and considered for the design of the grounding electrode system.
- ❒ The soil conditions at the site have been assessed, and the components of the grounding electrode system have been chosen accordingly.
- ❒ Concrete-encased electrodes were considered for new construction.
- ❒ A grounding electrode system suitable for the site (for example, a dedicated communications building, outdoor cabinet, Type A site, Type B site, or Type B2) is installed.
- ❒ The grounding electrode system resistance design goal requirements are met. If not, supplemental grounding electrode system components have been installed as required.
- ❒ Dispatch Centers, Core Sites, and Prime Sites (and similar sites) co-located with tower(s) have additional grounding components/techniques to help improve site protection (Type B2 site).
- ❒ Special grounding situations, such as limited topsoil, follow the minimum recommendations.
- ❒ Grounding electrodes meet the specifications and installation requirements.
- ❒ Where used, radial grounding conductors are properly sized and installed.
- ❒ Where used, grounding electrode encasement materials meet specifications and installation requirements.
- ❒ All grounding electrode systems at the site are interconnected to create a common grounding electrode system.
- ❒ An External Ground Busbar (EGB) is installed at the transmission line entry point.
- ❒ An EGB grounding electrode conductor is installed.
- ❒ A Tower Ground Busbar (TGB) (if required) is installed.
- ❒ A Bottom TGB grounding electrode conductor is installed.
- ❒ Each transmission line or other communications cable outer shield is properly bonded to the tower at the top of the tower near the antenna with a weather-sealed grounding kit.
- ❒ Each transmission line or other communications cable outer shield is properly bonded to the tower or a TGB at the vertical-to-horizontal transition point (toward the building) with a weather-sealed grounding kit.
- ❒ Each transmission line or other communications cable outer shield is properly bonded to the tower with a weather-sealed grounding kit at intervals not exceeding 61 m (200 ft) or 15.2 - 22.9 m (50 - 75 ft) for high-lightning areas.
- ❒ Each transmission line or other communications cable outer shield is properly bonded to the EGB (or grounding electrode system) with a weather-sealed grounding kit.
- ❒ Building and tower ground rings (where required) are properly installed, and ground rods are installed every 3.05 - 4.6 m (10 - 15 ft).
- ❒ The tower is grounded and bonded, with the required number of grounding conductors.
- ❒ Guy anchor points for guyed towers are grounded correctly to minimize galvanic corrosion.
- ❒ Generators external to the building are properly grounded and bonded.

- ❒ All fencing, gates, and gate support posts are properly bonded to the grounding electrode system.
- ❒ Ice bridge/cable supports and posts are properly bonded to the grounding electrode system.
- ❒ The following items, and other metallic items located within 1.8 m (6 ft) of the grounding electrode system or within 1.8 m (6 ft) of grounded objects, are properly bonded to the grounding electrode system as applicable:
  - ❒ Metallic members of all incoming telecommunications cables
  - ❒ Main electrical ground
  - ❒ Main telephone ground
  - ❒ Any other grounding electrode system at the site
  - ❒ Metallic entry ports
  - ❒ Metallic conduits, piping, and raceways
  - ❒ HVAC units
  - ❒ Vent covers and grates (if not already grounded/bonded inside)
  - ❒ Metal siding and/or roofing
  - ❒ Metal fuel storage tanks (above or below ground)
  - ❒ Skid plate or metal support frame of a prefabricated shelter
  - ❒ Metallic structures for antenna supports, light fixtures, and so on.
  - ❒ Handrails and safety rails
  - ❒ Ladders and safety cages
- ❒ Tower-mounted antenna preamplifiers are properly grounded/bonded to the tower.
- ❒ Roof-mounted antenna masts and metal support structures are properly grounded.
- ❒ Building side-mounted antennas are properly grounded.
- ❒ Rooftop-mounted towers are properly grounded with the required down conductors.
- ❒ Grounding conductors and down conductors meet specifications and are properly installed.
- ❒ Grounding conductors are routed continuously downward toward the EGB, TGB, or grounding electrode system without sharp bends.
- ❒ Grounding conductors are routed as straight as practicable and protected from physical damage as required.
- ❒ Grounding conductors are securely fastened as required.
- ❒ Grounding conductors meet or exceed the size requirements.
- ❒ Braided grounding conductors are not used anywhere in the external grounding electrode system.
- ❒ Galvanic corrosion has been considered, and installation methods have been utilized to help prevent it.
- ❒ Approved bonding techniques are used for bonding dissimilar metals.
- ❒ Approved methods are used for conductor connection and termination.
- ❒ Bonding surfaces for lugs and clamps are free of paint and corrosion, and a conductive antioxidant compound has been applied.

- ❒ Painted or galvanized bonding surfaces for exothermic welding were cleaned and painted to inhibit rusting.
- ❒ Appropriate mechanical lugs, connection devices, and hardware are used as required.
- ❒ All grounding/bonding connections have been tested for continuity using a clamp-on ground resistance meter (clamp-on ohmmeter) as described in “Clamp-On Ohmmeter Testing Procedure” on page D-19.
- ❒ The site is free of other known External Grounding and Bonding safety and/or equipment reliability concerns.

Chapter 5, “Internal Bonding and Grounding (Earthing)”

- ❒ An Internal Bonding and Grounding as-built document is available.
- ❒ An Internal Bonding and Grounding system appropriate for the site is installed.
- ❒ A Primary Bonding Busbar (PBB) is installed as required.
- ❒ A PBB grounding electrode conductor is properly installed.
- ❒ All conductor connections to the PBB adhere to approved connection methods and utilize the correct lugs and hardware.
- ❒ A Secondary Bonding Busbar (SBB), if required, is properly installed.
- ❒ SBBs are bonded to the PBB as required using the correctly sized bonding conductor.
- ❒ SBBs serving an entry point have a properly installed grounding electrode conductor.
- ❒ All conductor connections to the SBB adhere to approved connection methods and utilize the correct lugs and hardware.
- ❒ Where required, an Internal Perimeter Bonding Bus (IPBB) or Halo Ground Ring is properly installed.
- ❒ Only ancillary equipment is bonded to the IPBB or Halo Ground Ring.
- ❒ Each ancillary support apparatus is properly bonded to the PBB, SBB, IPBB, Halo Ground Ring, or grounding grid as required:
  - ❒ Battery racks
  - ❒ Ceiling grids
  - ❒ Dehydrators
  - ❒ Door frames and doors
  - ❒ Electrical panels
  - ❒ Exposed structural metal
  - ❒ Metallic conduits
  - ❒ Piping systems
  - ❒ Raised flooring systems
  - ❒ Unused entry ports
  - ❒ Other miscellaneous items not specifically listed.
- ❒ DC power systems are properly bonded and grounded.
- ❒ Internally installed generators are properly bonded and grounded.
- ❒ Separately derived AC or DC electrical systems are bonded to the PBB or SBB as required.

- ❒ Cable trays are bonded to the PBB or SBB as required.
- ❒ Each cable tray section is bonded to the adjoining section as required.
- ❒ Bonding bus conductors, bus conductor branches, and equipment bonding conductors are sized as required.
- ❒ Bonding conductors are securely fastened as required.
- ❒ Bonding conductors are routed as straight as practicable and protected from physical damage as required.
- ❒ All bonding bus conductors, bonding bus branches, and equipment bonding conductors are routed toward the PBB or SBB as required.
- ❒ Bonding connections to a bonding bus or branch are properly insulated as required.
- ❒ Racks and cabinets are properly bonded to the PBB, SBB, bonding bus, or Rack Bonding Busbar (RBB) using approved methods.
- ❒ RBBs located within a rack or cabinet are properly bonded to the PBB, SBB, or bonding bus using approved methods.
- ❒ Individual system component chassis equipment is properly bonded as required.
- ❒ Surge Protective Device (SPD) metal housings are bonded to the PBB, SBB, or IPBB as required.
- ❒ Telephone, control, and data network circuit SPDs are bonded to the PBB or SBB as required.
- ❒ RF transmission line SPDs are bonded to the PBB or an SBB as required.
- ❒ An Operator Position SBB is properly installed at Control, Dispatch, and Network Operator Positions as required, and the SBB is properly bonded to the Internal Bonding and Grounding System.
- ❒ All metallic objects, including but not limited to metallic furniture, electrical conduits, nearby building metal, and nearby raised floor pedestals, as well as all electronic equipment at a Control, Dispatch, and Network Operator Position are properly bonded to the Operator Position SBB as required.
  - ❒ Electronic equipment that cannot be directly bonded, such as computers, routers, and switches, receives power from a surge-suppressed power strip with a grounding point, which is connected to the Operator Position SBB.
- ❒ All bonding and grounding connections have been tested for continuity using a clamp-on ground resistance meter (clamp-on ohmmeter) as described in “Clamp-On Ohmmeter Testing Procedure” on page D-19.
- ❒ The Internal Bonding and Grounding System has been tested and determined to be free of objectionable AC and DC currents.
- ❒ The site is free of other known Internal Bonding and Grounding safety and/or equipment reliability concerns.

Chapter 6, “Power Sources”

- ❒ An electrical system as-built one-line diagram is available.
- ❒ A main service disconnect is installed as required.
- ❒ The neutral-ground bonding conductor is properly installed in the main service disconnect as required. This should be verified by a certified electrician.
- ❒ Electrical panels are properly labeled as required.

- ❒ Electrical panel ampacity ratings are properly coordinated for main panel, sub-panels, automatic transfer switch, etc.
- ❒ Adequate clearances around electrical panels are maintained, and no equipment is installed in the required free space.
- ❒ Exterior AC receptacles and circuits are GFCI-protected as required.
- ❒ Circuit breakers are labeled to identify the receptacle they are protecting.
- ❒ AC receptacles are permanently marked to identify their assigned circuit breakers and panels.
- ❒ AC receptacles are the correct type and are securely mounted to the supporting structure.
- ❒ Equipment grounding conductors are installed in the AC receptacles as required.
- ❒ AC receptacles have been tested and meet the requirements for correct wiring and voltage.
- ❒ Adequate and dedicated AC receptacles are provided for the service technician.
- ❒ AC receptacles are installed near the equipment as required.
- ❒ Each critical piece of equipment has a dedicated branch circuit and simplex AC receptacle.
- ❒ Redundant power supplies for the same equipment are sourced from different branch circuits.
- ❒ Extension cords and consumer-grade outlet receptacle strips are not used in the final installation.
- ❒ Power Distribution Units are listed and are installed according to the manufacturer's requirements.
- ❒ AC power receptacle strips are the correct type and are securely mounted as required.
- ❒ UPS and battery banks are installed with sufficient clearance to facilitate servicing.
- ❒ Solar panels are installed away from objects that could damage the panel or block sunlight to the panel.
- ❒ Solar panels and wind generators are installed using proper mounting practices.
- ❒ Battery racks are bolted to the floor or wall.
- ❒ Battery cables (multi-conductor assemblies) installed in cable trays are listed as Tray Cable (TC) rated or are enclosed in an approved conduit or raceway.
- ❒ Battery conductors (individual conductors not part of a cable assembly) installed in cable trays are enclosed in an approved conduit or raceway.
- ❒ Battery conductors are protected up to near the point of termination.
- ❒ DC plant terminations are protected from accidental contact.
- ❒ A battery disconnect and suitable circuit protection device have been installed as required.
- ❒ Standby power generators are installed properly.
- ❒ Standby power generators are located in areas accessible only to authorized personnel.
- ❒ Standby power generators are installed with adequate area for servicing.
- ❒ Fuel storage tanks for standby power generators are in a secure area.
- ❒ A dedicated electrical circuit is provided at the generator.
- ❒ A transfer switch with the proper ampacity rating is installed to switch between commercial power and standby generator power as needed, and the switch has been tested for proper operation.

- ❒ Standby, emergency, and backup power sources, such as batteries, generators, solar, wind, and UPS, have been tested for proper operation and switching in accordance with the manufacturer's acceptance test plan (ATP).
- ❒ The site is free of other known Power Sources safety and/or equipment reliability concerns.

Chapter 7, "Surge Protective Devices"

- ❒ All electrically conductive entry points (AC power, telephone, LAN, signal/control, site security and access, and RF) into a site are protected from surges using a surge protective device (SPD).
- ❒ A Type 2A (SAD/MOV) or 2B (MOV) SPD is installed at the electrical service entrance as required.
- ❒ A Type 2A SPD is installed at the distribution panel as required (typically applicable to prefabricated shelters or equivalent).
- ❒ A Type 2A or 2C SPD is installed at equipment room or dispatch area sub-panels as required (typically applicable to commercial buildings).
- ❒ A Type 2D SPD is installed on external branch circuits as required.
- ❒ Primary SPDs for telephone circuits are installed as required.
- ❒ Secondary SPDs for telephone circuits are installed as required.
- ❒ SPDs for alarm and control, data network, site links, site security, video, etc. are installed as required.
- ❒ Type 3 AC power SPDs (with ground point) are installed at dispatch center operator positions as required.
- ❒ All RF transmission lines (including test lines and spares) have coaxial RF-type SPDs installed as required.
- ❒ GPS lines have SPDs installed as required.
- ❒ Tower lighting system AC power and data/alarm circuits have SPDs installed as required.
- ❒ The site is free of other known Surge Protective Devices safety and/or equipment reliability concerns.

Chapter 9, "Equipment Installation"

- ❒ Equipment spacing and aisle widths are adequate and conform to requirements.
- ❒ Equipment is level and plumb.
- ❒ Equipment is square with respect to surrounding equipment and walls.
- ❒ Where applicable, seismic installation practices are observed.
- ❒ Cabinets and racks are secured as required using appropriate hardware.
- ❒ Cables are installed in a neat and professional manner and are protected from damage.
- ❒ Cables are not secured to the exterior of conduits.
- ❒ Cable groups with different functions maintain a minimum separation of at least 5 cm (2 in.) as required.
- ❒ Data, network, optical fiber, and RF cables meet or exceed minimum bending radius requirements.
- ❒ Plenum-rated cables are installed where required.
- ❒ Riser-rated cables are installed where required.

- ❒ Cables are of adequate length with no excess.
- ❒ Cables are properly secured at the required intervals.
- ❒ AC and DC power conductors installed in cable trays meet minimum installation requirements.
- ❒ Cables are properly identified at both ends using a standard labeling system.
- ❒ Abandoned cables have been removed or properly identified for future use.
- ❒ Fire-stopping material (if required) has been properly installed as required by code.
- ❒ Distribution frame wiring conforms to the proper punch-down or wire wrap techniques.
- ❒ CAT-5/6/8 (or equivalent) data cables maintain the proper separation distance from AC power cables.
- ❒ CAT-5/6/8 (or equivalent) data cables do not have sharp bends.
- ❒ CAT-5/6/8 (or equivalent) cables meet all other installation requirements.
- ❒ Field-built CAT-5/6/8 (or equivalent) cables have been tested and certified to the appropriate TIA or ISO standards.
- ❒ Cables located below raised flooring systems are properly installed.
- ❒ Cables installed above suspended ceilings are installed correctly and do not rest directly on the ceiling tiles.
- ❒ Site security systems meet proper installation requirements.
- ❒ Utility pole equipment installations maintain proper clearances and meet installation requirements.
- ❒ Trash and packing material have been removed.
- ❒ Electrostatic discharge handling practices are observed as required.
- ❒ The site is free of other known equipment installation safety and/or equipment reliability concerns.

Appendix F, "Cybersecurity Guidelines for Communication Sites"

- ❒ Cybersecurity guidelines have been considered according to Appendix F.

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