MIL-HDBK-413
28 March 1986

MILITARY HANDBOOK

DESIGN HANDBOOK
FOR
HIGH FREQUENCY RADIO
COMMUNICATIONS SYSTEMS

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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DEPARTMENT OF DEFENSE
Washington, DC 20301

Design Handbook for High Frequency Radio Communications Systems

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1. SCOPE

1.1 **Purpose.** This handbook provides uniform guidelines for communications engineers and staff planners for the implementation of high frequency (HF) radio communications systems.

1.2 **Application.** This handbook applies to Government-owned and -operated high frequency radio systems and equipment, Government-owned and contractor-operated high frequency radio systems and equipment, and other high frequency radio facilities provided by DoD resources.

1.3 **Objective.** This handbook provides general technical information pertaining to facility and system design of manpack, vehicular, transportable, and fixed station high frequency radio communications systems, receiving and transmitting sites, and antenna installations.

2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 **Specifications, standards, and handbooks.** Unless otherwise specified, the following specifications, standards, and handbooks, of the issue listed in that issue of the *Department of Defense Index of Specifications and Standards* (DoDISS) specified in the solicitation, form a part of this handbook to the extent specified herein.

STANDARDS

FEDERAL

FED-STD-1037	Glossary of Telecommunication Terms

MILITARY

MIL-STD-188-100	Common Long Haul and Tactical Communication System Technical Standards
MIL-STD-188-110	Equipment Technical Design Standards for Common Long Haul/Tactical Data Modems
MIL-STD-188-114	Electrical Characteristics of Digital Interface Circuits
MIL-STD-188-141	Interoperability and Performance Standards for High Frequency Radio Equipment
MIL-STD-188-148	(S) Interoperability Standard for Anti-Jam (AJ) Communications in the High Frequency Band (2-30 MHz) (U)
MIL-STD-188-200	System Design and Engineering Standards for Tactical Communications
MIL-STD-188-203-1	Subsystem Design and Engineering Standards for Tactical Digital Information Link (TADIL) A
MIL-STD-188-310	Subsystem Design and Engineering Standards for Technical Control Facilities
MIL-STD-188-317	Subsystem Design and Engineering Standards and Equipment Technical Design Standards for High Frequency Radio
MIL-STD-188-323	System Design and Engineering Standards for Long Haul Digital Transmission System Performance
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference

MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of

HANDBOOKS

MIL-HDBK-411	Power and Environmental Control for the Physical Plant of DoD Long Haul Communications
MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronic Equipments and Facilities

2.1.2 **Other Government documents, drawings, and publications.** The following other Government documents, drawings, and publications form a part of this handbook to the extent specified herein.

ACP 190, U.S. Supplement-1 (B), Annex D, "Guide to Frequency Planning"

National Bureau of Standards, Monograph 80, "Ionospheric Radio Propagation"

FAA Advisory Circular, AC 70/7460-1, Obstruction Marking and Lighting

Federal Aviation Regulation, Part 77, "Objects Affecting Navigable Airspace"

U.S. Army Radio Propagation Agency, Fort Monmouth, NJ, Technical Report No. 4, 1964

North Atlantic Treaty Organization (NATO) Standardization Agreements (STANAGs)

STANAG 4203	Technical Standards for Single Channel HF Radio Equipment
STANAG 5009	Minimum Military Characteristics of Radio Frequency Equipment for Naval Gunfire Support of Shore Forces
STANAG 5031	Minimum Standards for Naval HF, MF, and LF Shore-to-Ship Broadcast Systems
STANAG 5032	Basic Technical Characteristics for SSB Single Channel Voice Communications Between 1.5 and 30 MHz in the Mobile Services
STANAG 5035	Introduction of an Improved System for Maritime Air Communications on HF, LF, and UHF

Quadripartite Standardization Agreements (QSTAGs)

QSTAG 263A	Standards to Achieve Interoperability of ABCA Armies High Frequency Combat Net Radio Equipments

NTIA Report 85-173, "Atmospheric Radio Noise: Worldwide Levels and Other Characteristics," National Telecommunications and Information Administration

(Army) FM 11-65, High Frequency Radio Communications

(Army) FM 11-486-7, (AF) T.O. 31Z-10-22, Electrical Power Stations for Telecommunications Facilities

(Army) FM 11-486-24, (AF) T.O. 31Z-10-25, (Navy) 0969-LP-174-4010, Digital Data Transmission Error Protection

(Copies of specifications, standards, handbooks, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 **Other publications.** The following documents form a part of this handbook to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted shall be those listed in the issue of the DoDISS specified in the solicitation. The issues of documents which have not been adopted shall be those in effect on the date of the cited DoDISS.

Report 322-CCIR, "World Distribution and Characteristics of Atmospheric Radio Noise." Documents of the Xth Plenary Assembly, International Radio Consultative Committee, Geneva 1963

Recommendations and Reports of the CCIR, 1982, XVth Plenary Assembly, Geneva 1982, International Telecommunications Union, Geneva 1982

Recommendation 339-5	Bandwidths, Signal-to-Noise Ratios and Fading Allowances in Complete Systems
Recommendation 455-1	Improved Transmission System for HF Radiotelephone Circuits
Report 354-4	Improved Transmission Systems for Use Over HF Radiotelephone Circuits

ANSI C2-1981, National Electrical Safety Code, Institute of Electrical and Electronics Engineers, Inc. New York, NY

(Nongovernment standards are generally available for reference from libraries. They are also distributed among nongovernment standards bodies and using Federal agencies.)

2.3 **Order of precedence.** In the event of a conflict between the text of this handbook and Federal or military standards, the text of the standard shall take precedence.

3. DEFINITIONS

3.1 **Terms and definitions.** The use of telecommunications terms in this handbook will be as defined in Federal Standard 1037. Additional terms are defined below.

3.2 **Additional terms and definitions.**

a. **Algorithm.** A prescribed set of well-defined rules or processes for the solution of a problem in a finite number of steps.

b. **Automatic load control (ALC).** A method of automatically maintaining the peak power of a single-sideband suppressed-carrier transmitter at a nearly constant level.

c. **Counterpoise.** A conductor or a system of conductors (radial wires), elevated above and insulated from the ground, forming a lower system of conductors of an antenna. A counterpoise is frequently employed when an antenna requiring a ground surface is positioned over a poorly conducting surface such as dry sand. The counterpoise, in this case, serves as the ground surface.

d. **Dielectric constant.** That property which determines the electrostatic energy stored per unit volume for unit potential gradient.

e. **Director element.** A parasitic element located forward of the driven element of an antenna, intended to increase the directive gain of the antenna in the forward direction.

f. **Gaussian noise.** Unwanted electrical disturbances or perturbations described by a probability density function that follows a normal law of statistics.

g. **Geomagnetic field.** A conventionalized, symmetrical approximation of the earth's magnetic field having one diameter of the earth as its axis.

h. **Ionization.** The transformation of neutral particles into electrically charged ions by high energy radiation such as light or ultraviolet rays.

i. **Ionospheric storm.** An ionospheric disturbance associated with abnormal solar activity and characterized by wide variations in the state of the ionosphere from normal, including turbulence in the F region and increased signal absorption.

j. **Monopole antenna.** A vertical antenna with a voltage node at the lower end and a current node at the top, that is normally 0.25 wavelength at the operating frequency.

k. **Phase reversal.** A 180 degree change in phase such as a wave might undergo upon reflection under certain conditions.

l. **Post selector.** A device placed after a frequency converter, rf exciter, or other device, that passes signals of desired frequencies and reduces the amplitude of others.

m. **Preselector.** A device placed ahead of a frequency converter, receiver input, or other device, that passes signals of desired frequencies and reduces others.

n. **Product detector.** A type of heterodyne detector which has low distortion and intermodulation products.

4. GENERAL PRINCIPLES

4.1 HF radio communications systems.

4.1.1 **Basic system.** The basic HF radio system is comprised of a transmitter and receiver designed to operate in the 1.6- to 30-megahertz (MHz) radio-frequency (rf) spectrum, antennas with associated transmission lines, and the radio-wave propagation medium. The system provides interfaces for incoming and outgoing electrical signals. The transmitter impresses the incoming signals on an rf carrier through the process of modulation. It then amplifies the modulated rf signal for transmission. The transmission line feeds the amplified signal to an antenna which radiates corresponding electromagnetic energy into the propagation medium. The antenna on the receiving end intercepts rf energy and passes it, through its transmission line, to the receiver. The receiver selects the desired rf signal and demodulates it to recover the original electrical signals. Figure 1 is a block diagram of the basic HF radio communications system.

4.1.2 **HF radio principles.** This section presents HF radio principles by starting with the radio-wave propagation phenomena. Next, modulation theory is presented, since it is modulation which makes the transmission of information by radio waves possible. The remainder of the section deals with equipment for use in HF transmission, including the advanced, high-performance equipment which greatly increases the effectiveness of transmission at HF.

4.2 **HF radio propagation.** Radio wave propagation at HF is characterized by two basic mechanisms: Groundwave and skywave. The groundwave mechanism enables short-range communications, while the skywave mechanism enables global-range communications. In the groundwave mechanism, the radio waves travel on or near the surface of the earth. The skywave mechanism depends on radio wave refraction in the ionosphere. (Some texts refer to the ionospheric propagation mechanism as reflection from the ionosphere.)

4.2.1 **Groundwave.** The groundwave has three distinct components: Surface wave, direct wave, and ground-reflected wave. A fourth component, a tropospheric-refracted wave, sometimes occurs in conjunction with air density gradients. This is illustrated in figure 2.

4.2.1.1 **Surface wave.** The surface wave component moves along the surface of the earth. Therefore, the conductivity of the surface is a primary factor in attenuation of the surface wave. Energy is absorbed by the earth in accordance with its conductivity. Absorption increases with frequency and limits useful surface-wave propagation to the lower HF range. Vertically polarized waves propagate better over the earth's surface than horizontally polarized waves because they incur lower attenuation. (The polarization of radio waves is defined by the orientation of the electric lines of force in the electromagnetic field relative to the surface of the earth. The polarization with which radio waves are "launched" is determined by the transmitting antenna.)

4.2.1.2 **Direct wave.** The direct wave follows a direct path through the troposphere from the transmitting antenna to the receiving antenna. The path is somewhat curved by normal refraction in the atmosphere, enabling propagation somewhat beyond the visible horizon.

4.2.1.3 **Ground-reflected wave.** A portion of the propagated wave is reflected from the surface of the earth at some point between the transmitting and receiving antenna. Reflection causes a phase change of the transmitted signal. The phase change results in a reduction or enhancement of the combined received signal, depending on the time of arrival of the reflected signal relative to the other components. The relative times of arrival are, in turn, dependent upon the relative path distances traveled by the wave components.

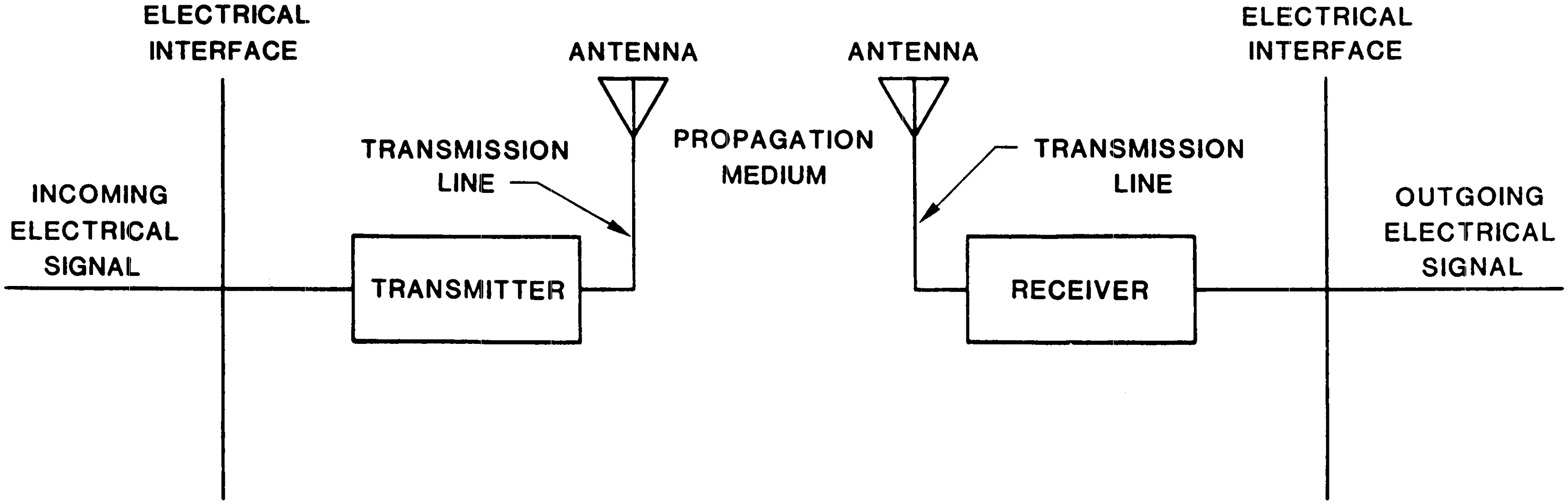


FIGURE 1. Basic HF radio communications system.

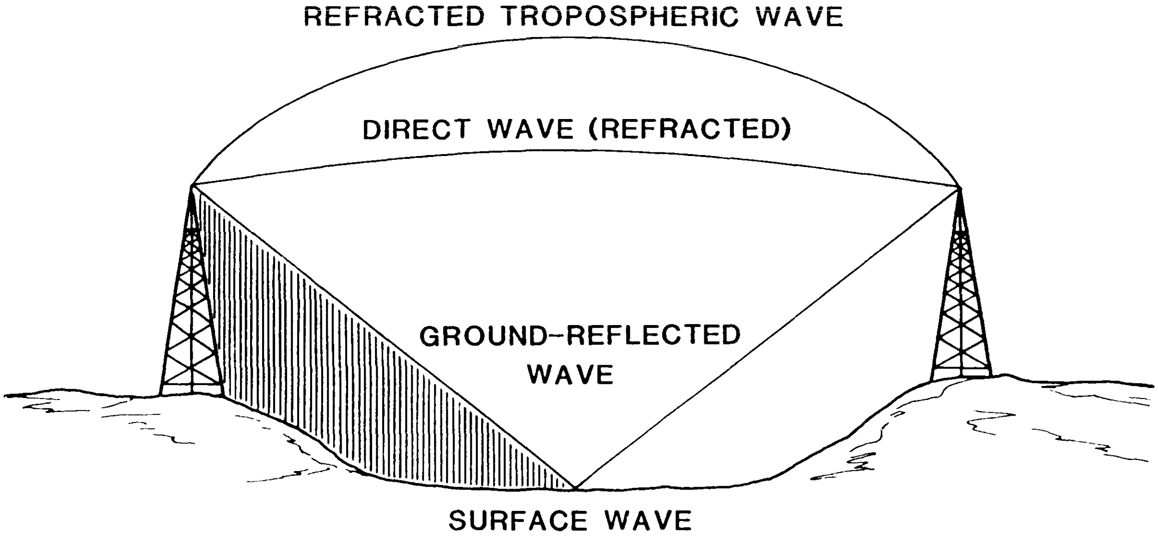


FIGURE 2. Groundwave components.

4.2.1.4 **Refracted tropospheric wave.** The refracted tropospheric wave (not to be confused with the normally refracted direct wave) results when abrupt differences in atmospheric density and refractive index exist between large air masses. This type of refraction, associated with weather fronts, is not normally significant at HF.

4.2.1.5 **Frequency dependence of groundwave propagation.** At frequencies below about 5 MHz, the surface wave is favored because the ground behaves as a conductor for the electromagnetic energy. Above 10 MHz, the ground behaves as a dielectric. In the region below 10 MHz, the existing path ground conductivity is a critical factor. As a general rule, surface waves travel best over sea water. Table I provides a rough assessment of the relative conductivity of various surface types. As frequencies approach 30 MHz, losses suffered by the surface wave become excessive and transmission is possible only by means of direct waves.

TABLE I. Conductivity of various types of surface.

Type of Surface	Relative Conductivity
Sea water	Good
Fresh water	Fair
Soil	Fair
Rocks	Poor
Desert	Poor
Jungle	Bad
Arctic	Bad

4.2.2 **Skywave.** Since skywave propagation results from radio wave refraction in the ionosphere, this mechanism is generally referred to as ionospheric radio propagation. The ionosphere is the region of the atmosphere in which ionization takes place with sufficient intensity to produce a significant ion density gradient with altitude. The density gradient is manifested as a gradual change in radio refractive index, which causes radio waves at HF to be refracted.

4.2.2.1 **Ionospheric layering.** Solar radiation (ultraviolet light and x-rays) and, to a lesser extent, cosmic rays impinge on ionospheric gases and cause ionization. Since these ionization sources vary in energy level, they penetrate to different depths of the atmosphere before causing ionization. The natural grouping of energy levels results in distinct layers being formed at different altitudes. Figure 3 illustrates ionospheric layering and gives the generally accepted layer designations. Not shown in the figure is the density gradient within the layers. The density increases with altitude to a maximum value, then decreases or remains constant up to the next higher layer, if any.

4.2.2.2 **F layer.** The highest of the ionized regions is called the F layer. It ranges in height from 130 to 460 km and is the primary medium for long distance HF propagation. If sporadic ionospheric disturbances are ignored, the height and density of this region varies in a predictable manner diurnally, seasonally, and with the 11-year sunspot cycle. Under normal conditions it exists 24 hours a day. At night, the layer has a single density peak and is called, simply, the F layer. During the day, the absorption of solar energy results in the formation of two distinct density peaks. The higher and most important of the two is called the F_2 layer. It ranges in height from 200 to 460 km. The lower peak, known as the F_1 layer, ranges in height from 130 to 300 km and seldom is predominant in supporting HF radio propagation. During daytime, the F layers increase in density, reaching a maximum several hours after local noon. Then they decrease exponentially from the maximum, reaching a combined minimum during the night.

4.2.2.3 **E layer.** The lowest layer to support HF radio propagation is the E layer. The average altitude of its central region is about 110 km. The atmosphere at this height is dense enough to allow rapid deionization as solar energy ceases to reach it. Ionization of this layer commences near sunrise and ceases shortly after sundown. Irregular cloud-like layers of ionization, called sporadic E, often occur in the region of normal E-layer appearance. These areas are highly ionized and are sometimes capable of supporting the propagation of frequencies within and well above the HF range.

4.2.2.4 **D layer.** During daylight hours, there also exists a weakly ionized region at 50 to 90 km altitude, known as the D layer. The density of this region is closely proportional to the solar elevation angle. Due to the greater penetration ability of higher radio frequencies, the D layer has little effect on frequencies above about 10 MHz. At lower frequencies, however, absorption by the D layer is significant.

4.2.2.5 Geometry of ionospheric refraction.

a. As the path traversed by radio waves of a particular frequency, f, enters an ionospheric layer at a sufficiently oblique angle, θ, relative to a line extended from the center of the earth to the entry point, refraction gradually curves the path and turns it back toward the surface of the earth. The refraction is gradual because the ion density and, hence, the refractive index of the ionospheric layer increases with height, up to its maximum. The gradual refraction can be viewed as equivalent to a reflection from an abrupt discontinuity in refractive index, at a height referred to as the virtual height. This is illustrated in figure 4.

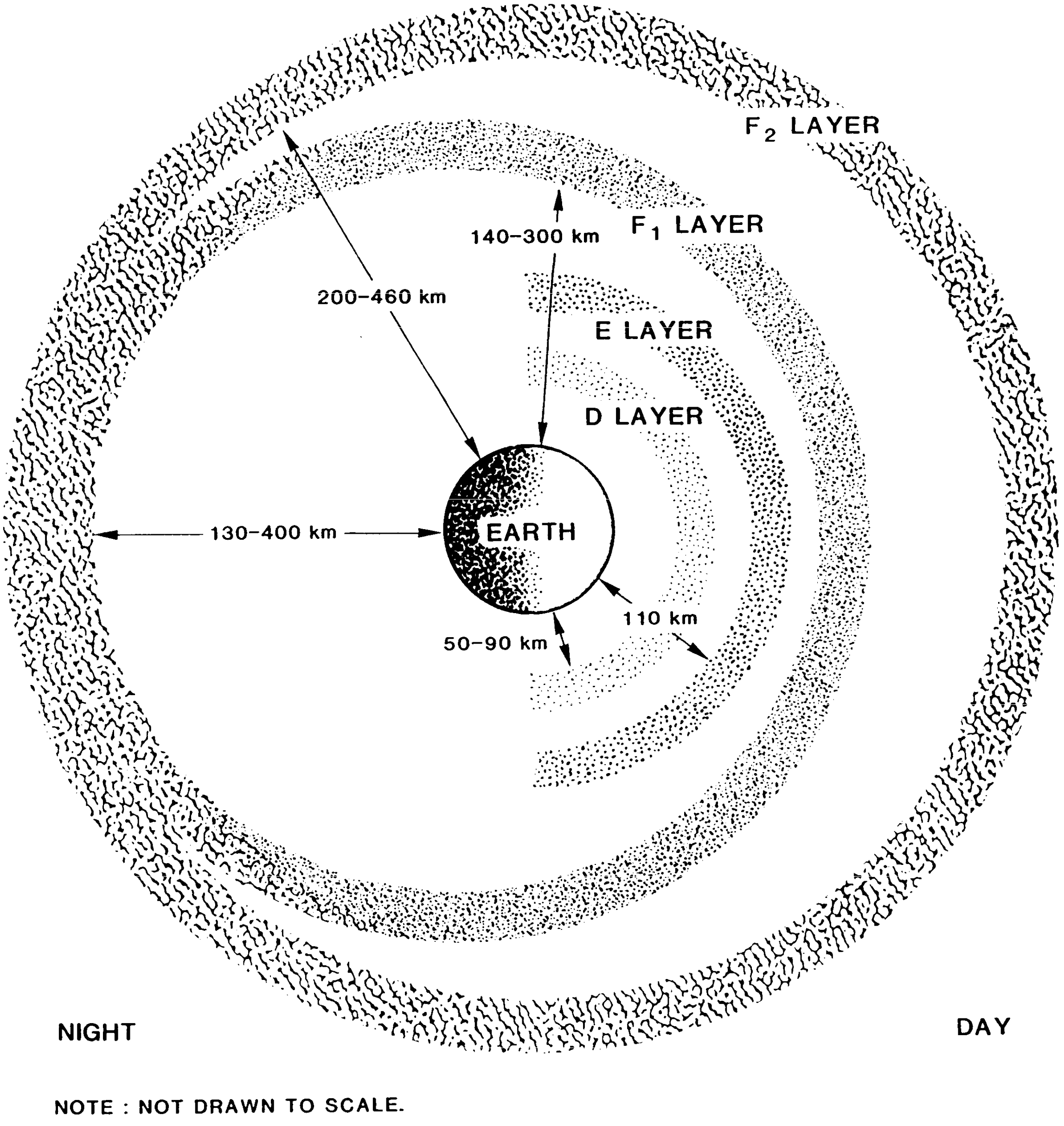


FIGURE 3. Structure of the ionosphere.

b. The highest frequency that will be reflected at vertical incidence is called the critical frequency, f_c. Through an application of Snell's Law (see National Bureau of Standards Monograph 80), the highest frequency, f, that will be returned to earth from oblique incidence is given by

$$f = f_c \sec \theta \tag{4-1}$$

where θ is the angle of incidence, measured from the normal to the plane of the layer. This relationship, known as the secant law, shows that at oblique incidence, the ionosphere can reflect much higher frequencies than at vertical (normal) incidence. It can also be seen that the greater the angle of incidence, the higher the frequency that will be returned to earth. (The secant law, as stated, applies to a plane ionospheric layer. For a treatment of the curved ionosphere, refer to National Bureau of Standards Monograph 80.)

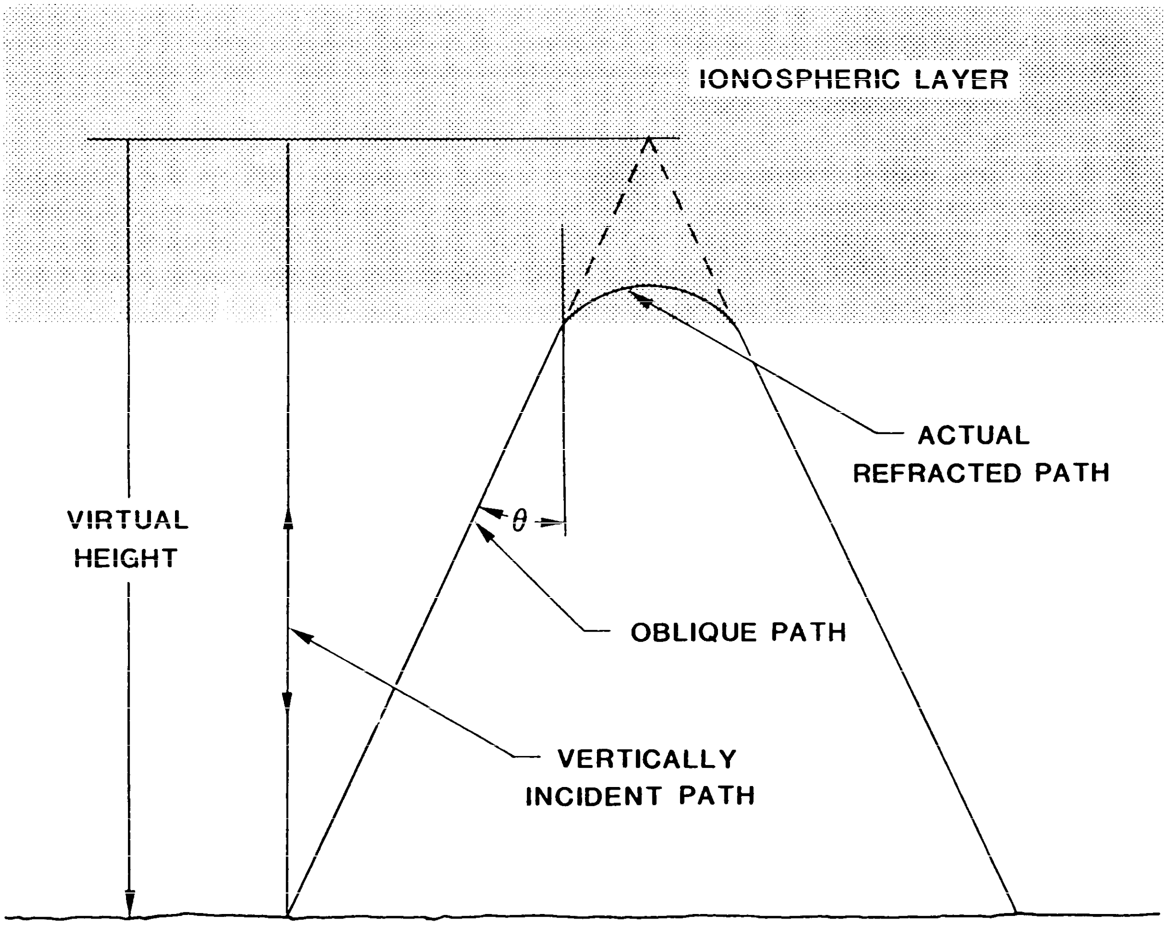


FIGURE 4. Concept of virtual height.

4.2.2.6 **Maximum usable frequency.** The highest frequency at which radio waves are returned to earth is, of course, the maximum frequency that can be used to effect ionospheric propagation between two points at a specific time. This frequency is termed the maximum usable frequency (MUF). Because the ionization of the ionospheric layers is extremely variable, MUF must be statistically defined. The accepted working definition of MUF is the highest frequency predicted to occur via a normal reflection from the F_2 layer on 50 percent of the days of the month at a given time of day on a specified path.

4.2.2.7 **Frequency of optimum traffic.** The ionospheric layers, particularly the D and E layers, absorb radio-frequency (rf) energy as the radio waves pass through. This absorption is higher at the lower frequencies and is inversely proportional to the square of the frequency. Consequently, it is desirable to use the highest frequency possible — in other words, the MUF. The MUF, as defined, however, is unsuitable for reliable communications. Therefore, a frequency below the MUF is chosen to provide a margin for the daily variations in MUF. This frequency, called the frequency of optimum traffic (FOT), is usually computed as 0.85 times the monthly median MUF. Statistically, the FOT so computed lies below the actual daily MUF 90 percent of the time. It should be noted that the FOT bears this statistical relationship with the MUF and is not calculated as the frequency which will provide the maximum received signal power. Sophisticated propagation prediction programs do not use the 0.85 factor, but instead compute the FOT directly from statistical distributions. (The original terminology from which the letters FOT were derived is the French, *frequence optimum de travail.*)

4.2.2.8 **Lowest useful frequency.** The lowest useful frequency (LUF) is the statistically calculated lowest frequency at which the field intensity at the receiving antenna is sufficient to provide the required signal-to-noise ratio (SNR) on 90 percent of the undisturbed days of the month. Unlike the MUF and FOT, the LUF is partly dependent on the transmitter power output and on the noise levels at the receiving station.

4.2.2.9 **Anomalous ionospheric propagation.** Deviations from normal ionospheric propagation occur as the result of certain irregularities and transient conditions in the ionosphere. The most significant of these anomalous propagation mechanisms are sporadic E (E_s), sudden ionospheric disturbances (SIDs), ionospheric storms, polar cap absorption, and spread-F or spread-E (depending upon the ionospheric layer affected).

4.2.2.9.1 **Sporadic E.** In addition to the relatively regular ionospheric layers (D, E, and F), there are a number of irregular layers of transient occurence. The significant irregular reflective layer, from the point of view of HF propagation, is known as sporadic E (E_s) since it occurs in the same altitude region as regular E. It is theorized that E_s occurs as a result of ionization from high altitude wind shear in the presence of the magnetic field of the earth, rather than from ionization by solar and cosmic radiation. Areas of E_s generally last only a few hours, and move about rapidly under the influence of high altitude wind patterns. When E_s occurs, it produces a marked effect on the geometry of radio propagation paths which normally involve the regular layers, as shown in figure 5. Although E_s is difficult to predict, it can be used to advantage when its presence is known. It has been found that close to the equator, E_s occurs primarily during the day and shows little seasonal variation. In the auroral zone, by contrast, it is most prevalent during the night and again shows little seasonal variation. In middle latitudes, E_s occurrence is subject to both seasonal and diurnal variations. In these latitudes, it is more prevalent in local summer than in winter and during the day than at night.

4.2.2.9.2 **SIDs.** A SID can totally disrupt HF propagation. SIDs occur without warning and last from a few minutes to several hours. All radio links operating within, or even partially in, the daylight side of the earth are affected. The majority of SIDs are associated with solar flares. Therefore, the occurrence of SIDs is related to the 11-year sunspot cycle. The primary cause of the propagation disruption (fadeout or blackout) is a sudden, abnormal increase in the ionization of the D region. The region then absorbs all the lower range of HF frequencies and partially absorbs the higher frequencies.

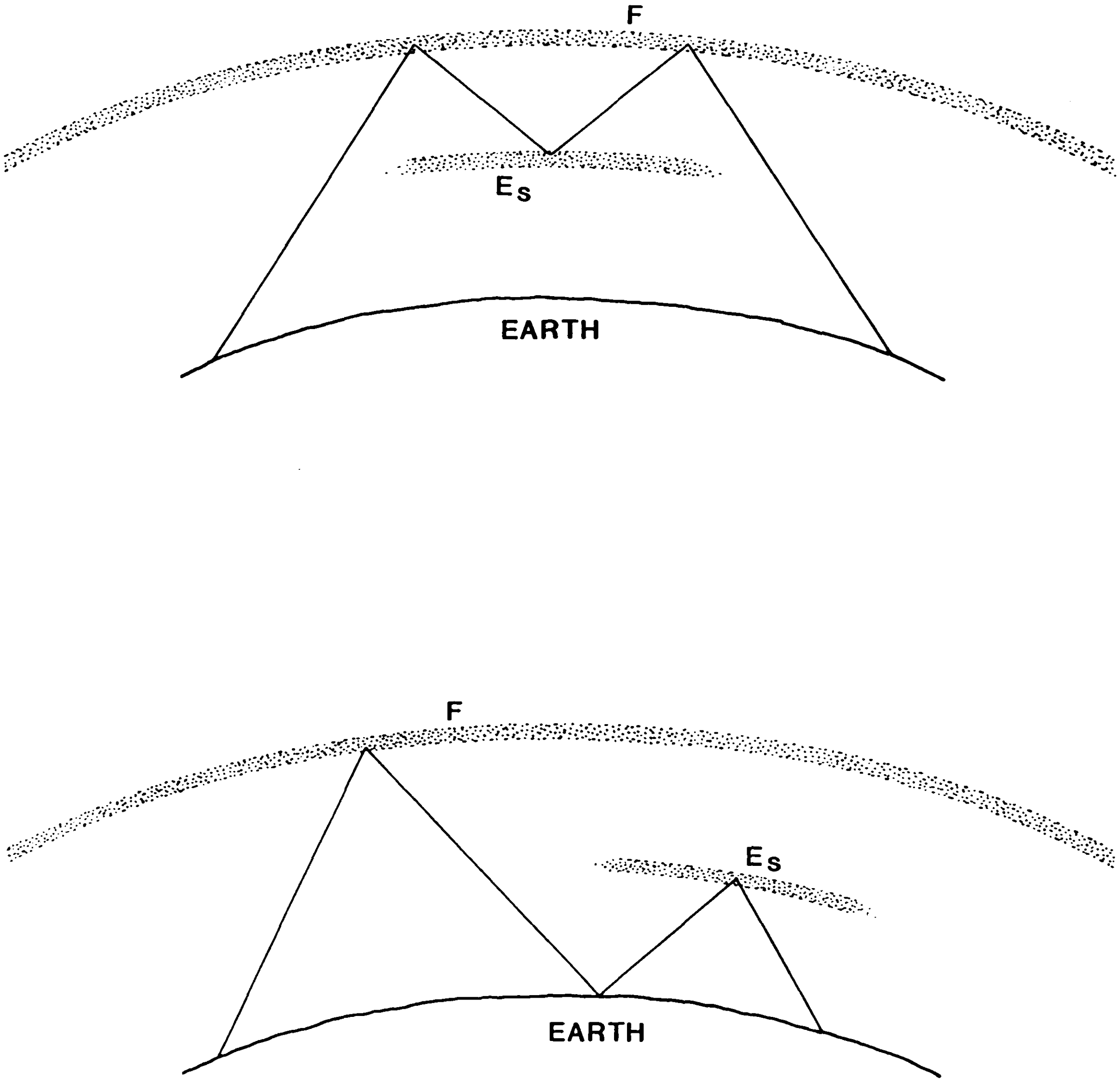


FIGURE 5. Anomalous propagation by sporadic E.

4.2.2.9.3 **Ionospheric storms.** Ionospheric storms are the result of sudden large increases in solar activity. This increased activity can produce large variations in critical frequencies, layer heights, and absorption. The storms may last from several hours to several days. The intensity of the storms varies and the effects usually extend over the entire earth. The storms usually follow solar-flare-initiated SIDs by anywhere from 15 minutes to 72 hours. Ionospheric storms also occur during periods of very high sunspot activity without SIDs. During the storms, ionospheric propagation is characterized by low received signal strengths and flutter-fading, a form of fading that is especially deleterious to voice communications. During the first few hours of a severe ionospheric storm, the ionosphere is in a state of turbulence, layer-forming stratification is destroyed, and propagation is, consequently, erratic. During the later stages of severe storms, and throughout more moderate storms, the upper part of the ionosphere is expanded and diffused. As a result, the virtual heights of the layers are much greater and the maximum usable frequencies much lower. Absorption of radio waves in the D layer is also increased.

4.2.2.9.4 **Polar cap absorption.** When high energy protons are deflected toward the polar regions by the magnetic field of the earth, D-layer ionization in the area is increased. This causes severe absorption of radio waves traversing the polar regions. The resultant attenuation of signals may last for several days, especially when the polar cap is in daylight.

4.2.2.9.5 **Spread-E/F.** Irregularities in ionospheric surfaces scatter, or defocus, radio waves. When this occurs in the F layer, the disturbance is called spread-F; in the E layer, spread-E. The surface abnormalities occur as a result of random motion within the ionized layers and changes in ion density profiles.

4.2.2.9.6 **Nuclear effects.**

a. HF radio using ionospheric propagation is more susceptible to the disrupting effects of nuclear explosions in the atmosphere than is any other radio propagation mechanism in any other frequency band. This is due primarily to catastrophic changes in the structure of the ionosphere. Such changes occur minutes after the explosion and last for several minutes to several days. When explosions occur on the day side of the earth, continuing ionization by the sun can restore ionospheric layers in as little as ten minutes. When the explosions occur on the night side, this major ionization source is blocked by the earth and the effects last until daylight. Decaying effects of the explosion, however, may reappear each night for several nights. The primary effects on skywaves are:

   (1) Greatly increased attenuation through absorption in the D layer.

   (2) Loss of F-layer propagation paths, due to depletion of electrons in the layer.

   (3) Anomalous propagation modes caused by irregular ionization enhancement.

   For nuclear explosions below about 100 km in altitude, the predominant effect is signal absorption. Above about 100 km, the major effects are refraction and dispersion.

b. Kiloton-yield bursts below about 30-km altitude have no appreciable effect on ionospheric propagation. Megaton yields, on the other hand, either form a gamma-ray-induced D layer or augment an existing D layer, leading to increased signal absorption. Moreover, a shock-driven acoustic wave distorts the structure of the F layer, in turn distorting the refraction geometry and possibly causing loss of propagation path. Both effects occur within about five minutes of the explosion. The effects of low-altitude bursts are illustrated in figure 6.

c. At intermediate altitudes of 30 to 100 km, yields near a megaton are important. The effects just described for low-altitude bursts are magnified and four major new effects are produced:

   (1) X-rays from the burst increase D-layer absorption.

   (2) Free electrons from the burst increase D-layer absorption.

(3) Electrons in the F layer are depleted.

(4) A fireball-driven acoustic gravity wave distorts the ionospheric structure.

These effects are illustrated in figure 7.

d. In addition, three other effects are sometimes troublesome (see figure 8).

   (1) Wave-reflection from the fireball, setting up new radio paths.

   (2) A conjugate D layer being formed at some distance from the explosion. (Electrons kicked upward from the D layer in the vicinity of the burst travel along the geomagnetic field to another location, where they form the conjugate D layer.)

   (3) A short-lived plume of plasma (gas made up of charged particles, in this case electrons) emanating from the fireball and aligned with the geomagnetic field produces a refracting/reflecting layer at a very high altitude, producing anomalous propagation paths.

e. A high-altitude explosion, above about 100 km, exacerbates all of the effects mentioned to this point, as well as two other important effects:

   (1) An extensive, long-lasting, structured plasma plume at a very high altitude which produces anomalous propagation paths.

   (2) A debris patch near and below the explosion plus a conjugate debris path formed by debris streaming along the geomagnetic field. This increases signal absorption in the area and produces scattering.

These effects are illustrated in figure 9.

4.2.2.10 **Multipath propagation.**

a. Most HF antennas radiate over a broad vertical angle. As a result, the radiated energy impinges on one or more ionospheric layers at different angles of incidence. The refracted waves, then, follow different paths. Some paths may undergo reflection from the ground and return to the ionosphere one or more times before reaching the destination. Such multihop paths, being physically longer, delay the waves traversing them substantially relative to a single-hop path. Consequently, the received signal is dispersed over time. This is particularly deleterious to digital transmissions at high data rates, since it causes intersymbol interference. The multipath propagation mechanism is illustrated in figure 10.

b. The difference in the time of arrival of waves traversing the different paths is called multipath spread. Up to a point, multipath spread is inversely related to distance, because of the smaller number of modes that will propagate or reflect on the longer paths. This relationship is plotted in figure 11.

c. Multipath spread can be minimized by selecting frequencies as close to the MUF as possible. Experimental data has shown that as the MUF is approached, the time dispersion decreases. Curves based on the experimental data are given in figure 12. The ordinate of the graph is labelled multipath minimization factor (MMF). The scale is the ratio of the selected frequency to the MUF. Thus, the MUF defines a frequency above which the multipath spread will be less than that determined by the curve.

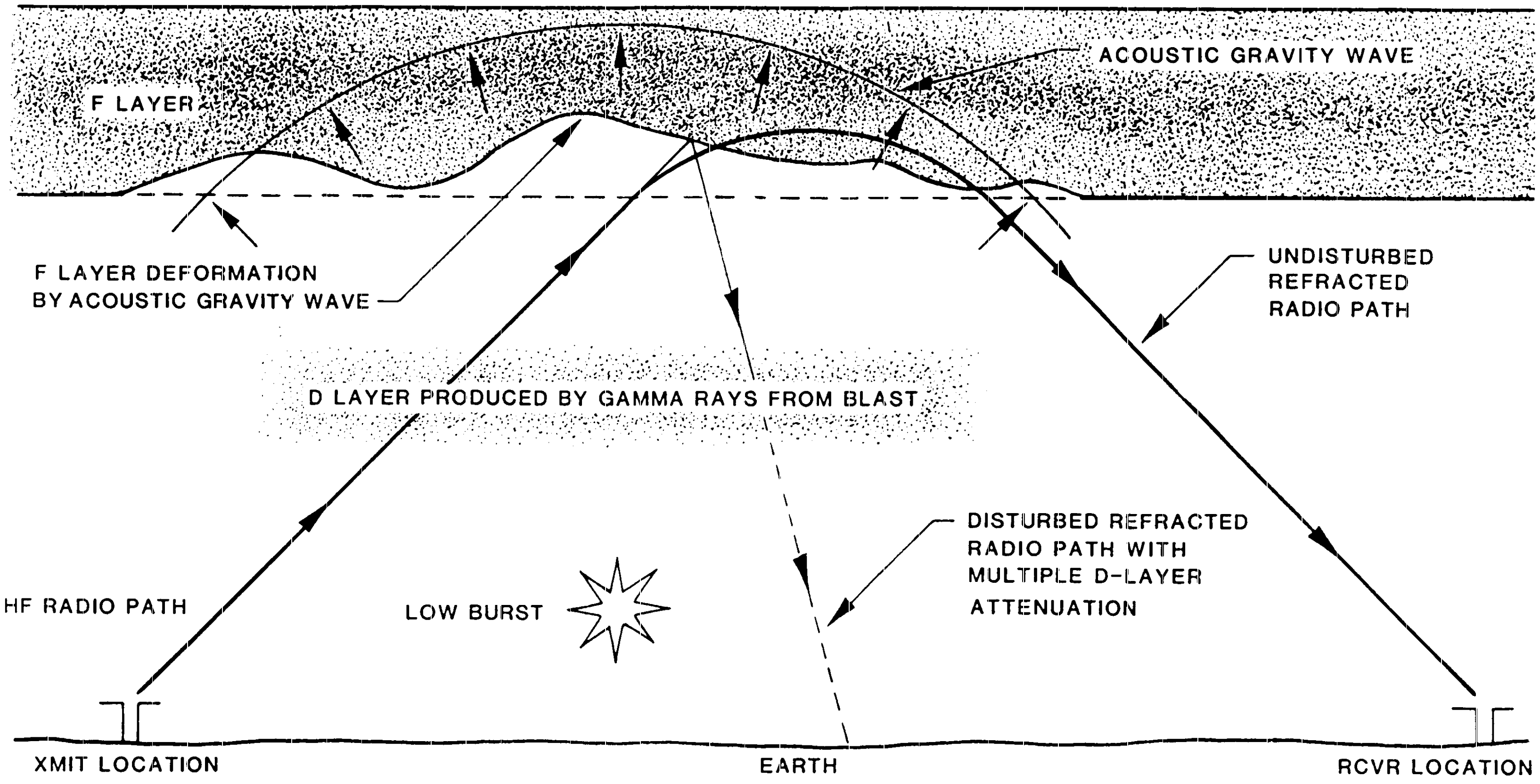


FIGURE 6. Low altitude nuclear burst effects.

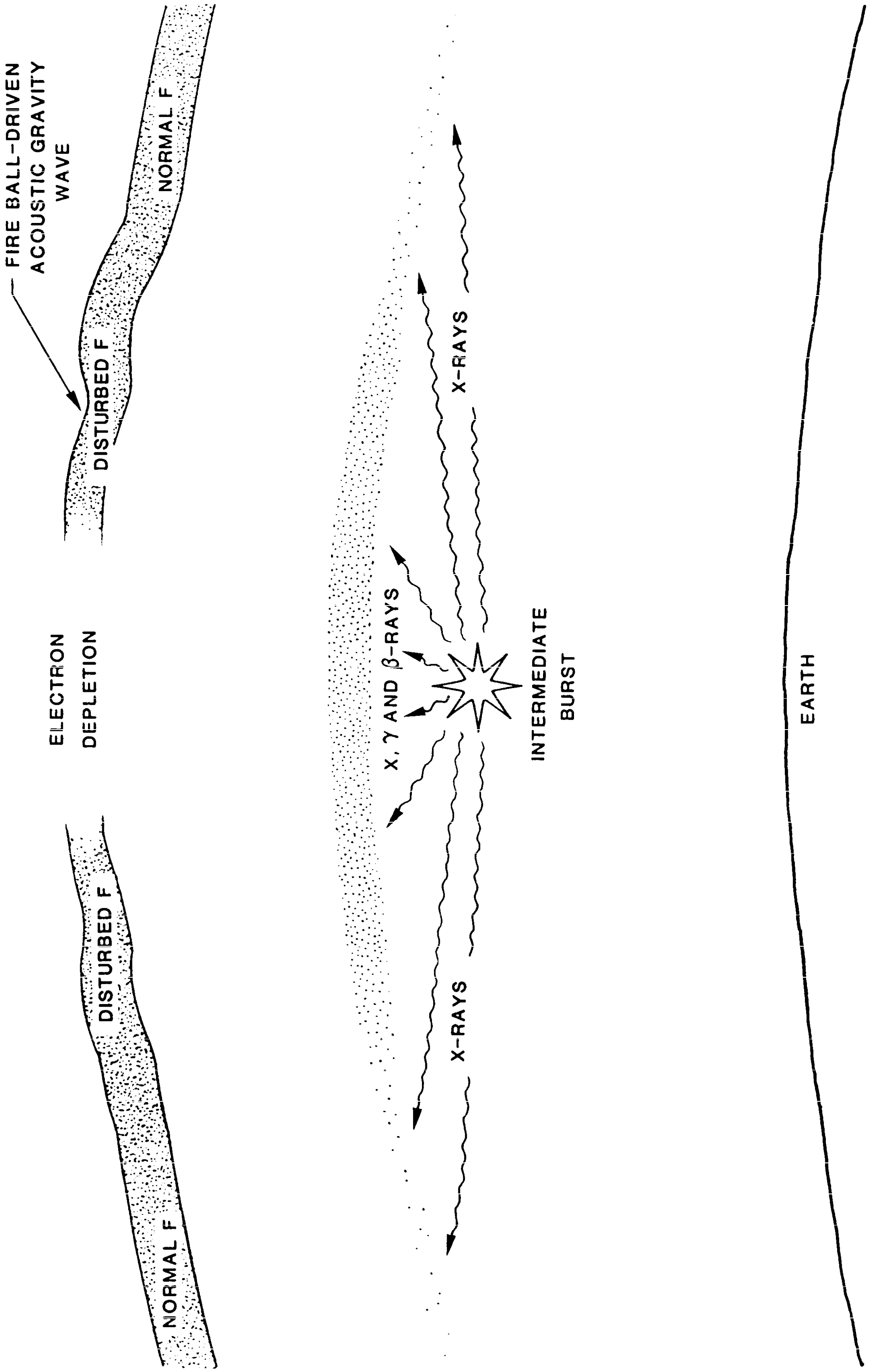


FIGURE 7. Intermediate altitude nuclear burst primary effects.

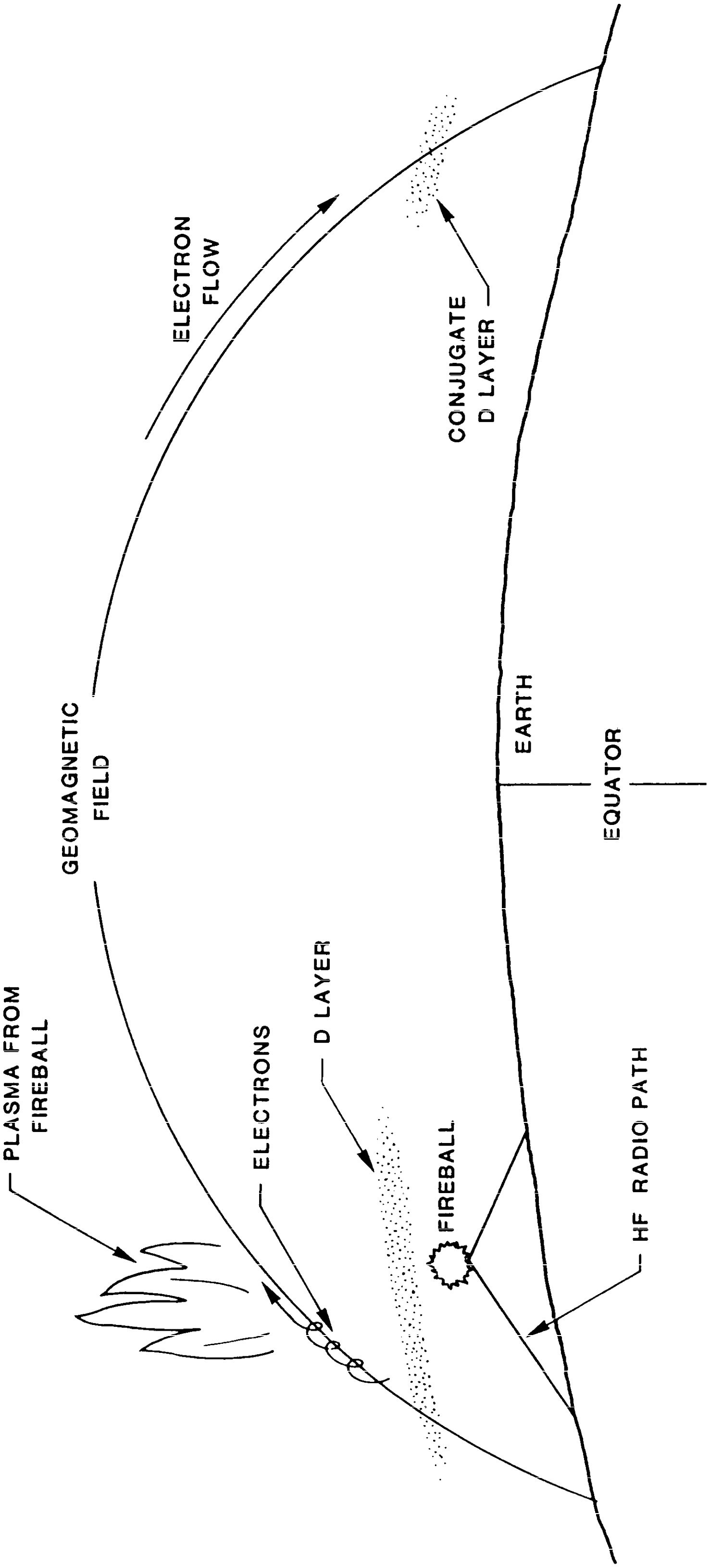


FIGURE 8. Intermediate altitude nuclear burst secondary effects.

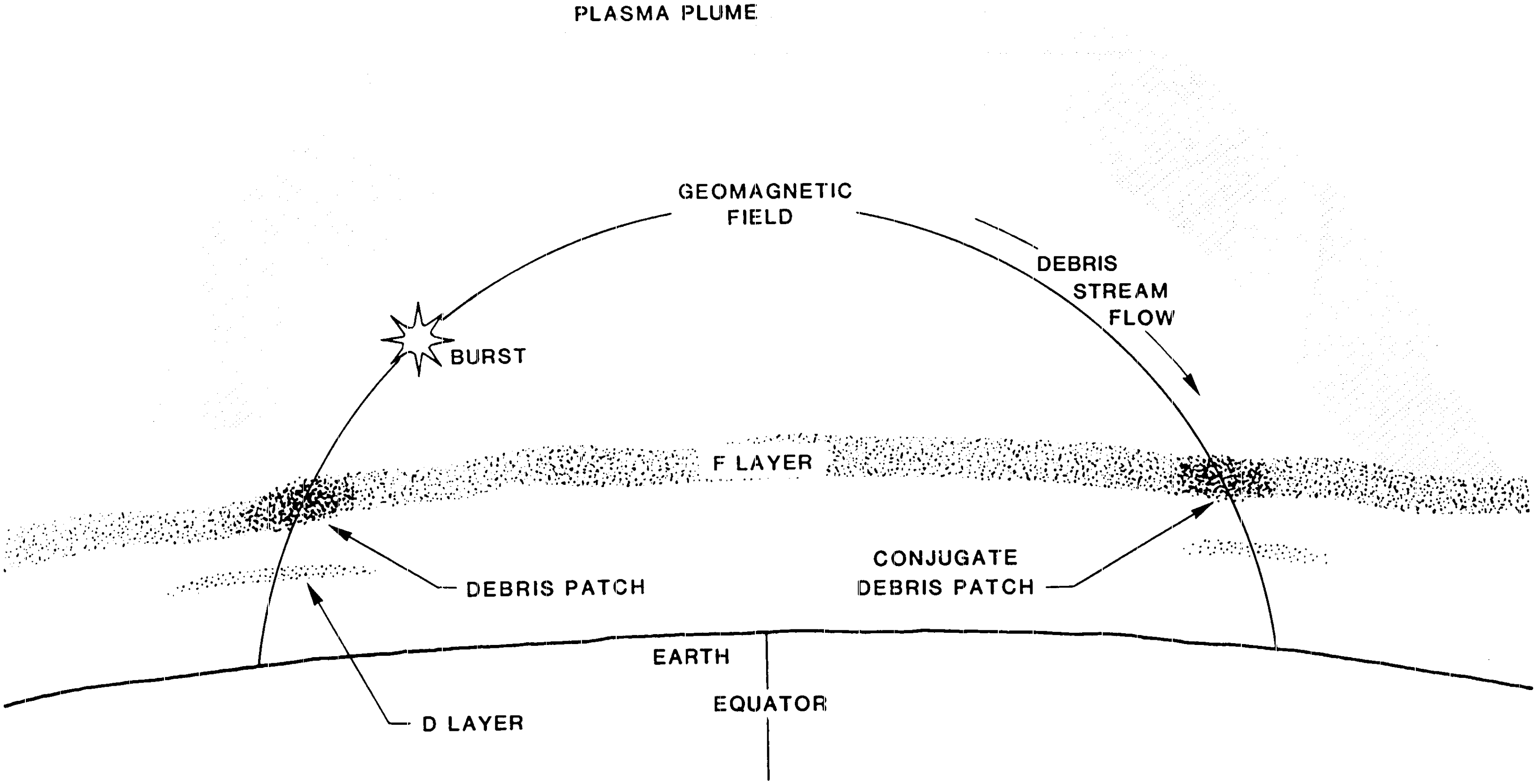


FIGURE 9. High altitude nuclear burst effects.

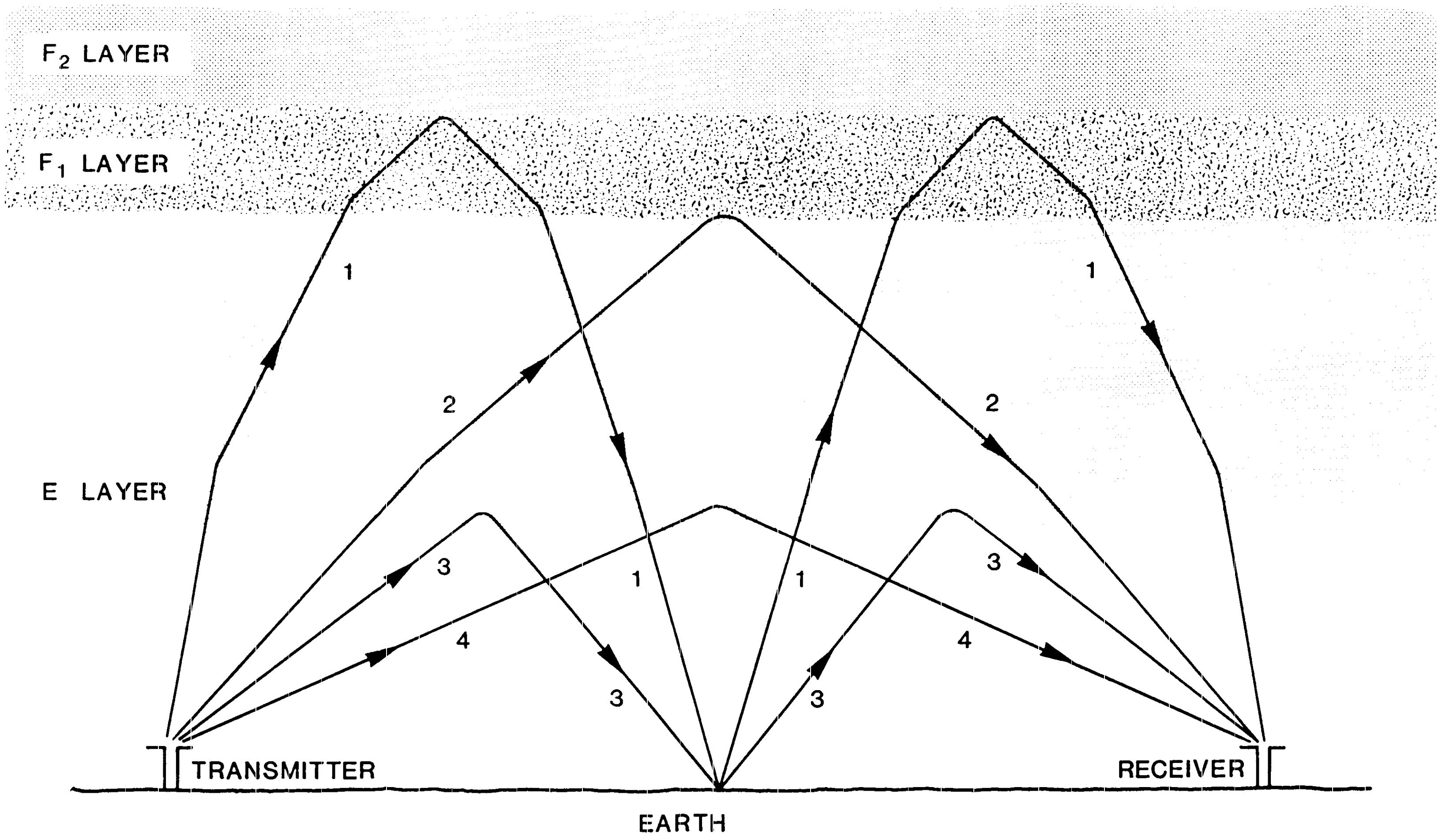


FIGURE 10. Example of multipath reception.

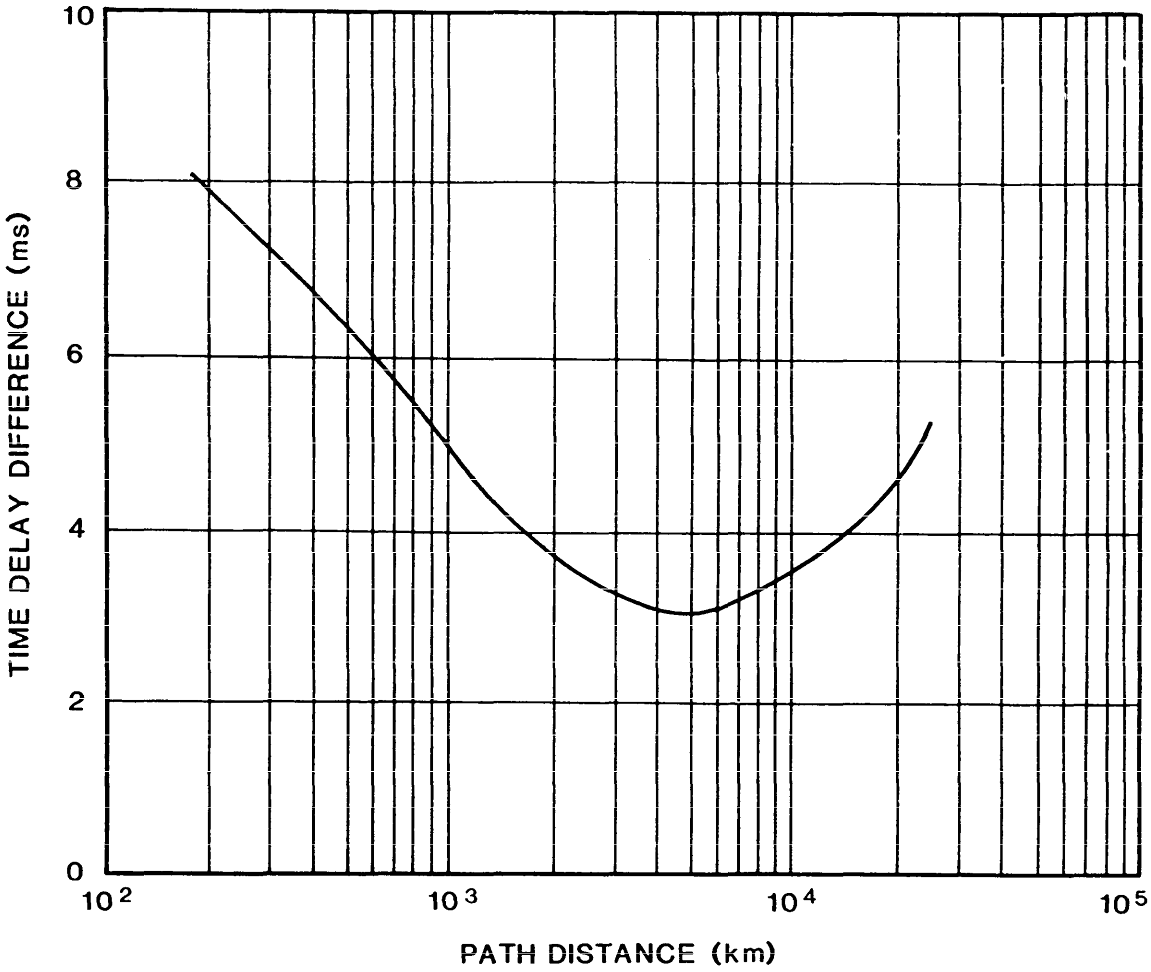


FIGURE 11. Multipath spread as a function of distance.

4.2.2.11 **Doppler spread.** Variations in the refractive index cause volumes of different ion densities to move with respect to each other. The variations occur in both horizontal and vertical planes. They are caused by variations in the density of ionization and molecules in adjacent regions and by variations in the magnitude of the geomagnetic field. The relative motions between density volumes produce doppler shifts of about 1 hertz (Hz). Such shifts transform single-frequency signals into a spectrum of frequencies centered around some mean frequency. The result is evidenced as fading of the radio signal. Doppler spread has little impact on analog signals but can cause severe problems in data transmissions, particularly at the higher data rates. Although doppler spread does not lend itself to detailed analysis, it has been empirically determined that it establishes a fundamental error probability in data transmission over a single path. It is known, however, that doppler shift occurs independently on different paths. For this reason, path diversity (see 4.9.1.5) minimizes the effect. This is illustrated in figure 13, which gives the probability of error, P_e, for no diversity and for dual diversity as a function of doppler spread for a differential quadriphase phase-shift keying signal. (This type of keying is described in 4.3.8.)

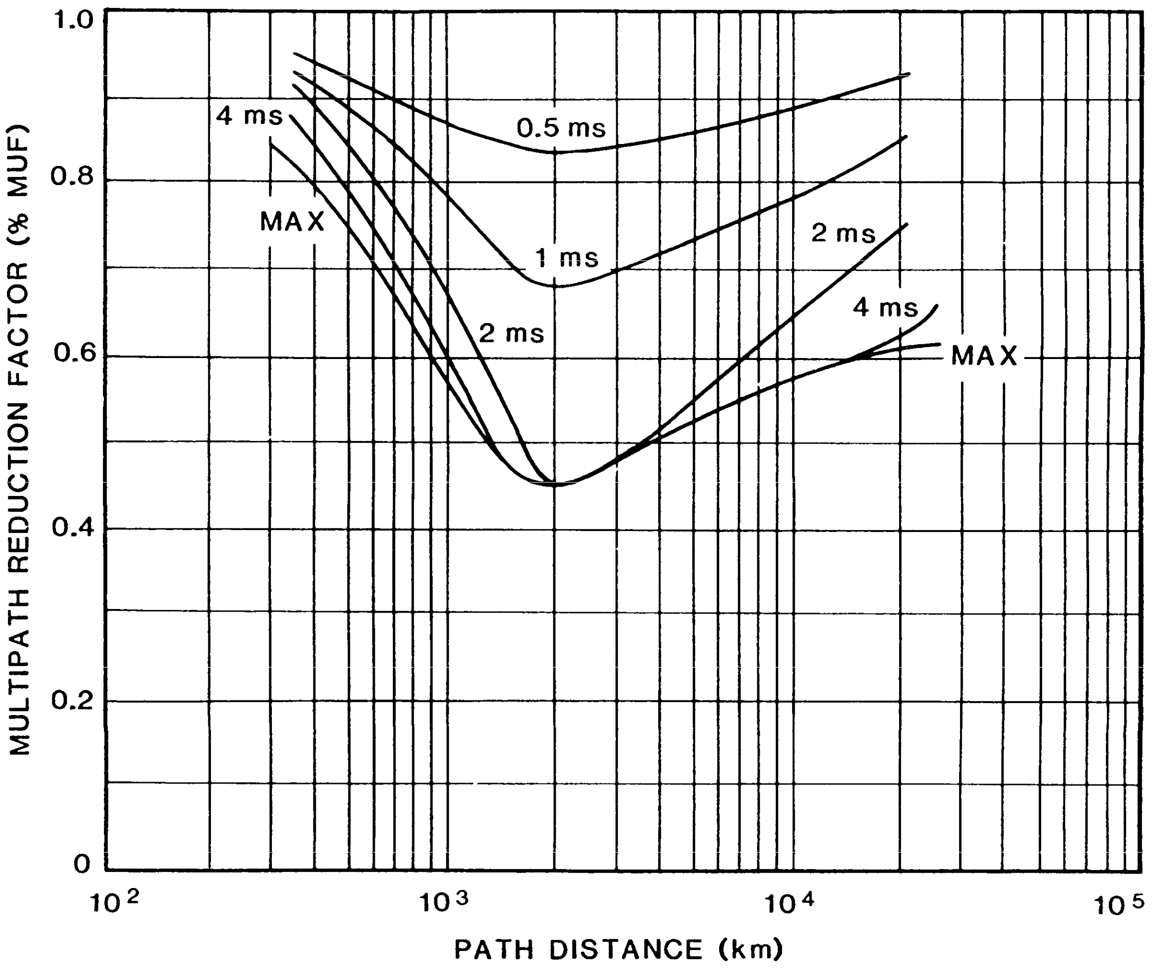


FIGURE 12. Multipath reduction factor.

4.2.3 **Noise.** Noise is the limiting factor in transmitting information by radio signals. In HF radio systems, three sources of noise predominate: man-made, atmospheric, and galactic.

4.2.3.1 **Man-made noise.**

a. Near civilization, man-made noise is the predominant noise component over much of the HF band. It emanates from power lines, industrial machinery, and electrical devices such as relays, voltage regulators, arc-welders, and the ignition systems of internal combustion machines. Consequently, it occurs most strongly in cities and industrial areas. It tends to be cyclic, corresponding to the periodicity of the noise-generating devices; it also tends to vary during the day in accordance with working periods. Man-made noise is less strong in residential areas, and even less significant in rural areas. In areas remote from civilization, it ceases to be a factor. Figure 14 shows the relationship of noise to frequency for the different types of areas. In dense electromagnetic environments of man-made noise, such as may be experienced on ships, the man-made noise levels may exceed those shown for business areas in figure 14.

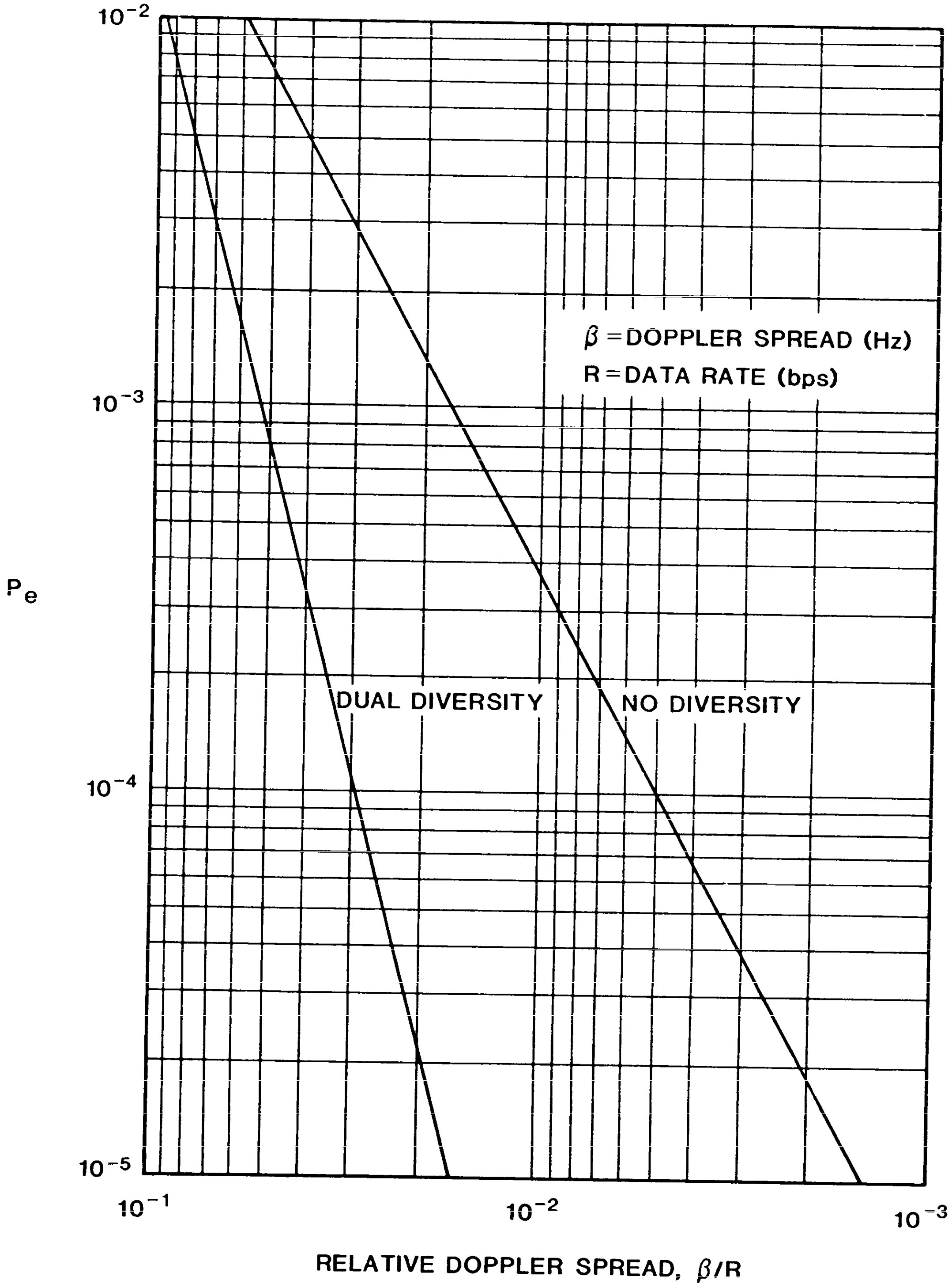


FIGURE 13. Error rate due to doppler spread using DQPSK.

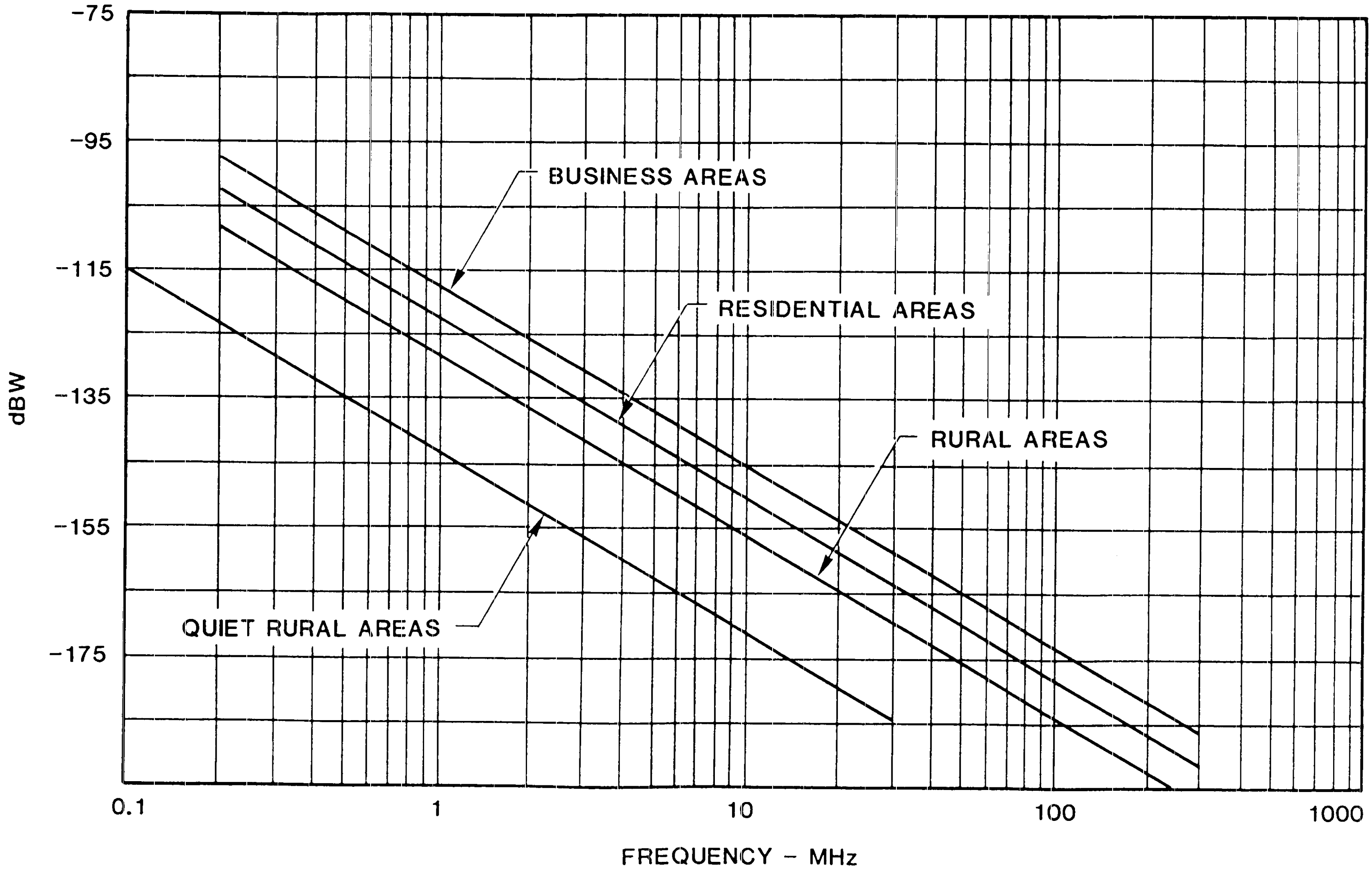


FIGURE 14. Estimates of upper decile values of man-made noise.

b. Deliberate man-made noise known as jamming can prevent information transmission by conventional HF systems. Such noise can be generated by an enemy and transmitted on the operating frequency in the direction of the receiving terminal. Specially designed HF radio systems are required for operation in the presence of severe jamming. (See 4.3.9.)

4.2.3.2 **Atmospheric noise.**

a. Atmospheric noise comes primarily from lightning discharges all over the Earth. The noise from local lightning appears as impulse noise. Atmospheric radio noise is characterized by large, rapid fluctuations, but if averaged over several minutes, the average values are nearly constant during a given hour with variations rarely exceeding ±2 dB except during local thunderstorms or sunrise-sunset. The amplitude of the noise varies approximately inversely with the square of the frequency. It is propagated in all directions similar to normal radio signals.

b. In general, atmospheric noise is greater at night for frequencies from 1 to 5 MHz, because of the long-range nighttime propagation of those frequencies. From 10 to 15 MHz, there is little difference in intensity between day and night. Moreover, the atmospheric noise level is greater in local summer than winter, as may be expected from the relative frequency of thunderstorms. Atmospheric noise becomes progressively less important at the higher latitudes of the temperate zones, because of both the distance from the equatorial sources and the auroral absorption of the propagated waves.

c. Charts showing expected values of atmospheric radio noise worldwide are available for the four seasons of the year and for 4-hour increments of any typical day during a season. The charts are published in Report 322 of the International Radio Consultative Committee (CCIR). NTIA Report 85-173 has updated some of these charts.

4.2.3.3 **Galactic noise.** Galactic noise, also known as cosmic noise, originates in outer space. Its characteristics are similar to thermal, or white, noise. The sources of cosmic noise are distributed unevenly throughout space. For our purposes, they tend to be concentrated in several regions, the principal region being near the center of the Milky Way galaxy. Consequently, for reception on a directional antenna, galactic noise varies from hour to hour and day to day, as the antenna beam intercepts the galactic plane. Galactic noise is relatively insignificant, compared to atmospheric noise, below 20 MHz. From 20 to 30 MHz, galactic noise constitutes a minor noise component at sites having low man-made noise.

4.3 **Modulation and demodulation.**

a. Modulation is the process by which some characteristic of an electromagnetic wave, often called a carrier, is varied in accordance with the instantaneous value or samples of the electrical information signal to be transmitted. Demodulation is the recovery of the electrical information signal from the modulated carrier.

b. In HF radio systems, continuously variable, electrical information signals, such as voice signals, are generally transmitted using a form of amplitude modulation (AM). (In engineering terminology, continuously variable, electrical signals are called analog signals because they are electrically analogous to the physical process, such as speech sound waves, that they represent.) Single sideband (SSB) is the most frequently used form of AM, due to its efficient use of transmitter power output. A variant of SSB called AM equivalent (AME) is also used.

Up to four voice signals can be transmitted simultaneously over a single HF radio channel by a derivation of SSB known as independent sideband (ISB). A form of frequency modulation (FM), known as narrowband FM (NBFM), can be used in some cases to transmit continuously variable signals.

c. In contrast to continuously variable signals, digital signals are discontinuous. They carry digital data; that is, information that is represented by a code consisting of a sequence of discrete elements. Digital data is produced by teletypewriters, digital facsimile equipment, and computer terminals, among other sources. Digital signals are generally transmitted by forms of modulation known as frequency-shift keying (FSK) and phase-shift keying (PSK). In special cases, an historically early form of digital signaling, known as interrupted continuous wave (ICW), is used.

d. Closely related to modulation is the class of signal processing techniques known as spread spectrum. Of the several spread spectrum techniques in use, only frequency hopping has found some application in HF radio systems.

4.3.1 **AM.**

a. AM is produced when a modulating, information signal is mixed with a carrier signal. The mixing process is also called heterodyning. The modulating signal is the electrical representation of the information to be transmitted. The carrier signal is a single frequency much higher than the range of frequencies in the modulating signal.

b. If the modulating signal is a single frequency — a sine wave — the output of the mixing process includes two new frequencies in addition to the injected frequencies (carrier and modulating sine wave). One is the carrier frequency plus the modulating signal frequency; the other, the carrier frequency minus the modulating signal frequency. For example, if the modulating signal is 1 kHz and the carrier signal is 500 kHz, mixing produces the two new signals, 501 kHz and 499 kHz.

c. If the modulating signal is a band of frequencies, as in a voice channel, the frequency components of the signal form bands of sum and difference frequencies. The band of sum frequencies is above the carrier frequency and is called the upper sideband (USB). The band of difference frequencies is below the carrier frequency and is called the lower sideband (LSB). To illustrate, assume a nominal 3-kHz voice channel (300 to 3000 Hz). If it is mixed with a 500-kHz carrier signal, the USB will extend from 500.3 kHz to 503.0 kHz. The LSB will extend from 497.0 kHz to 499.7 kHz. Note that the frequency relationships in the LSB are the inverse of those in the USB. That is, the lowest frequency in the modulating signal, 300 Hz, is the highest frequency in the LSB, 499.7 kHz, while the highest modulating frequency, 3000 Hz, is the lowest LSB frequency, 497.0 kHz. Thus, the LSB is referred to as inverted, while the USB is termed normal or erect. The transmitted AM signal spectrum is illustrated in figure 15. It should be noted with regard to the mixed output spectrum that the original modulating signal, although present at the output, is attenuated to the point of insignificance by the coupling circuitry.

d. The simplest method for demodulating the AM signal upon reception involves rectification of the received carrier followed by detection of the envelope of the carrier (low-pass filtering of the rectified signal in a resistance-capacitance (RC) network). The process is generally referred to simply as envelope detection. Figure 16 illustrates the waveforms involved in AM modulation and envelope detection.

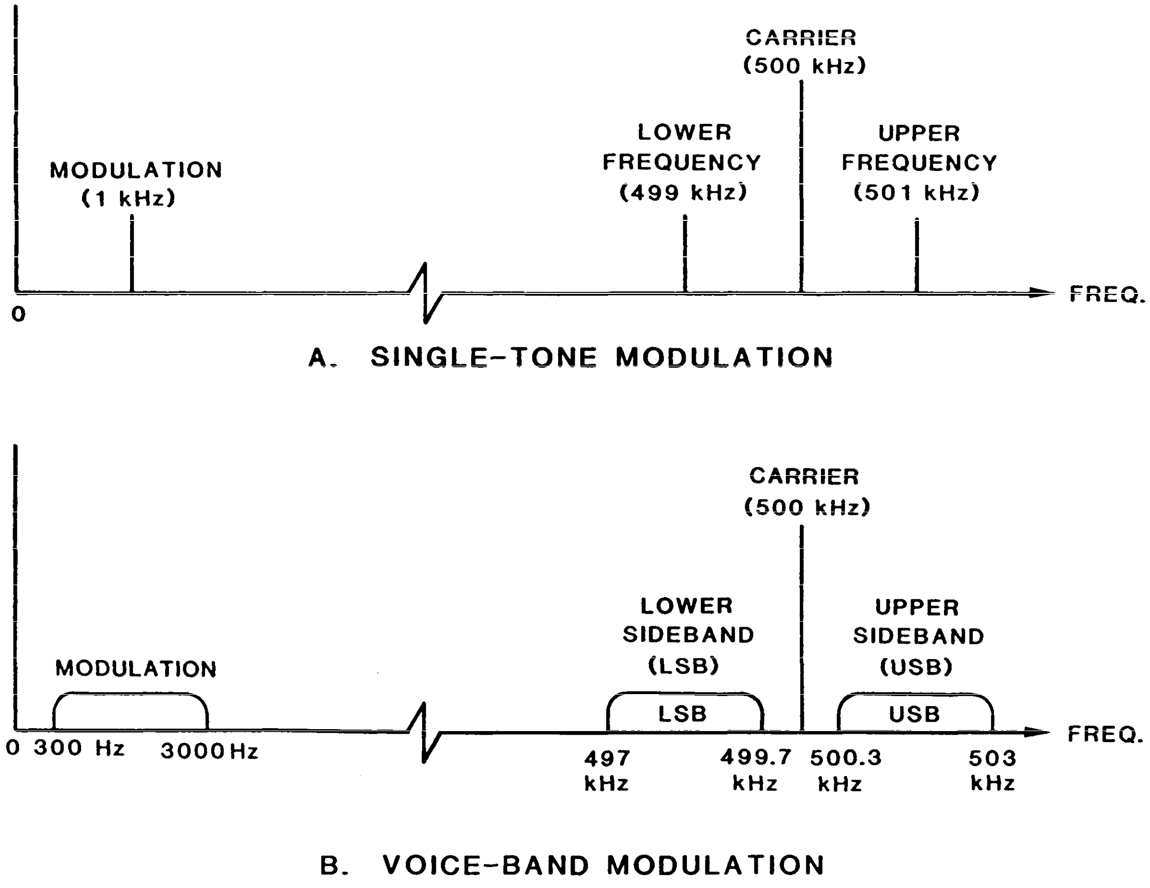
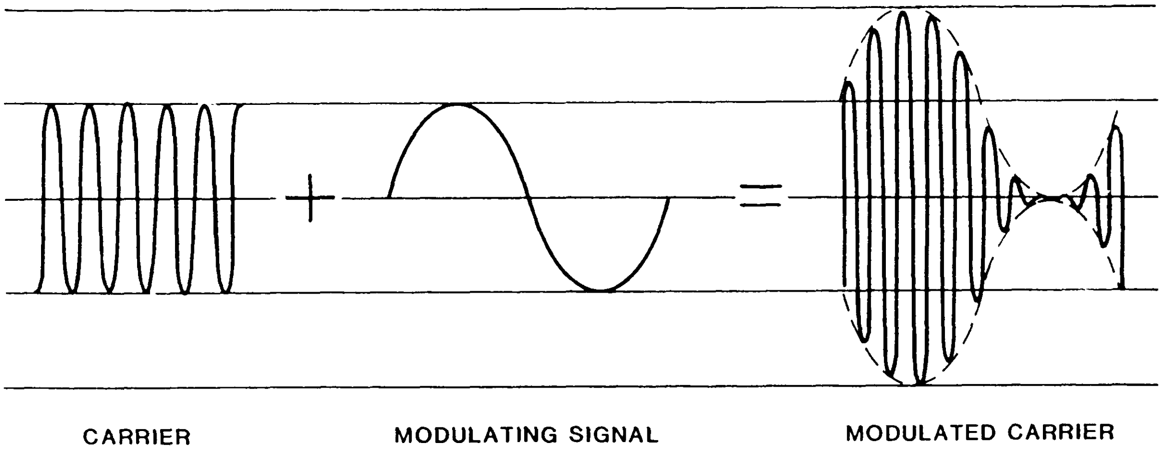


FIGURE 15. AM signal spectrum.

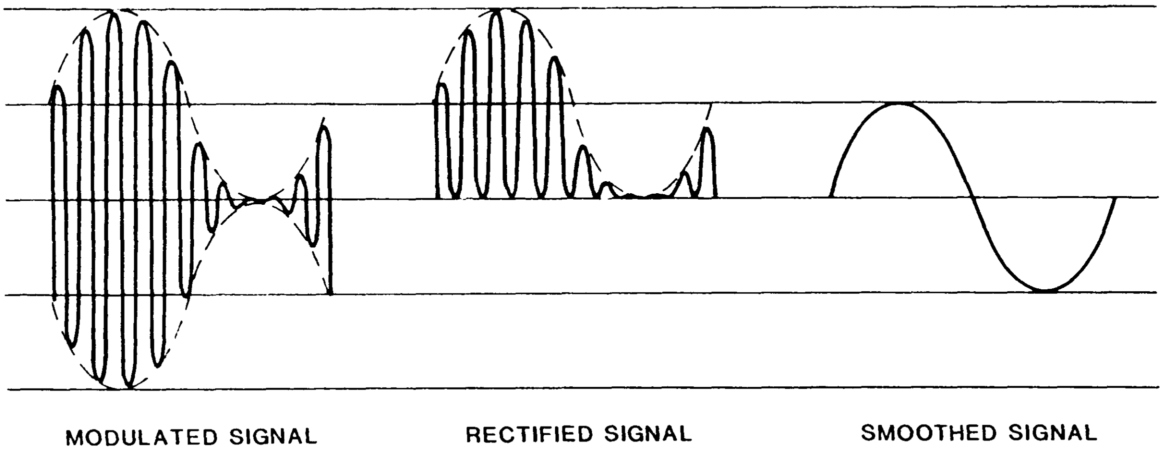
4.3.2 **SSB.**

a. The upper and lower sidebands produced in AM convey the identical information. The carrier itself conveys no information, other than its presence, although it is needed for the envelope detection process. SSB transmission concentrates the available signal power in one sideband. The other sideband and the carrier are removed before transmission. The unwanted sideband is removed by filtering. The carrier is suppressed both through the use of a balanced modulator and the sideband filter.

b. Demodulation of an SSB signal requires carrier reinsertion at the demodulator. The reinserted carrier is locally generated. Mixing the incoming SSB signal with the reinserted carrier again produces sum and difference frequencies. In the case of a voice channel, the band of difference frequencies is the original channel band. The band of sum frequencies lies above a frequency that is twice the carrier frequency. To illustrate, again using a 1-kHz modulating tone and a 500-kHz carrier, one side frequency resulting from the modulation is 501 kHz. Mixing it with a 500-kHz carrier upon reception produces a 1-kHz difference frequency and a 1001-kHz sum frequency. The sum frequency or frequency band from demodulation is readily filtered out, leaving the difference frequency or frequency band. This type of demodulation, employing mixing and filtering, is referred to as product detection. SSB modulation and demodulation are illustrated in figure 17.



A. MODULATION

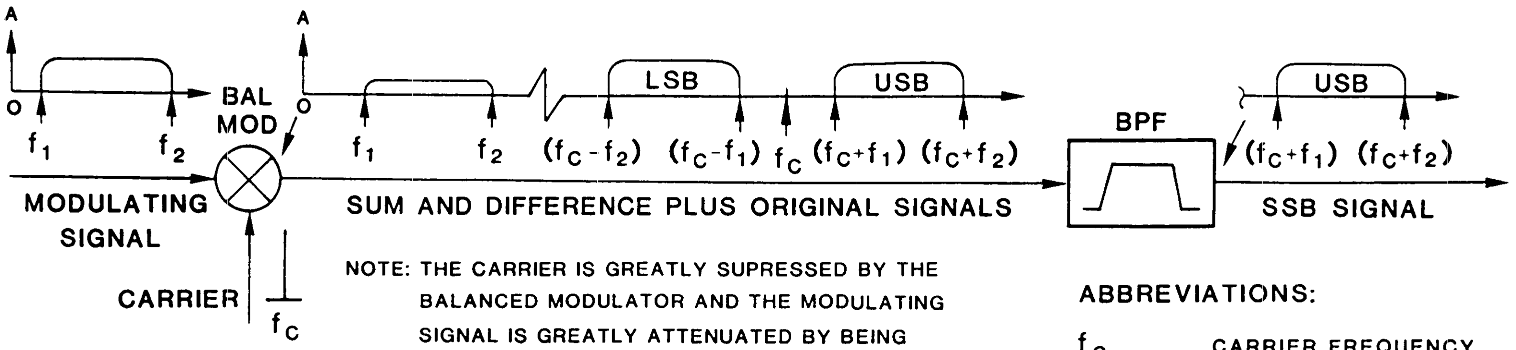


B. ENVELOPE DETECTION DEMODULATION

FIGURE 16. AM modulation and demodulation waveforms.

4.3.3 ISB.

a. An ISB signal contains both upper and lower sidebands. In contrast to AM, the sidebands are formed independently of each other, using SSB modulation, to carry different information signals. In military ISB systems, each sideband is nominally 6 kHz wide and carries two 3-kHz

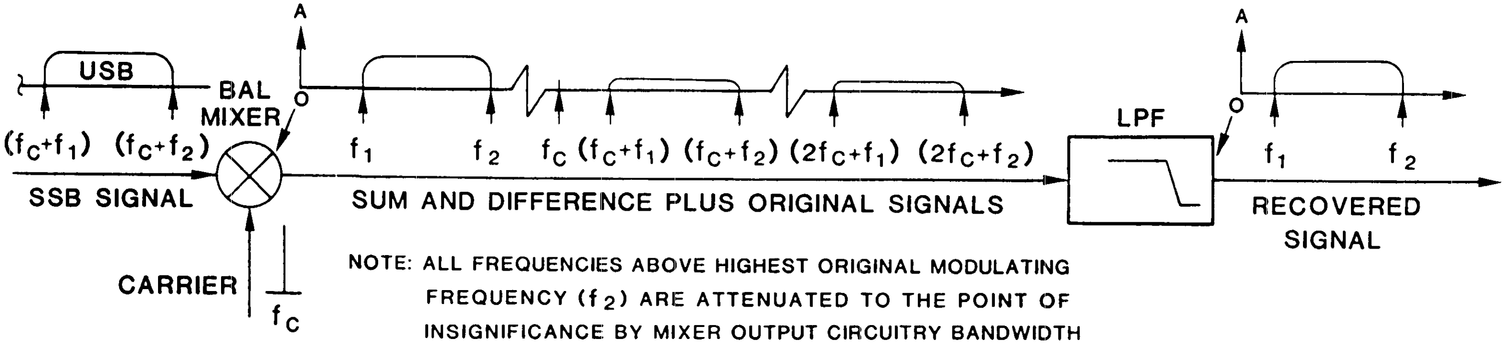


NOTE: THE CARRIER IS GREATLY SUPRESSED BY THE BALANCED MODULATOR AND THE MODULATING SIGNAL IS GREATLY ATTENUATED BY BEING OUTSIDE THE BANDWIDTH OF THE MODULATOR OUTPUT COUPLING CIRCUIT.

A. MODULATION PROCESS PRODUCING USB.

ABBREVIATIONS:

f_C	CARRIER FREQUENCY
f_1	LOWEST MODULATING FREQUENCY
f_2	HIGHEST MODULATING FREQUENCY
LSB/USB	LOWER/UPPER SIDEBAND
BPF/LPF	BANDPASS/LOWPASS FILTER
BAL MOD	BALANCED MODULATOR
A	RELATIVE AMPLITUDE



NOTE: ALL FREQUENCIES ABOVE HIGHEST ORIGINAL MODULATING FREQUENCY (f_2) ARE ATTENUATED TO THE POINT OF INSIGNIFICANCE BY MIXER OUTPUT CIRCUITRY BANDWIDTH AND LOWPASS FILTER.

B. DEMODULATION PROCESS

FIGURE 17. SSB modulation and demodulation.

channels. By convention, the upper 6-kHz sideband is referred to as the A side and the lower sideband, the B side. The 3-kHz channels closest to the carrier are called inboard channels; the others, outboard channels. Thus, Channels A1 and B1 are inboard channels, while A2 and B2 are outboard channels. Figure 18 illustrates the ISB signal spectrum. The 3-kHz channels may carry voice signals or digital data signals. Generally, one of the 3-kHz channels is assigned to carry up to 16 teletypewriter signals in a voice frequency carrier telegraph (VFCT) scheme described in 4.7.1.

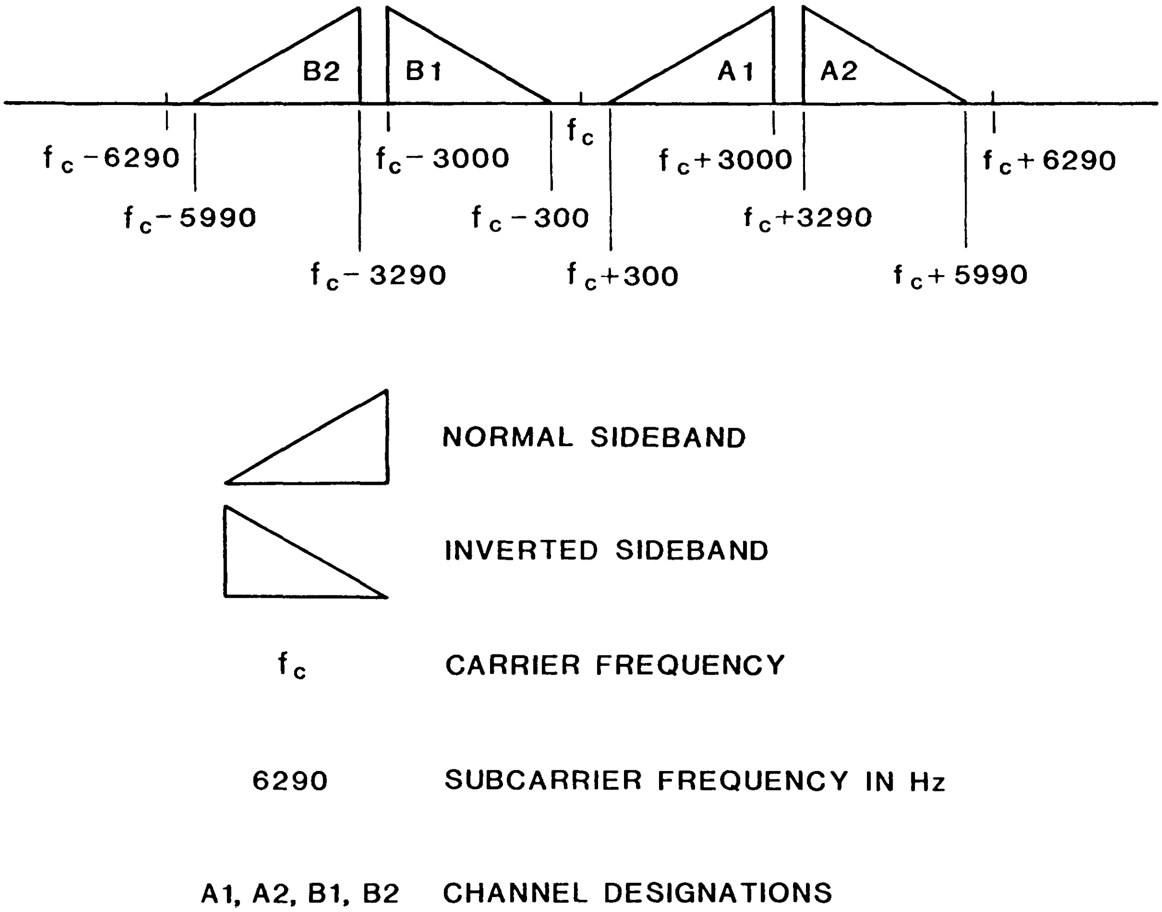


FIGURE 18. Four-channel ISB signal spectrum.

b. In one method of forming a 4-channel ISB signal, a 2-channel frequency division multiplexer, similar to a 2-channel ISB modulator, combines two 3-kHz channels, A1 and A2, to form a single, composite, 6-kHz channel, as shown in figure 19. The multiplexer passes the inboard channel, A1, without alteration. It mixes the outboard channel, A2, with a subcarrier (6290 Hz) and by filtering passes the LSB. Thus, the composite signal consists of Channel A1 in its original form and Channel A2 as an inverted LSB of the modulated subcarrier. A separate 2-channel multiplexer similarly combines Channels B1 and B2 in a

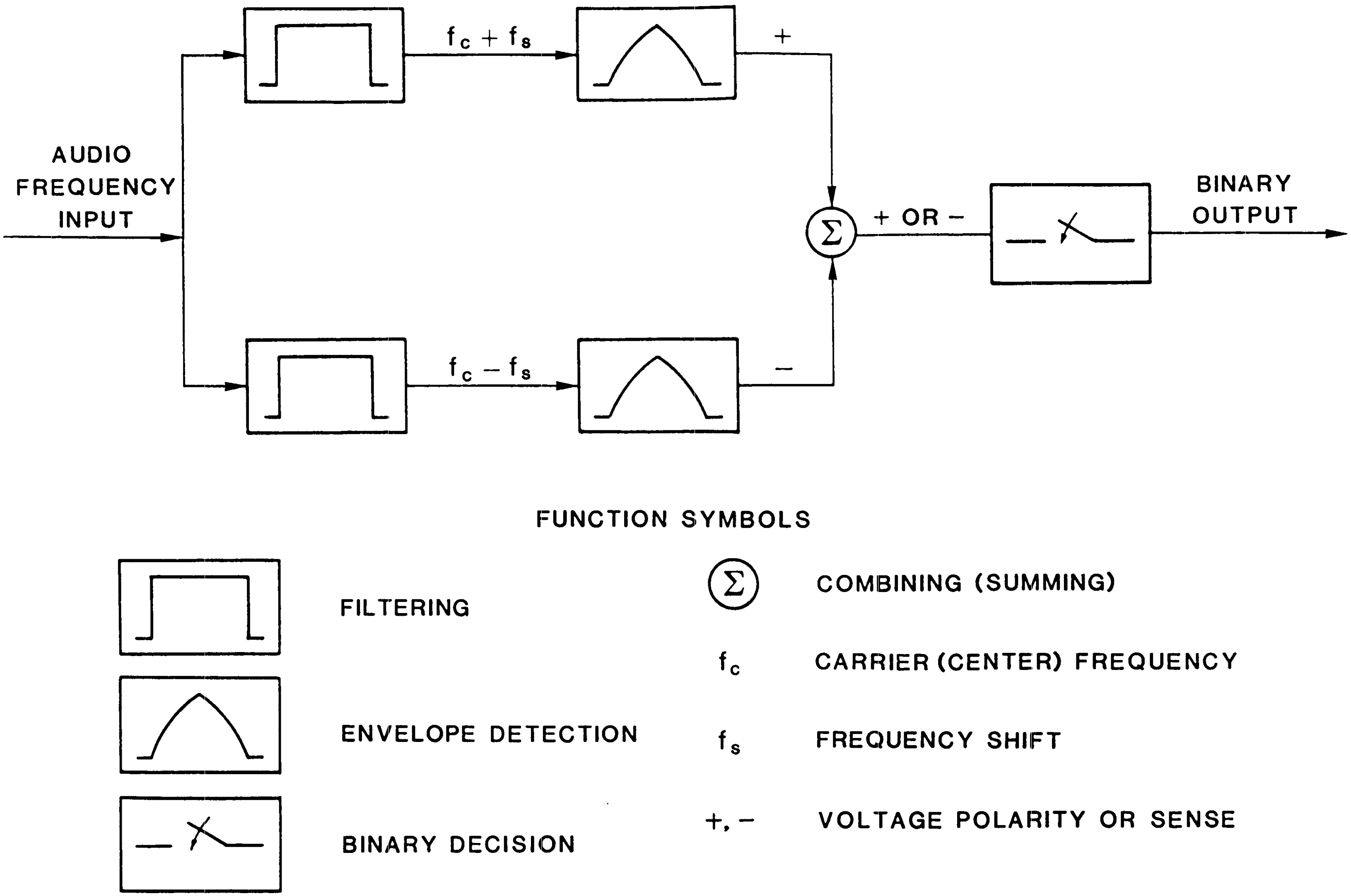


FIGURE 19. ISB modulation using two-channel multiplexing.

composite 6-kHz channel. Each of the composite channel signals modulates the main carrier in separate SSB modulators. The A-channel modulator produces a USB signal spectrum; the B-channel modulator, an LSB signal spectrum. The two spectra are brought together in a combiner to form the ISB output channel. As in single channel SSB modulation, the use of balanced modulators effectively suppresses the carrier and subcarriers.

c. Another method of forming a 4-channel ISB signal multiplexes the four signals in one stage. Mixing Channel A1 with the main carrier in a balanced modulator, and appropriate filtering, forms a 3-kHz USB of the main carrier. Similarly, Channel B1 forms a 3-kHz LSB using the same carrier. Channel A2 modulates a subcarrier, at the main carrier frequency plus 6290 Hz, and the inverted LSB is retained. Channel B2 modulates another subcarrier, at the main carrier frequency minus 6290 Hz, and the normal USB is retained. The four sidebands are then combined into a composite 12-kHz signal. Since both methods form identical ISB formats, they are compatible.

4.3.4 **AME.** AME is SSB with a reduced carrier transmitted. While AME is less efficient in the use of transmitter power output than SSB, it permits demodulation by an envelope detector. It is not necessary to synthesize and reinsert a carrier.

4.3.5 NBFM.

a. In basic frequency modulation (FM), the frequency of the rf carrier, rather than the amplitude, is varied in accordance with the amplitude of the modulating signal. FM demodulation utilizes circuitry known as a limiter-discriminator. The limiter function removes amplitude variations in the received signal that have been introduced during propagation or caused by electrical interference. Limiting is required because discriminators respond to both amplitude and frequency variations. The discriminator converts the frequency variations back into the amplitude variations of the information signal. Limiter-discriminator demodulation of FM provides an improvement over AM with regard to performance in signal-fading conditions and electrically noisy environments. It provides this improvement, however, at the cost of increased transmission bandwidth. FM modulation and demodulation waveforms are shown in figure 20.

b. Conventional FM requires many times the bandwidth of AM for transmission. An AM signal, as explained in 4.3.1 has two distinct sidebands. The bandwidth required for its transmission, then, is twice the highest modulating frequency. In the case of a nominal voice channel, with a 3-kHz top frequency, the required bandwidth is 6 kHz. FM, on the other hand, produces an infinite number of sidebands. The transmitted energy, however, is not uniformly distributed among the sidebands, so that not all of them are necessary, or even significant. The fact remains, though, that the more sidebands received, the greater the FM improvement.

c. The transmission bandwidth that is supported by HF radio propagation via the ionosphere is severely limited by multipath propagation (see 4.2.2.10). NBFM is a compromise between the wide bandwidth requirement of conventional FM and the limitations of the propagation medium. It provides a modest FM improvement using a 15- or 16-kHz bandwidth. (NBFM as defined by the Federal Communications Commission (FCC) has a bandwidth that does not exceed that of double-sideband (DSB) AM and, consequently, provides no inherent SNR improvement over AM.)

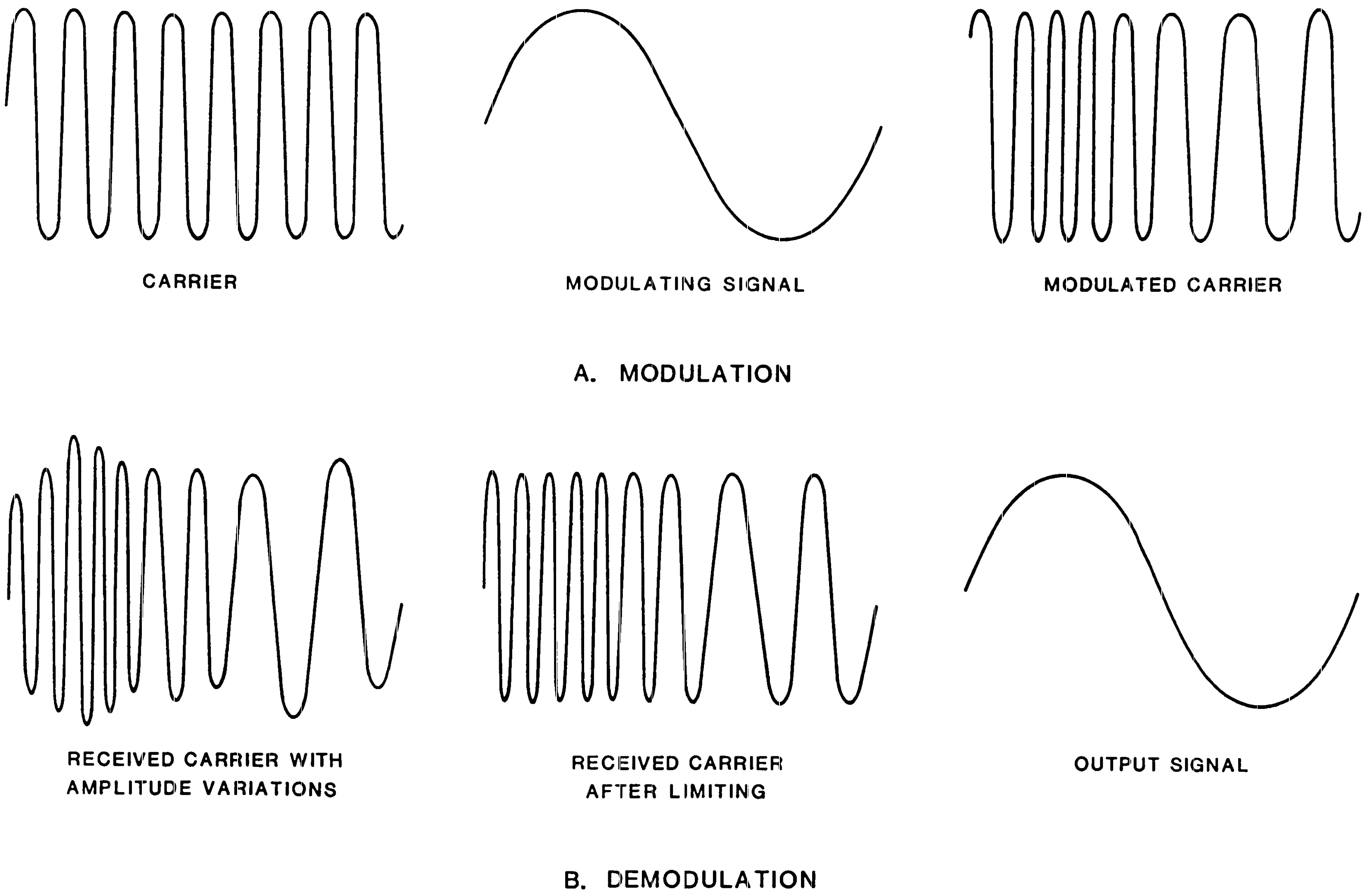


FIGURE 20. FM modulation and demodulation waveforms.

4.3.6 **ICW.**

a. In the early days of radio, a telegraph key was used to switch the rf carrier on and off in accordance with a telegraph code. Since the rf was a continuous wave when it was on, this form of transmission was called interrupted continuous wave, or ICW. Also, it was commonly referred to simply as continuous wave (CW).

b. Since the rf could not be heard, early radiotelegraph receivers used a beat frequency oscillator (BFO) to produce an audible tone. The BFO produced a frequency that was offset from the radio frequency by the frequency of an audio tone, say 1 kHz. Mixing the BFO frequency with the incoming rf then produced a 1-kHz, audible difference frequency. A major problem with the simple BFO circuitry was that the audible signal would be severely distorted if the received signal were at a higher level than the BFO signal.

c. The SSB product detector incorporated in modern receivers eliminates the distortion problems encountered with the BFO. By providing a telegraph keying option, most tactical equipments have a backup ICW communications capability. ICW is also used in a form of transmission known as burst communications, in which telegraph code is recorded in advance and transmitted in short, high-speed bursts, the purpose being to evade enemy interception of the transmissions. It is apparent that ICW is highly susceptible to electrical interference and amplitude variations such as those produced by signal-fading. In non-automated ICW systems, throughput is highly dependent on the level of operator training and experience.

d. A variant of ICW, known as modulated continuous wave (MCW), eliminates the need for a receiver BFO. In MCW, the rf carrier is modulated with an audio tone. Thus, on reception and demodulation by an envelope detector, the audio tone is recovered. On transmission, the tone is keyed on and off by the digital information signal. The recovered audio tone, then, is present or absent in accordance with the keying.

4.3.7 **FSK.**

a. Modulation is generally referred to as "keying" in digital data (or teletypewriter code) transmission. This is because some property of the carrier is caused to vary, or shift, in response to keying by discrete-state digital input signals. In FSK, it is the frequency of the carrier that is shifted. Assuming a binary digital input signal, such as the marks and spaces of teletypewriter code or the 0's and 1's of digital data, the output frequency is shifted between two discrete values.

b. There are two ways to refer to the magnitude of the frequency shift. In one, the shift is considered to be between a hypothetical carrier or center frequency and the shifted frequency on either side. For example, ±42.5 Hz, ±85 Hz, and ±425 Hz are references to commonly used frequency shifts. Alternatively, the shift is considered to be the total frequency span between the two shifted frequencies. Thus, the frequency shifts in the example above become 85 Hz, 170 Hz, and 850 Hz, respectively. Figure 21 gives both a waveform (time domain) and a spectral (frequency domain) representation of FSK.

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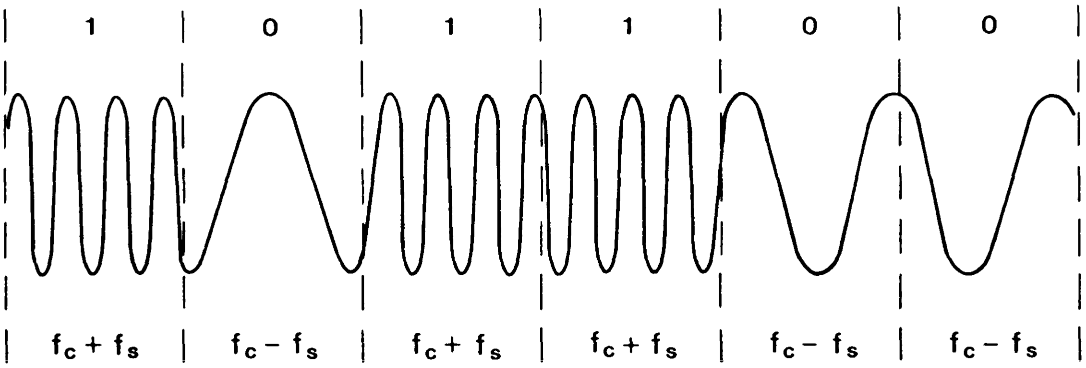
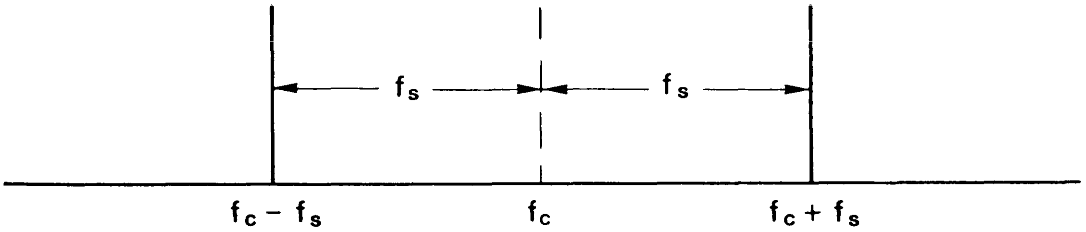


A. WAVEFORM REPRESENTATION



B. SPECTRAL REPRESENTATION

1, 0	BINARY STATES
f_c	CARRIER FREQUENCY
f_s	FREQUENCY SHIFT (TO EACH SIDE OF CARRIER)

FIGURE 21. Frequency shift keying.

c. In older equipment, a real carrier was shifted in frequency to produce FSK. New equipment, employing SSB modulation, uses a compatible system called audio frequency shift keying (AFSK). In this system, two audio tones which differ from each other by the required frequency shift are applied in accordance with the keying pattern to the SSB transmitter audio input.

d. A common method of demodulating FSK signals uses two bandpass filters. This FSK demodulation takes place at audio frequencies, after conventional frequency translation and amplification. The center frequency of one filter is tuned to one frequency of the FSK pair;

the center frequency of the other filter, to the other frequency. Each filter is followed by a separate envelope detector. When a signal of one frequency of the FSK pair is detected, a positive voltage is sent through a combiner to a decision device, such as a polar relay. If the other frequency is detected, a negative voltage is sent. The decision device responds to the polarity of the input voltage to produce an output voltage that represents a binary state. That is, if the input voltage is positive, the device outputs one binary state; if negative, the other. This method, referred to as the twin-filter method, is illustrated in figure 22.

e. Another FSK demodulation method uses a limiter-discriminator in conjunction with a level-sensing decision circuit. Generally, the discriminator is fed by an intermediate frequency (IF) or audio frequency (AF) signal produced by conventional frequency translation. A limiter keeps the amplitude of the signal at a constant level for input to the discriminator. The output voltage of the discriminator assumes one of two levels, depending upon the frequency (one of the FSK pair) at its input. When the output voltage exceeds a predetermined threshold level, the decision circuit outputs a voltage representing one binary state. When the output voltage is below the threshold, the circuit outputs a voltage representing the other binary state. The limiter-discriminator method of FSK demodulation is illustrated in figure 23. A ratio detector, which is relatively insensitive to amplitude variations in the received signal, is sometimes used instead of the limiter-discriminator combination. Detailed descriptions of both types of demodulators can be found in a number of texts.

4.3.8 **PSK.**

a. In PSK, the phase of the carrier is caused to shift in response to digital keying. Absence of a phase shift represents one binary state and presence of a phase shift, usually 180°, the other, as shown in figure 24. Such an arrangement is sometimes referred to as biphase PSK to distinguish it from a variant called quadriphase PSK (QPSK). Limiter-discriminator demodulation converts the phase shifts into voltage levels representing the binary states. QPSK uses phase shifts of 0°, 90°, 180°, and 270°. Each phase represents a different pair of bits, as shown in figure 25. The possible bit pairs, known as dibits, are (1,1), (1,0), (0,1), and (0,0). Relative to biphase PSK, QPSK enables the transmission of a higher bit rate within the same bandwidth or transmission of the same bit rate in a reduced bandwidth. The advantage is gained at the expense of an increased signal-to-noise ratio requirement for a given data error rate.

b. Without a local carrier synchronized in phase with the transmitter carrier, the receiver has no "sense" of absolute phase. Therefore, most PSK systems in HF applications use a scheme known as differential encoding, in which encoding and decoding are based on changes in phase (see FM-11-486-24). Systems of this type are called differential PSK (DPSK) systems. To illustrate, using biphase PSK, if the carrier phase remains the same in one interval as it was in the preceding interval, the current interval is interpreted as a binary 1. If the carrier phase is different from that of the preceding interval, it is interpreted as a binary 0. To implement this scheme, the binary information must be differentially encoded. Figure 26 illustrates a differential code in which a negative-going transition (binary 1 to binary 0) in the input bit stream produces a transition in the output bit stream. A positive-going transition (binary 0 to binary 1) in the input bit stream does not produce a transition in the output bit stream. Also, a binary 0 followed by a binary 0 in the input produces a transition in the output; a binary 1 followed by a binary 1 does not.

following information

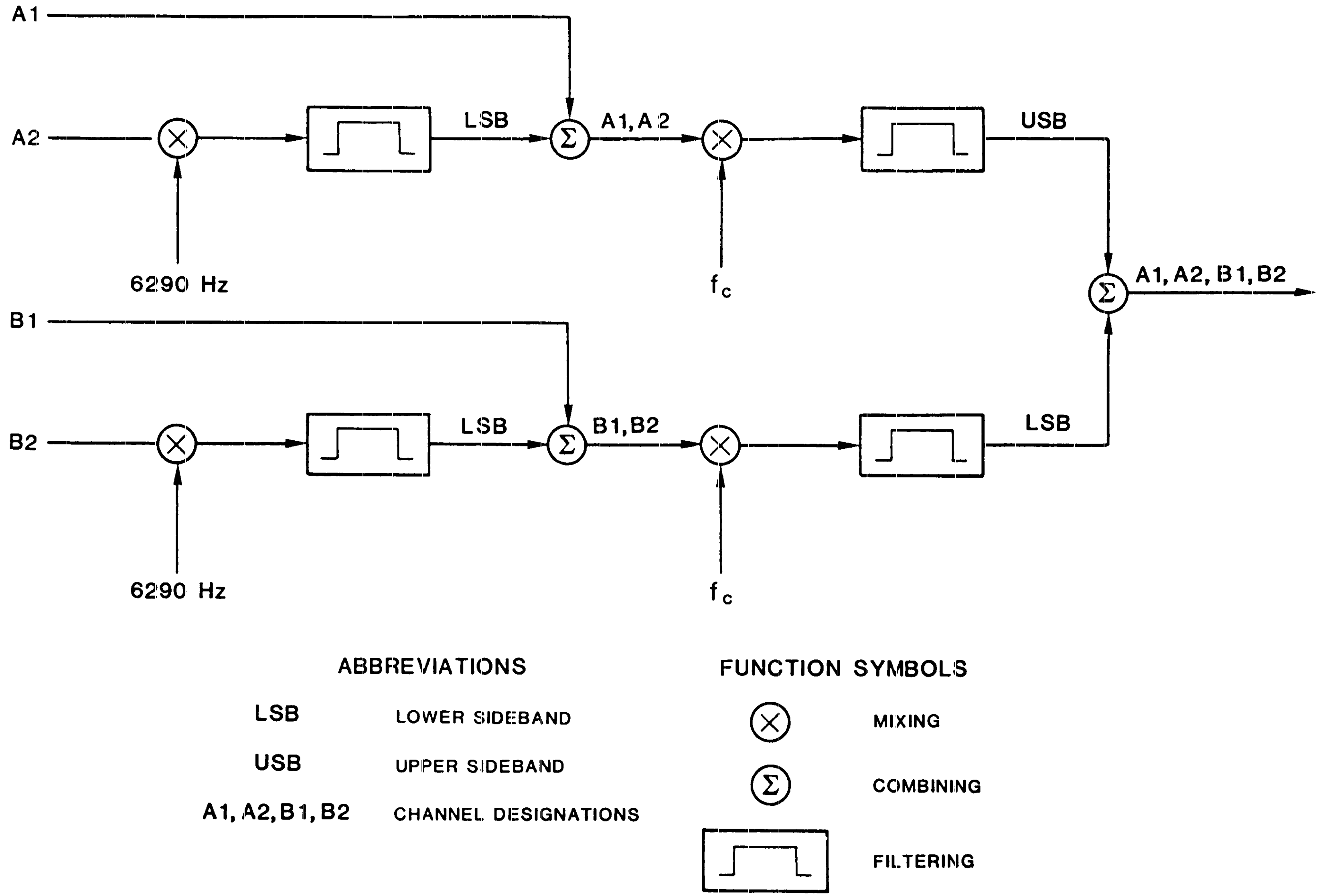


FIGURE 22. Twin-filter demodulation of FSK signal.

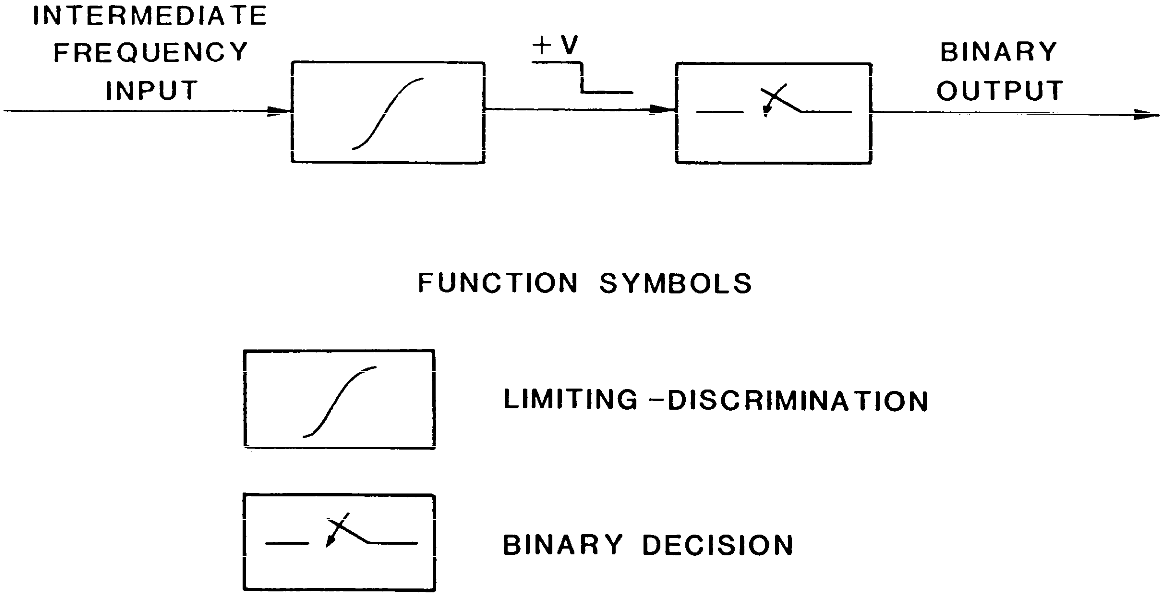


FIGURE 23. Limiter-discriminator demodulation of FSK signal.

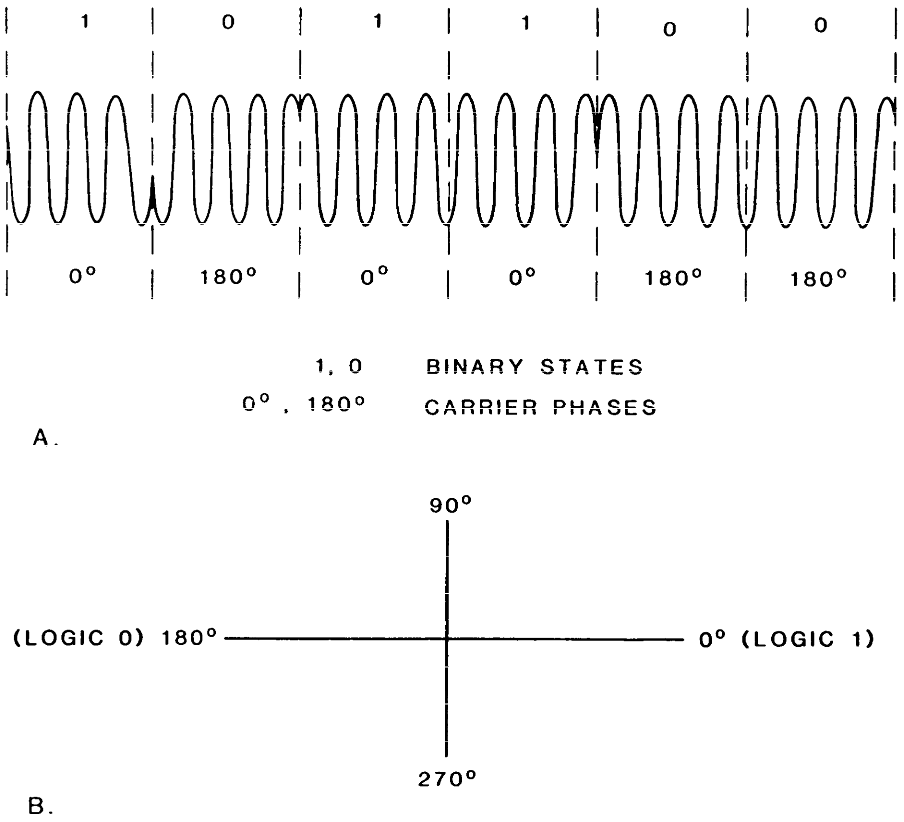


FIGURE 24. Phase-shift keying waveform.

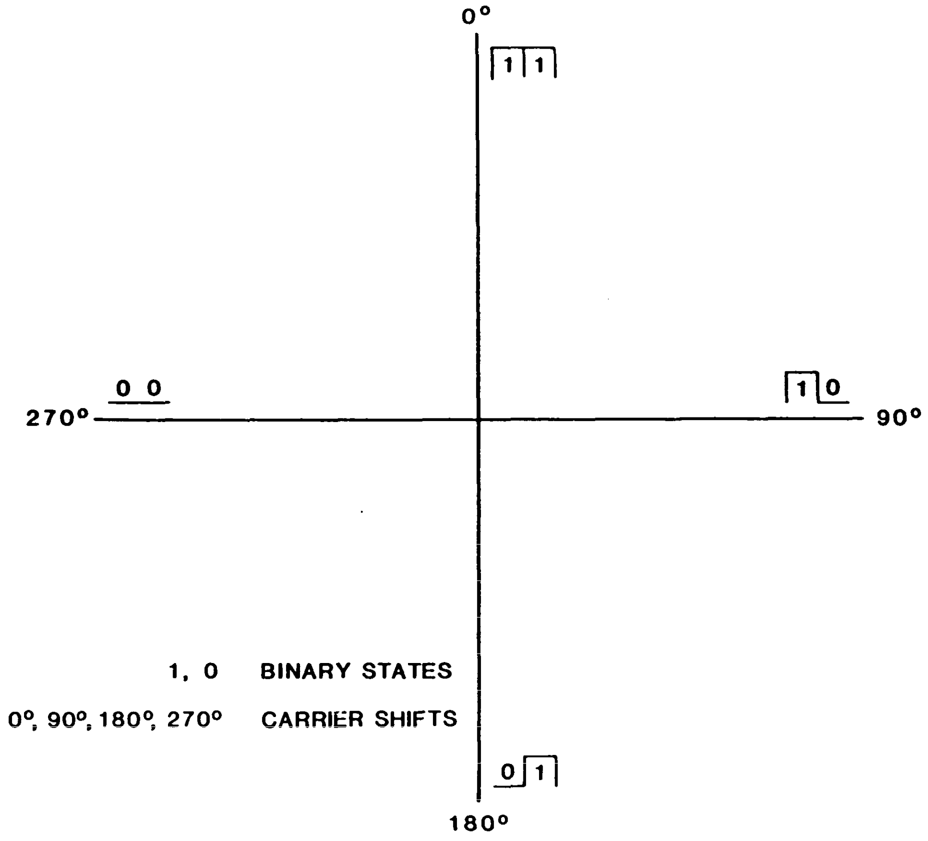


FIGURE 25. Quadriphase PSK scheme.

INPUT SIGNAL		1	0	1	1	0	0	0	1	1
DIFFERENTIALLY ENCODED SIGNAL	1[a]	1	0	0	0	1	0	1	1	1
TRANSMITTED PHASE	0°	0°	180°	180°	180°	0°	180°	0°	0°	0°
OUTPUT SIGNAL		1	0	1	1	0	0	0	1	1

a REFERENCE BIT TO START ENCODING SEQUENCE

1, 0 BINARY STATES

0 , 180° CARRIER PHASES

FIGURE 26. Encoding/decoding scheme for DPSK.

4.3.9 **Frequency hopping.**

a. Frequency hopping is one of several bandwidth-spreading techniques for producing signals known as spread spectrum signals. Such signals have high resistance to jamming and a low probability of interception. Of the available techniques, frequency hopping is the most commonly used in HF radio systems.

b. In frequency hopping, the spread spectrum signal is formed by shifting the transmitted frequency in discrete increments in some predetermined order. The predetermined order is generally the result of a pseudorandom code sequence. Pseudorandom means only seemingly random. The sequence is actually repeatable and is repeated upon reception to despread the signal. In spread spectrum usage, the signal corresponding to a pseudorandom code is called a pseudorandom signal.

c. The digital data is embedded in the transmitted spread spectrum signal in one of two ways. The most common method is to add the digital data signal to the pseudorandom signal, using modulo 2 addition. (The rules of modulo 2 arithmetic are given in appendix D.) The resulting signal then modulates the carrier. In this case, modulation means that the transmitted frequency is selected in accordance with the sequence of binary states in the bit stream of the modulo 2-added signal. That is, the first binary state causes a frequency, f_1, to be transmitted; a change in state, f_2; the next change in state, f_3; and so on. This scheme is diagrammed in figure 27A.

d. In the demodulator on the receiving end, a pseudorandom signal identical to that used on the transmitting end keys an identical sequence of frequencies, with one difference. The frequencies are offset by a set amount such that when each frequency is mixed with its transmitted counterpart, the difference frequency from the mixing process is another carrier frequency. This second carrier frequency is generally taken as an intermediate frequency (IF). (An IF is an intermediate carrier frequency for use in a frequency converter stage of a transmitter or receiver.) (See 4.4.1 and 4.5.2.) Thus, $f_1 - (f_1 + f_{IF}) = f_{IF}$, and $f_2 - (f_2 + f_{IF}) = f_{IF}$, and so on. It can be seen that if the pseudorandom signal, without the addition of the digital data signal, was transmitted, the result upon demodulation would be a constant frequency at IF. Addition of the digital data signal, however, causes the frequency shifts to occur at times other than those dictated by the pseudorandom signal. The shifts occur in accordance with the sequence of binary state changes in the modulo 2-added signal. Thus, at a given bit interval, the transmitted (and hence, received) frequency may not be the same as the frequency generated by the demodulator pseudorandom signal. In this case, the difference frequency will not be the IF, but some other frequency outside the passband of the demodulator. For example, assume that f_7 is transmitted at a time when the pseudorandom signal to the demodulator is f_8. Then, $f_7 - (f_8 + f_{IF}) \neq f_{IF}$, and the demodulator will produce no output. In this way, the IF will be turned on and off in a sequence indicating the binary states of the original digital data signal. This is illustrated in figure 27B. The recovery of the carrier signal from the spread spectrum signal is referred to as despreading or demapping.

e. If the method is used in which the digital data signal modulates the carrier before spreading by the pseudorandom signal, the carrier is first shifted in frequency (or phase) by the data signal. The shift may be biphase or m-ary. (M-ary means multivalued.) The modulated carrier is then shifted in frequency in accordance with the binary pattern of the pseudorandom signal. Assuming binary FSK modulation by the digital data signal for ease of under-standing, one binary state is represented by no carrier shift; the other by a predetermined shift. Then, modulation by the pseudorandom signal results in the predetermined frequency shift for one binary state and the predetermined shift plus the binary FSK shift for the other state. On mixing with the pseudorandom-determined frequencies in the demodulator, two IF signals are produced, one representing each binary state. This is illustrated in figure 28.

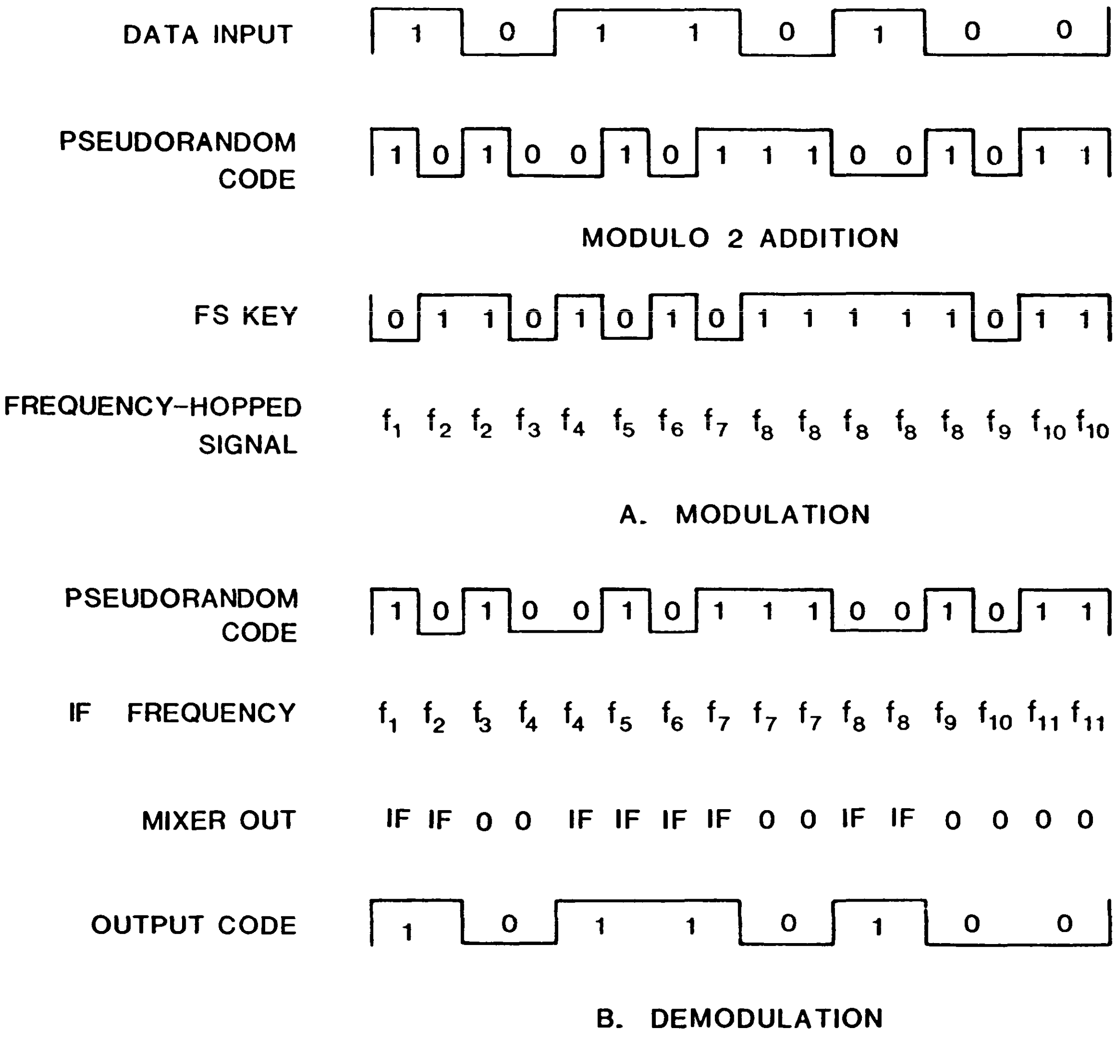
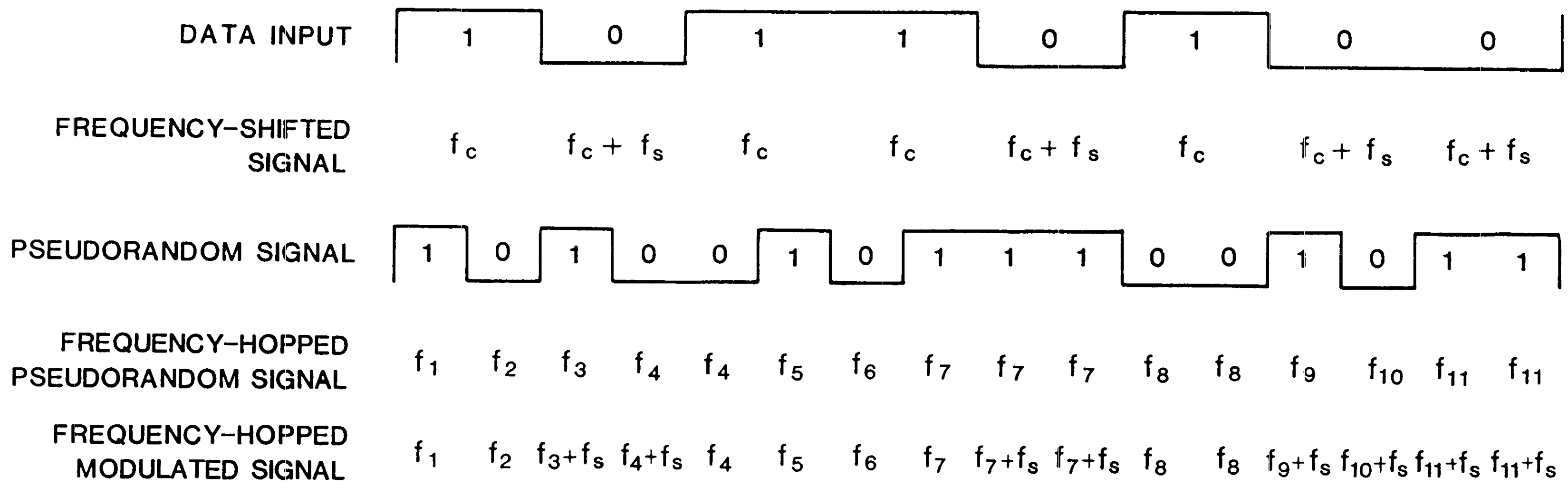
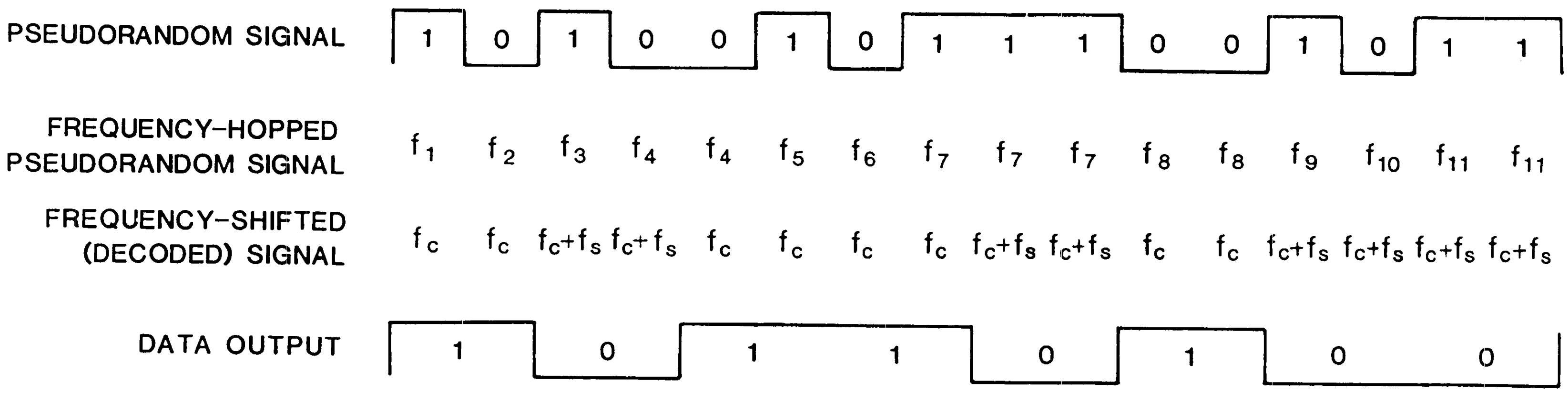


FIGURE 27. Frequency hopping using modulo 2 addition of data signal and pseudorandom signal.

4.4 **HF transmitters.** Most modern HF transmitters are capable of operation with several types of modulation, either directly or through the use of special optional units and modems. Frequency hopping and adaptive functions (see 4.3.9) require specially designed transmitting systems. Basically, all transmitters consist of an exciter and one or more power amplifiers.



A. MODULATION



B. DEMODULATION

FIGURE 28. Frequency hopping using direct modulation of carrier by data signal.

4.4.1 Exciter.

a. The term exciter encompasses the signal input stage, the modulator, frequency translation stages, and a postselector. An rf carrier generator provides required carrier injection frequencies for the modulator and frequency translation stages. The sequence of stages is shown in figure 29.

b. The input stage provides the required electrical interface with the modulating signal. It provides peak limiting on voice signals and raises them to the proper level for input to the modulator. For data signals, the input stage provides the required levels and wave shaping for input to the modulator.

c. The modulator impresses the information signal on a carrier frequency by one of the processes described in 4.3. FSK and PSK signals may originate in external modems and be routed directly to the frequency translation stage.

d. To provide a spectrally pure output signal, frequency translation to the final frequency may require more than one substage. Since the function of frequency translation is to raise the frequency of the modulator output to the carrier frequency to be transmitted, the process is referred to as up-conversion and the stage as an up-converter. An rf amplifier may be included in the frequency translation stage to provide the proper output level for transmission in the case of low-power transmitters, or the proper drive level for input to the power amplifier stage in higher power transmitters.

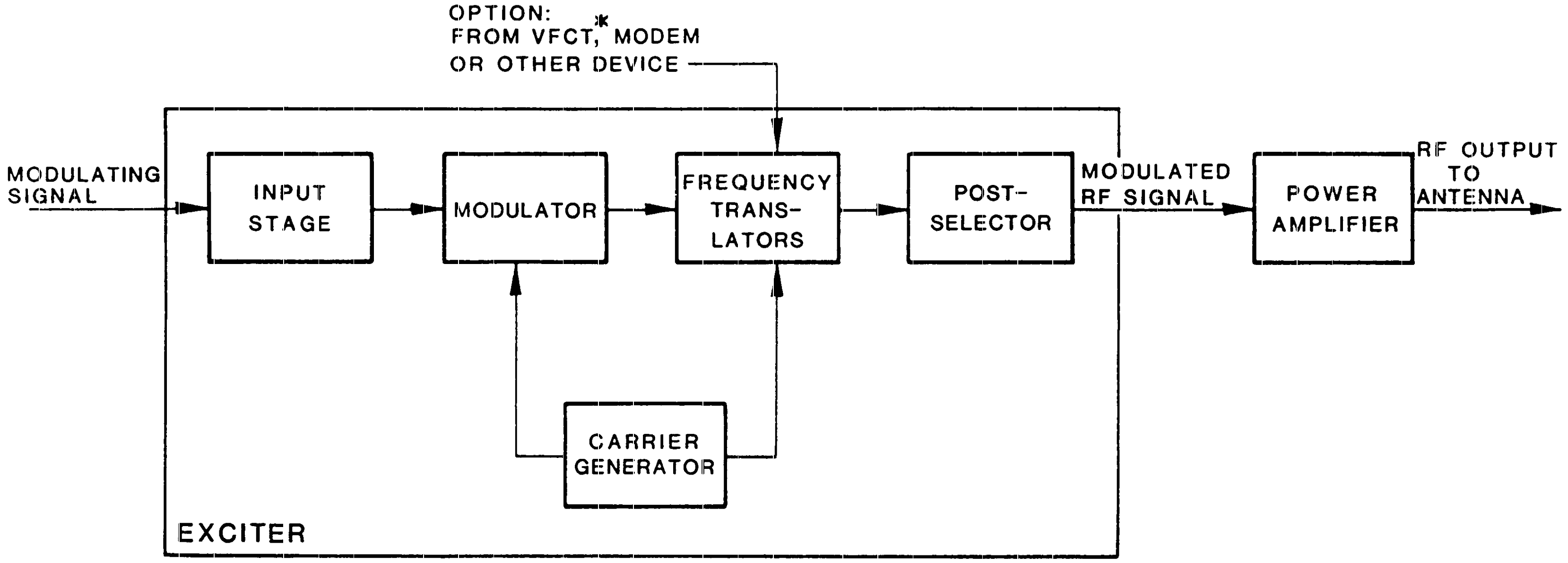
e. Postselectors, or bandpass filters, limit the exciter output bandwidth into the next stage or to the antenna. The purpose is to minimize spurious emissions. The postselectors may be manually or automatically tuned, depending on the equipment design.

f. The rf carrier generator, which provides the various injection carrier frequencies required by the modulator and frequency translation stages, is generally a frequency synthesizer. A frequency synthesizer is a highly stable source of carrier frequencies. It derives its frequencies from an oven-controlled crystal oscillator or other type of stabilized oscillator. It can be slaved to a station frequency standard, in which case it takes on the accuracy of the standard.

4.4.2 Power amplifier.

a. The power amplifier raises the modulated or keyed signal to the level required for transmission. In the case of AM, SSB, and ISB signals, linearity is a key requirement on the transmitter to preclude intermodulation distortion. The power amplifiers used for such transmissions are often referred to as linear power amplifiers (LPA).

b. Peak envelope power (PEP) outputs of 1 and 10 kW are common. Some power amplifiers are designed to provide power outputs of 50 kW or more, depending upon application. To provide maximum power output without overloading on signal peaks, power amplifiers incorporate automatic load control (ALC) circuits. ALC circuits reduce the gain of preceding rf stages when the onset of overload in the amplifier power output envelope is detected.



*VFCT - VOICE FREQUENCY CARRIER TELEGRAPH

FIGURE 29. Simplified functional block arrangement in HF transmitter.

4.5 **HF receivers.** Most modern HF receivers are capable of operation with all of the conventional types of modulation used in HF transmission: AM, SSB, ISB, AME, ICW, NBFM, FSK, and PSK. The latter two types, FSK and PSK, are provided in conjunction with external modems. Frequency hopping and adaptive functions (see 4.3.9 and 4.9.3) require specially designed receiving systems. Both conventional and special receivers, however, share the basic functional elements common to all receiving systems: rf stage, frequency translation stage (or stages), demodulator, output stage, and rf carrier generator. The interrelationship of the functional stages is shown in the block diagram of figure 30. In addition to the major functional elements, HF radio receivers generally include automatic gain control (AGC) circuitry and provisions for diversity reception (with the possible exception of tactical equipment).

4.5.1 **Rf stage.** The rf stage in HF receivers intended for high-quality operation generally consists of a preselector to minimize overload and interference from adjacent channels. The preselector comprises a set of bandpass filters. The filters are preset in some receivers, tunable in others. Preset filters have fairly wide bandwidths and are switched manually or automatically, depending upon the receiver design, to receive the current operating frequency. Tunable filters are generally narrower in bandwidth and are adjusted for the same purpose. Some receiver rf stages incorporate attenuators for use under conditions where the received signal is of sufficient strength to cause receiver overload problems. Either step attenuators or continuously variable attenuators can be used. Rf stages in receivers intended for operation with inefficient antennas, such as whips or aircraft antennas, include rf amplifiers. Such receivers generally include provision for bypassing the amplifier when used with more efficient antennas.

4.5.2 **Frequency translation stage(s).**

a. Modern HF receivers use multiple frequency translation stages. The stages are referred to as intermediate frequency (IF) stages. Generally, three IF stages are employed, the arrangement being called triple-conversion. The conversions, either up or down depending upon the IF, are the result of mixing the input signal with the IF injection frequency supplied by the carrier generator. A bandpass filter at the output of each IF stage passes the desired frequency band to the next stage. Modern receivers use balanced mixers, which emphasize the sum and difference products while attenuating the input signals.

b. The first IF in a triple-conversion arrangement usually operates between 40 and 100 MHz in the very high frequency (VHF) range. The up-conversion involved greatly reduces image-frequency reception. (An image frequency is an unwanted input frequency capable of producing an IF signal upon mixing with the IF carrier. Since the rf stage limits input frequencies to bands in the HF range, possible VHF image frequencies are tuned out.) The use of a VHF IF also simplifies the design of circuitry for continuous HF range coverage. The output of this frequency translation stage is generally narrowband, as provided by a crystal filter.

c. The second IF is a midrange IF (3 to 9 MHz) and involves down-conversion. A crystal filter is also usually employed with this stage to provide a narrowband output.

d. The third IF is a low-frequency IF (300 to 500 kHz) and also involves down-conversion. Ceramic or mechanical filters meet the more stringent narrowband requirements of this stage. An IF output port is commonly provided at this stage to route the signal to peripheral devices such as voice frequency carrier telegraph (VFCT) modems (see 4.7.1).

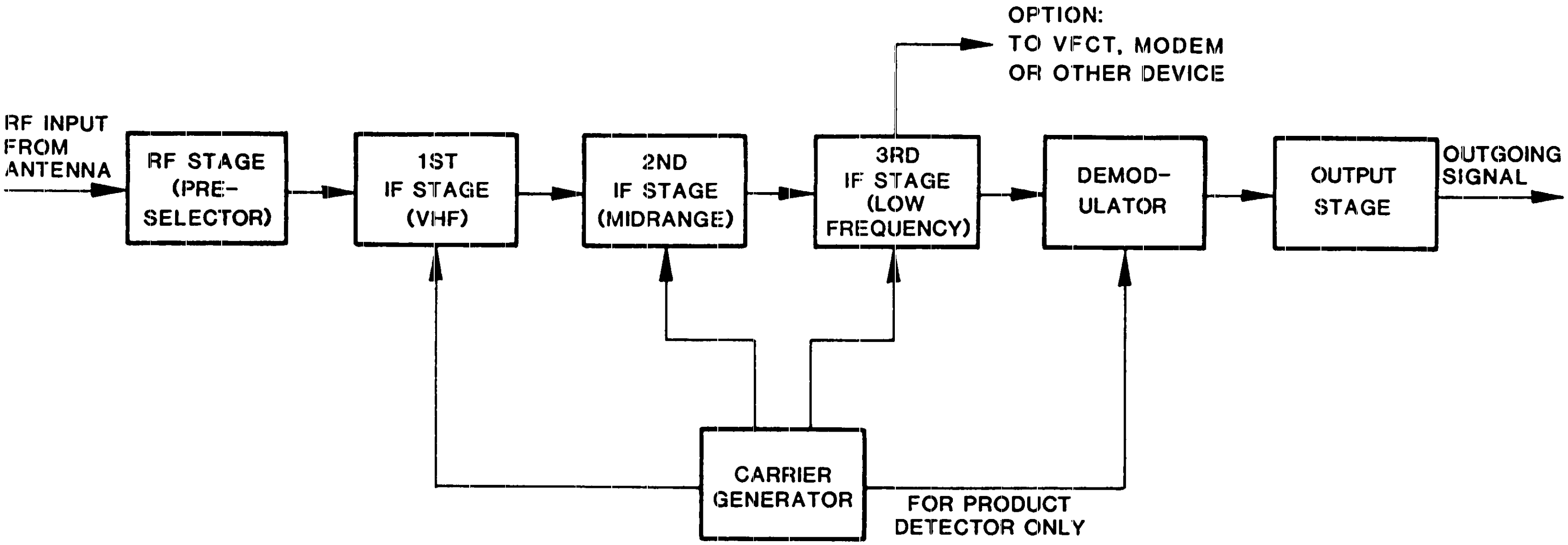


FIGURE 30. Simplified functional block arrangement in HF receiver.

4.5.3 **Demodulator.** As explained in 4.3, the demodulator restores the original information signal from the modulated carrier. The type of demodulator used depends upon the type of modulation: envelope detector for AM, AME, and MCW; product detector for SSB and ISB; twin-filter or limiter-discriminator for FSK; and limiter-discriminator for PSK and NBFM. (The twin-filter or limiter-discriminator demodulators may be contained in separate modems, rather than as integral parts of the receiver.) The output of the demodulator provides either a) an audio-frequency signal for voice or other continuously variable signals, or b) discrete frequencies for digital data or single-channel teletypewriter signals.

4.5.4 **Output stage.** The function of the output stage is to provide a compatible interface with the user end equipment or the communications lines to remote users. For AF signals, this stage uses AF amplifiers to provide the required output levels. Resistance-capacitance (RC) or active filters shape the input bandwidth response to the amplifiers.

4.5.5 **Carrier generator.** A frequency synthesizer provides several injection carriers as required by the IF and demodulator (product detector) stages. These generated carriers are normally derived from voltage-controlled oscillators which are phase-locked to a stable frequency reference. This source reference can be provided by an internal stabilized crystal oscillator or, when higher accuracy and stability is required, an external frequency standard.

4.5.6 **AGC.**

a. HF radio signals arriving by ionospheric paths tend to exhibit extreme variations in amplitude — on the order of 70 dB — over short periods of time. Such wide ranges of amplitude cannot be handled successfully by most mixers, which are sensitive to input level. Consequently, some form of level control is required ahead of the demodulator in HF receivers.

b. In FSK, PSK, and NBFM, amplitude limiting provides adequate level control. Limiting is precluded for use with any of the forms of AM, however, because it would effectively remove the modulation by reducing all incoming signal levels to the same value.

c. An alternative to limiting is to vary the gain of the rf and IF stage(s) in accordance with the strength of the input signal. This is done through a feed-back loop in which a dc offset voltage of the demodulator output controls the gain of the amplifier(s). The dc offset is proportional to the rf signal level. It provides bias to the amplifier(s). As a result, lower-level input signals are amplified more than higher-level signals. The process and the circuitry are referred to as automatic gain control (AGC).

d. Generation of the dc offset requires a reference level as the basis for sensing level variations. In older SSB and ISB equipment, a pilot carrier (a reduced-level rather than highly suppressed carrier) was transmitted to provide the reference. In ISB systems carrying VFCT tones in one channel, a tone is often used to provide the level reference. With all-voice transmissions, however, there is no reliable reference because of the wide variations in speech amplitudes. Such systems often use a voice-operated gain-adjusting device (VOGAD). The VOGAD uses the average level of voice syllables as a reference. The reference is not stable, but enables a limited measure of AGC.

e. CCIR Recommendation 455-1 and CCIR Report 354-4 describe a device known as linked compressor and expander (Lincompex). Lincompex serves the basic purpose of improving voice-channel quality through level compression on the transmitting end and level expansion on the receiving end. (Also see 5.4.5.2.) The compression-expansion process is controlled by an FM tone at the high end of the voice channel spectrum. This tone also provides a level reference for AGC. Modern versions of Lincompex use a digital control signal instead of the FM tone. This signal is equally useful as an AGC reference.

4.5.7 **Diversity combiners.**

a. Diversity reception is a means of counteracting the signal fading that occurs over ionospheric radio paths. (The various types of diversity are explained in 4.9.1.) Diversity reception involves two or more receivers. Diversity combiners then combine the signals from these receivers.

b. There are two categories of diversity combiners, depending on the stage at which combining takes place: predetection and postdetection. Predetection combining takes place at the IF stage (or the rf stage in some systems); postdetection, at baseband (i.e., after demodulation). In VFCT operation, postdetection combining takes place after the VFCT modem. (VFCT modems are described in 4.7.1.)

c. Three types of diversity combiners commonly used are selection, equal gain (or linear adder), and maximal ratio (or ratio squared). The selection combiner simply selects one receiver at a time. The full diversity improvement of this type occurs only when the receiver with the strongest signal is selected. In actual operation, the receiver with the strongest signal-plus-noise is selected. The equal gain combiner simply adds the receiver outputs, providing somewhat more improvement than the selector type. The maximal ratio combiner adjusts the gain of the combined signal in accordance with the ratio of the two signals. It provides the best performance of the three types and works best as a predetection combiner.

4.6 **Antennas and transmission lines.** Antennas and transmission lines are the major elements involved in transferring rf energy to space at the transmitting end of a radio link and intercepting the energy at the receiving end. Associated elements, some of which are essential for operation and others of which provide flexibility of operation, are matching devices, multicouplers, and rf patching equipment.

4.6.1 **Antennas.** From the system design point of view, the essential characteristics of HF antennas are gain, directivity, input impedance, and land area requirements. (HF antenna theory is covered in FM 11-65.) Gain is the ratio of the power density radiated by the antenna in a given direction to that radiated by a reference antenna (usually an isotropic point source) when both have equal input powers. Directivity is the ratio of the maximum power radiated by an antenna to the average radiated power. Gain and directivity are related in that increased gain is accompanied by more directivity or greater efficiency. This is because the total radiated power remains constant. Thus, an increase in power in some directions results in a decrease in power in other directions. Generally, directivity is considered in terms of vertical (take-off angle) and horizontal (azimuthal beamwidth) angular patterns. The many types of antennas in common use in HF radio provide different combinations of the essential characteristics to meet specific radio link needs. Table II summarizes the characteristics of the most commonly used HF antennas.

TABLE II. Characteristics of common HF antennas.

Antenna Type	Gain (dB_i)	Directivity		Land Area (acres)
		Take-off Angle (deg)	Azimuthal Beamwidth (deg)	
Horizontal, half-wave dipole	2-5	5-90	80-180	1
Vertical monopole	2-4	0-45	(Omni)	2-5
Whip	1-2	0-5	(Omni)	(none)
Long wire	1-7	10-40	15-60	(length)
Yagi	6-12	5-30	28-50	1
V	3-17	5-30	10-40	3-7
Rhombic	8-23	3-35	6-26	5-15
Log-periodic	10-17	5-45	55-75	2-4

4.6.1.1 **Horizontal half-wave dipole.** The horizontal half-wave dipole, illustrated in figure 31, is a simple and inexpensive antenna for use over short- or medium-length skywave links. Since it belongs to the resonant class of antennas, it operates well only over a very narrow band of frequencies: ±5 percent of the center frequency. At heights of less than a quarter-wavelength above ground, it radiates and receives well at the steep angles involved in short-length skywave links and is almost omnidirectional in azimuth. At greater heights, the antenna is bidirectional, with maximum lobes at right angles to the length of the antenna. Even though the antenna impedance is nominally 73 ohms at a quarter-wave above ground, it is acceptable to feed it directly by 50-ohm coaxial cable. A variation of the half-wave dipole, with multiple dipoles cut to different frequencies and fed at a common point, provides operation over a broad range of frequencies.

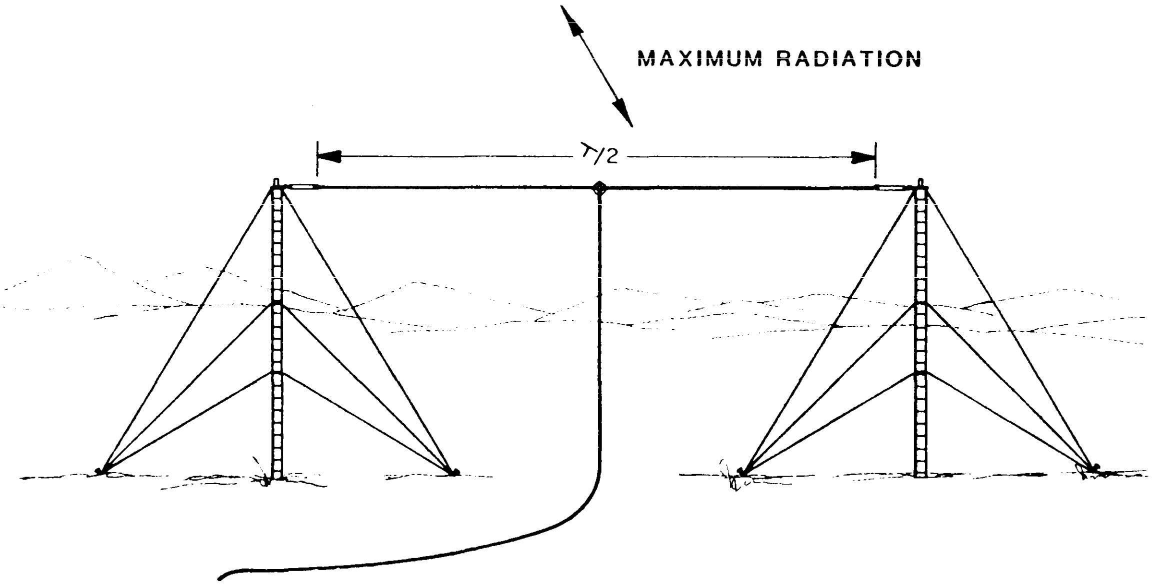


FIGURE 31. Horizontal half-wave dipole.

4.6.1.2 **Vertical monopole.**

a. The radiating element of a vertical monopole is either physically or electrically a quarter-wave long. This element is normally the tower itself. It requires a "good" ground plane to provide a quarter-wave mirror image and, thus, in combination forms a half-wave antenna. Such a ground plane generally consists of a system of wires installed in a radial pattern from the tower base.

b. To avoid excessive height, inductance can be added to the middle or the base of the vertical radiating element to increase its electrical length. Tuning is then provided by varying the reactance(s) in the antenna coupling circuit.

c. Another method of reducing the physical height is through the use of top-loading. Rather than using inductors, top-loading normally consists of adding capacitance at the top of the radiating element. This entails the installation of a large flat or spoked disk, cylinder, or sphere. Top-loading can be effectively used in conjunction with inductive loading. The disadvantage of using either or both loading methods is that reducing the physical size of an antenna tends to reduce its efficency.

d. The vertical monopole is suited for groundwave and low-angle skywave radiation, but has a relatively narrow usable bandwidth. The antenna is omnidirectional in azimuth. The characteristic impedance is approximately 35 ohms. If the tower is insulated from ground, it is series-fed; if uninsulated, shunt-fed. (See 4.6.3.1 and 4.6.3.2 for descriptions of series and shunt feeds.)

e. The vertical monopole can be used in conjunction with a second mast that acts as a parasitic element in a directional array. The parasitic element acts as a director or reflector, depending on the phase of the induced current in the parasitic element. This arrangement provides directional gain and is illustrated in figure 32.

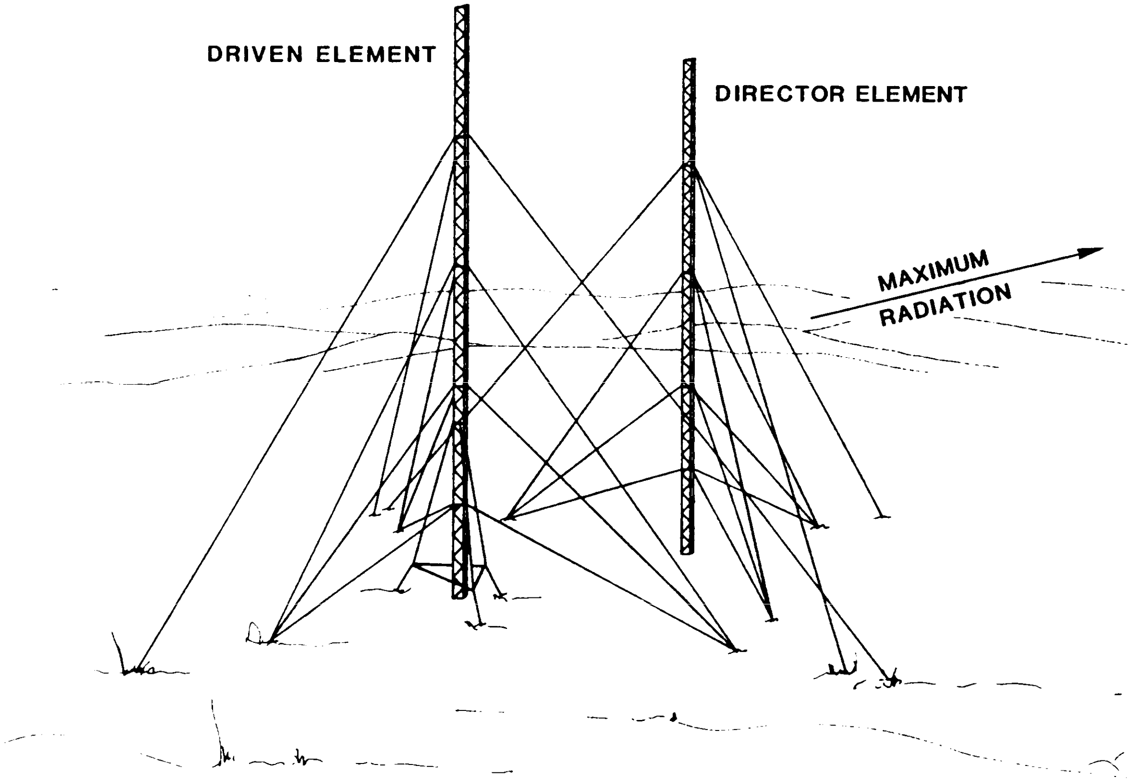


FIGURE 32. Vertical monopole directional array.

f. A conical monopole is constructed of wires and spacers about a central tower. As shown in figure 33, it has the shape of two cones set base to base. The vertical dimension is relatively short, on the order of 0.16 wavelength. A ground plane is required. It can be constructed as a broadband antenna covering the full 1.6- to 32-MHz frequency range. It has a 50-ohm, unbalanced impedance. It is typically available as a transportable assemblage.

4.6.1.3 **Whip.** The whip antenna is a vertical antenna. Its primary use is with vehicular or manpack radio equipment, where resonant-length antennas are impractical. Loading is used to provide an effective electrical quarter-wavelength. The loading is variable to accommodate a range of frequencies and is accomplished by an antenna tuning unit. The antenna requires a ground or a counterpoise. A counterpoise is an artificial ground constructed of wire. It has radials, which should be at least one-quarter wavelength long. It is constructed above ground and insulated from it. The antenna feed is usually through a nonresonant coaxial cable of about 50 ohms impedance. The radiation pattern of a whip antenna is essentially omnidirectional. When mounted on a vehicle, however, the omnidirectional pattern is distorted somewhat by the metal of the vehicle. The metal of the vehicle serves as the counterpoise.

4.6.1.4 **Yagi.** The Yagi antenna consists of a driven dipole element and one or more parasitic dipole elements. The driven dipole element is center-fed, typically by a 50-ohm coaxial cable. The parasitic elements are electromagnetically coupled to the driven element. A simple three-element

Yagi has a director element in front of the driven element. The director element is shorter than the driven element by about five percent. The third element of the three-element Yagi is the reflector element; it is behind the driven element and about five percent longer. Yagis commonly have from two to five elements when used in the HF range. Any additional elements are usually directors. Since they are constructed to operate at a given frequency, they have only limited bandwidth. They can be given multiband capability by the installation of parallel-tuned circuits, known as traps. The take-off angle of Yagis depends on the height of the antennas above ground. A 4-element Yagi provides an azimuthal beamwidth of about 60 degrees and is illustrated in figure 34.

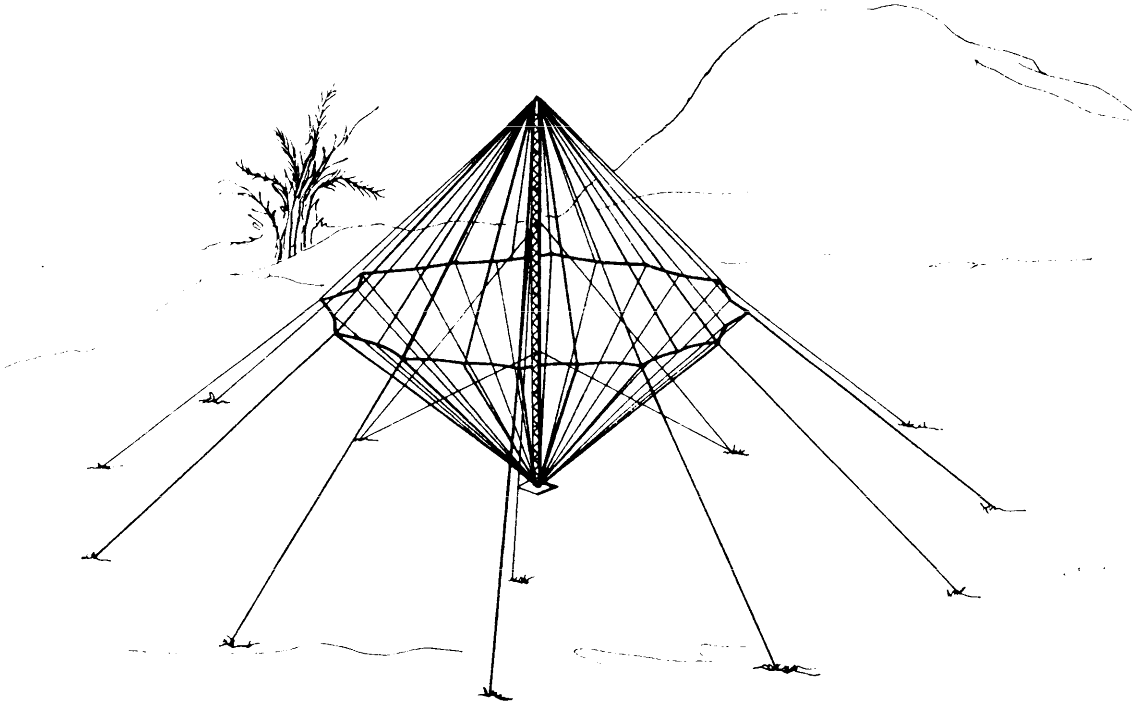


FIGURE 33. Conical monopole.

4.6.1.5 **V.** The V antenna is constructed of two wires forming the letter V. One of the two types of Vs, the nonresonant V, is shown in figure 35. In the horizontal V, the antenna is supported a half-wavelength above the ground by three towers or poles. The two wires are fed at the apex by a 500-ohm balanced open-wire line or by a 50-ohm coaxial cable through a balun (see 4.6.3.3). The angle of the V is chosen so that the main lobes of the two wires reinforce each other along the center line between the legs of the V. Since the wires support formation of other lobes, the antenna tends to have bidirectional characteristics, although some of the lobes in other directions cancel. Such an antenna is referred to as a "resonant V". To produce a unidirectional nonresonant V, terminating resistors, with resistance equal to the characteristic impedance of the antenna, are installed at the far end of each leg of the V. The resulting main lobe is in the direction of the open end of the V. A variation of the V is the sloping V, in which only one support tower or pole of appreciable height is required. The ends of the two legs are mounted on short poles. The V antenna is broadband and has a low take-off angle and narrow azimuthal beamwidth.

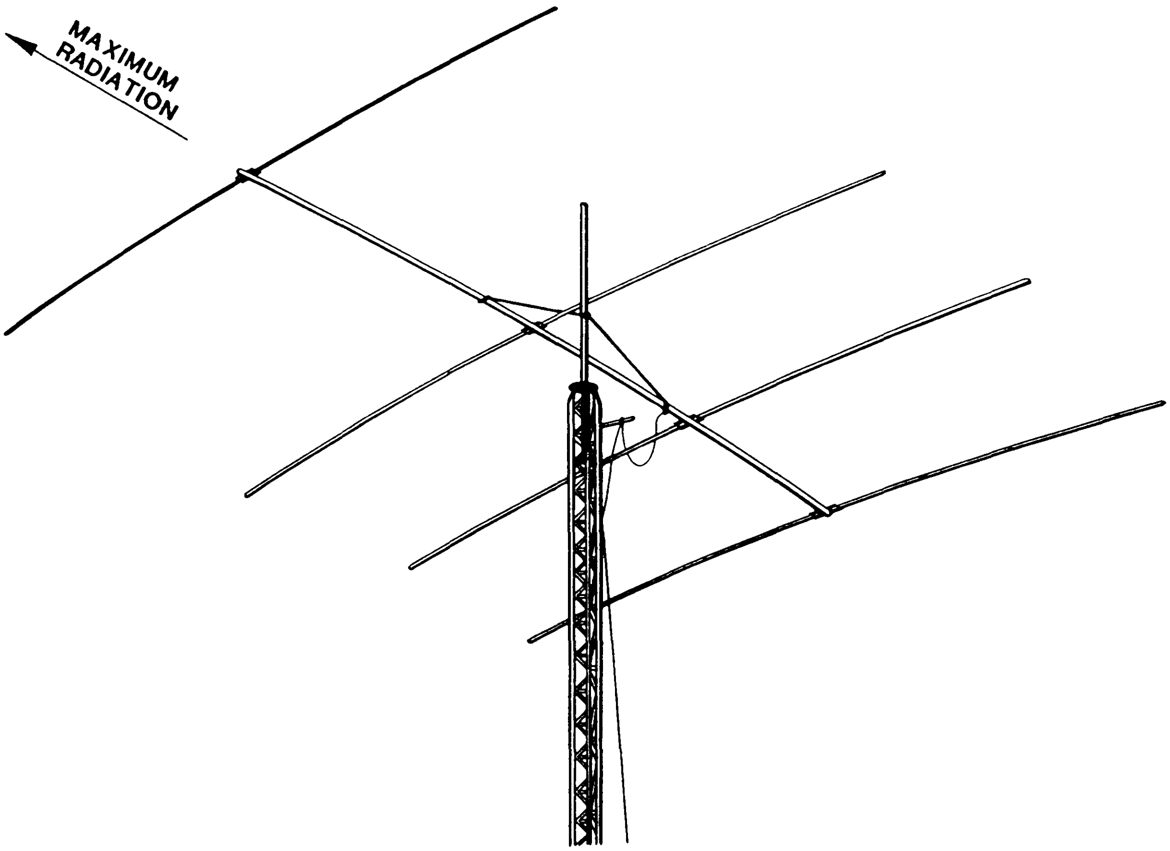


FIGURE 34. Yagi antenna.

4.6.1.6 **Rhombic.**

a. The single rhombic antenna has four sides made of wire and, as the name implies, is shaped like a rhombus (figure 36). The wires are supported by four towers or poles. The legs may be made up of one or more wires, typically three. As with the V antenna, the main lobes of the wire legs combine and reinforce each other along the major axis of the rhombus. The antenna has a characteristic impedance from 650 to 850 ohms for single-wire legs, and from 560 to 600 ohms for three-wire legs. It is fed at one end of its major axis and terminated in an appropriate resistor or dissipation line at the other end. The antenna is broadband and has a low take-off angle and very narrow beamwidth.

b. Rhombics are applied in a number of special configurations to meet specific needs. Figure 37A shows a double-tier rhombic, which provides a much narrower vertical radiation pattern than the single rhombic. This reduces vulnerability to multipath propagation and noise arriving from high vertical angles. Figure 37B shows a double-tier, interlaced rhombic. This configuration provides improved gain over the single rhombic. The Laport rhombic in figure 37C provides increased gain through beamwidth narrowing. The sloping rhombic in figure 37D broadens the vertical radiation pattern. The nested rhombic, figure 37E, reduces the space required to install a high and low band rhombic. In transmit configurations, only one antenna is used at a time. Nesting of rhombic antennas results in some decrease in gain.

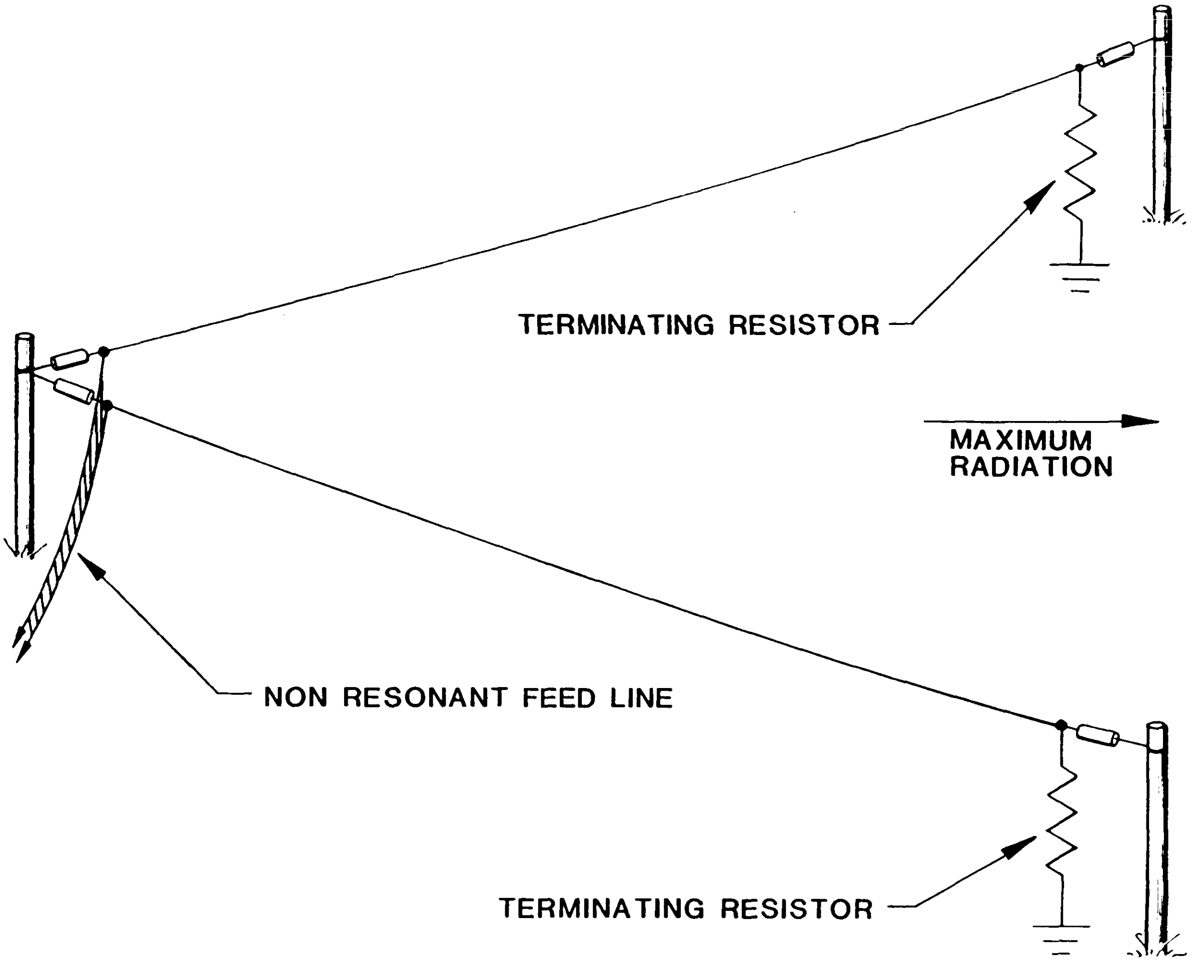


FIGURE 35. Nonresonant V antenna.

c. A distinctly different antenna, the half-rhombic, also known as the obtuse angle V, has only two legs. It is illustrated in figure 38A. It is fed at the far end (away from the apex) of one leg. A terminating resistor at the other far end provides a unidirectional radiation pattern. The half-rhombic can also be constructed in the vertical plane, as shown in figure 38B, with the advantage that only one support tower or pole is needed.

4.6.1.7 **Log-periodic.**

a. The log-periodic antenna is one of the most popular in HF use, since it provides good performance in a relatively small area. The horizontal log-periodic antenna shown in figure 39 consists of parallel elements in the same horizontal plane. The electrical length of and spacing between successive elements are calculated so that the input impedance and pattern characteristics repeat periodically with the logarithm of the operating frequency. The antenna is extremely broadband, with the low-frequency cutoff occuring at the frequency at which the longest element is approximately a half-wavelength long. The high-frequency cutoff occurs at the frequency at which the shortest element is a quarter-wavelength long. For frequencies between the two extremes, antenna currents are greatest in elements that are a half-wavelength long at those frequencies. The longer and shorter elements, then, act somewhat as parasitic reflectors and directors.

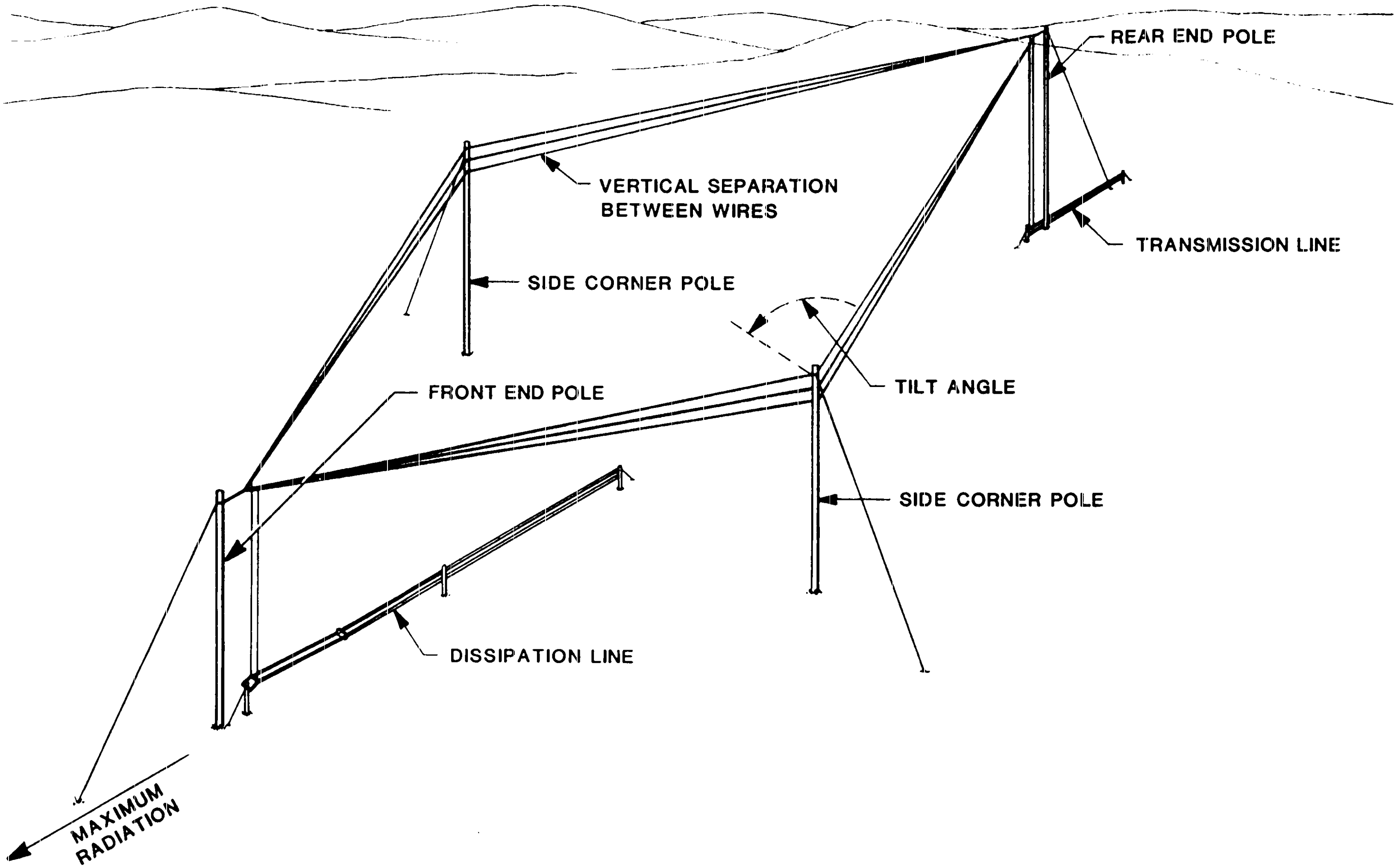
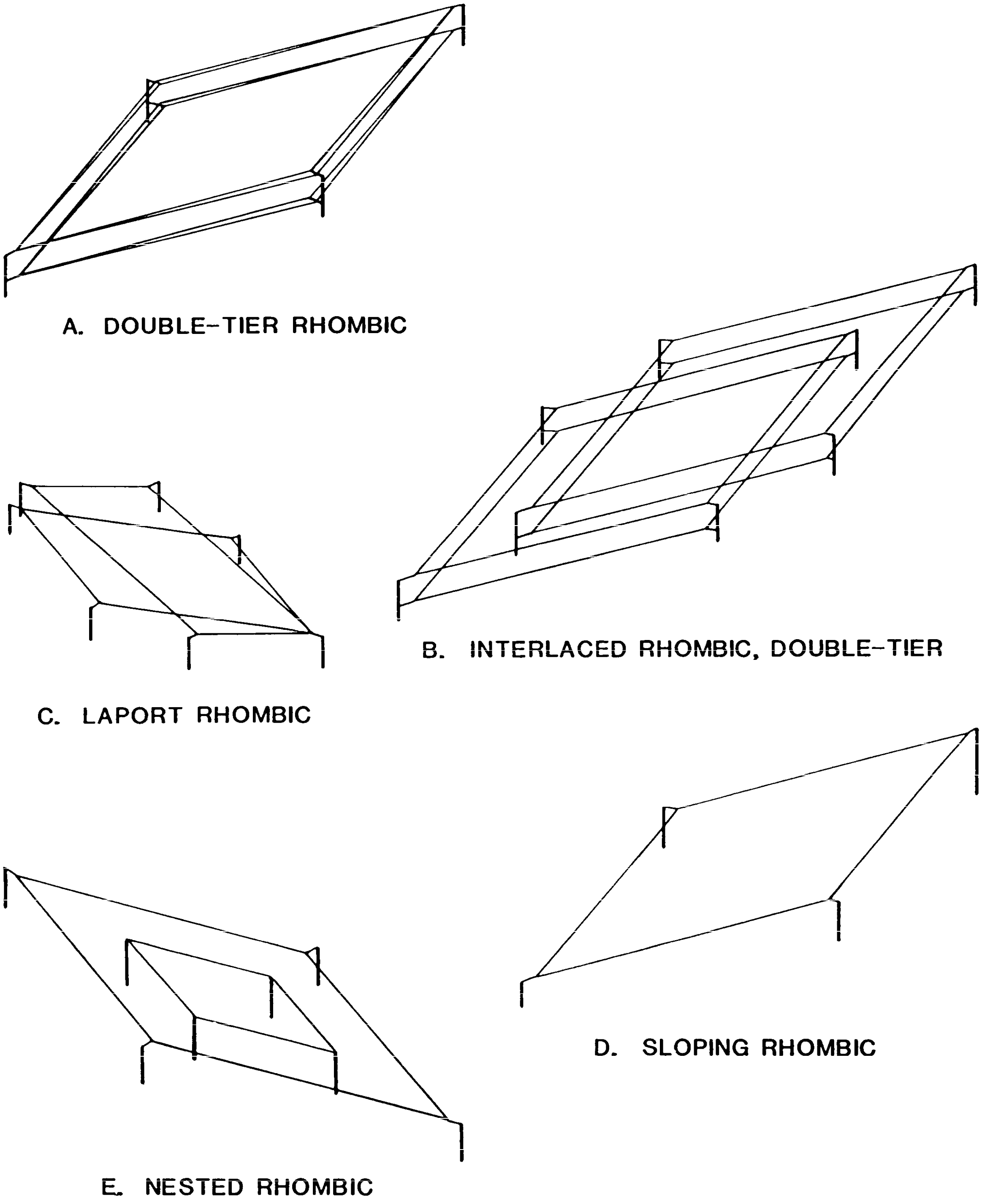


FIGURE 36. Three-wire rhombic with dissipation line.



A. DOUBLE-TIER RHOMBIC

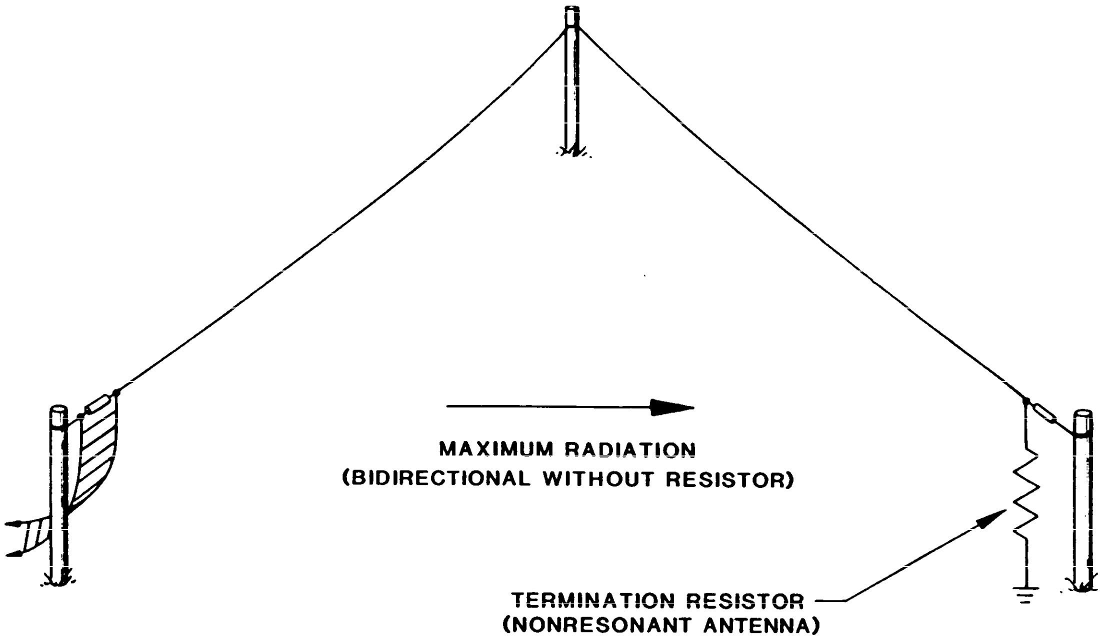
B. INTERLACED RHOMBIC, DOUBLE-TIER

C. LAPORT RHOMBIC

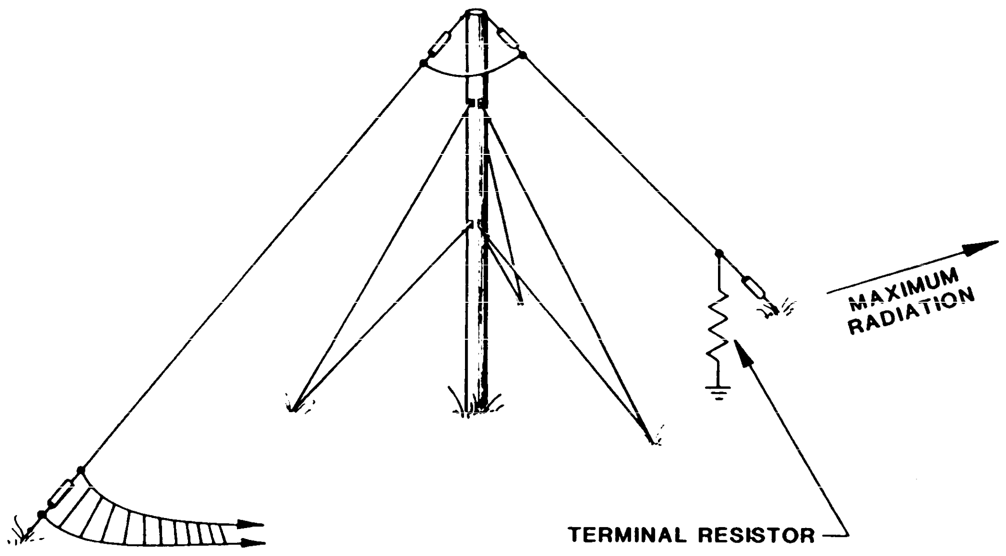
D. SLOPING RHOMBIC

E. NESTED RHOMBIC

FIGURE 37. Rhombic variations.



A. HORIZONTAL HALF-RHOMBIC



B. VERTICAL HALF-RHOMBIC

FIGURE 38. Half-rhombics.

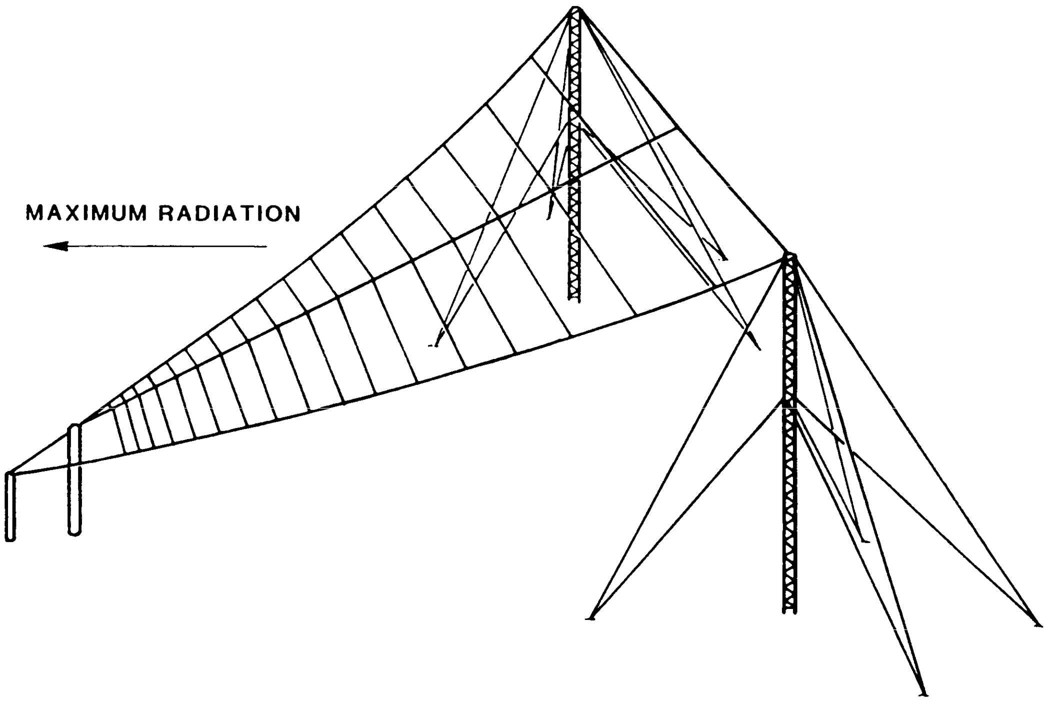


FIGURE 39. Horizontal log-periodic.

b. Log-periodic antennas may be constructed in a number of configurations for specific requirements. Moreover, a number of manufacturers produce fixed, transportable, and rotatable log-periodic antennas. Two of the more common configurations, the vertical log-periodic antenna and the rotatable log-periodic antenna, are shown in figures 40 and 41, respectively. Other log-periodic antenna variations include the double-curtain horizontal, for lowering the take-off angle and increasing the gain; the vertical curtain rosette, to provide four independent overlapping beams for ground-to-air and shore-to-ship links; and vertical curtains in broadside array, to provide high directivity, high gain, and low take-off angle for long links.

4.6.1.8 **Long wire.**

a. The basic long-wire antenna consists of three or more half-wavelength sections fed from a single point. In other words, it is a wire three or more half-wavelengths long. The more half-wavelengths in length, the higher the gain and the closer the main lobes are to the axis of the antenna, i.e. the direction of the wire. Typically, the long wire is end fed and installed parallel to and at least one-quarter wavelength above ground.

b. A derivation of the long-wire antenna known as the Beverage antenna is two or more wavelengths long, fed at one end, and terminated at the far end by connection to ground through a dissipation resistor. Often, it is made of three wires to provide a wider frequency range. The antenna is installed parallel to the ground at a height of between 3 m and 6 m and is supported on wooden or other nonconductive poles.

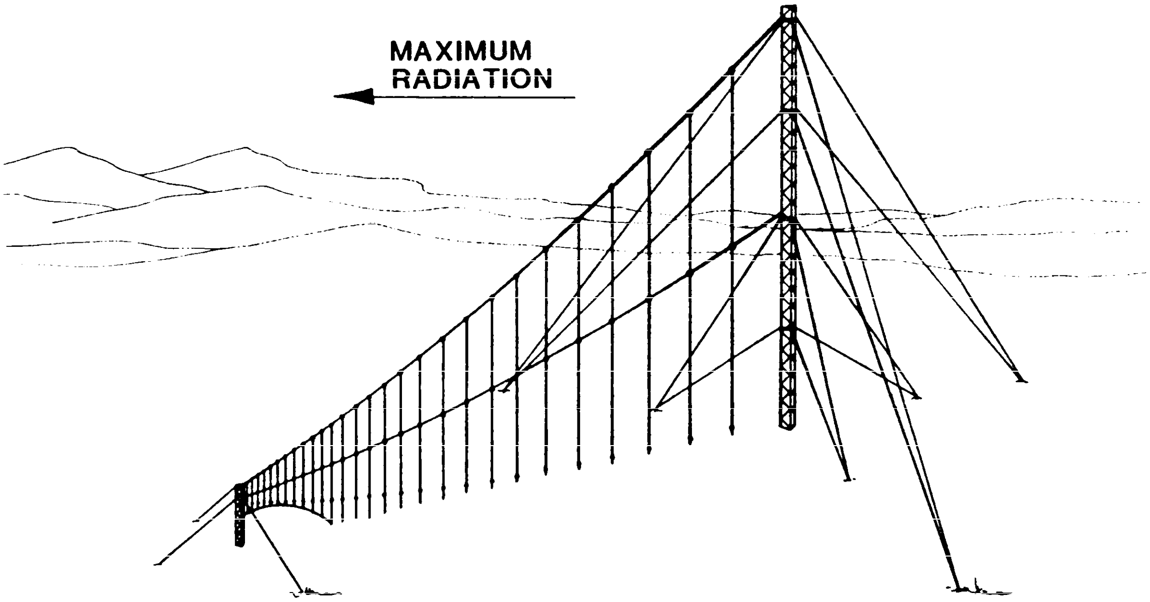


FIGURE 40. Vertical log-periodic.

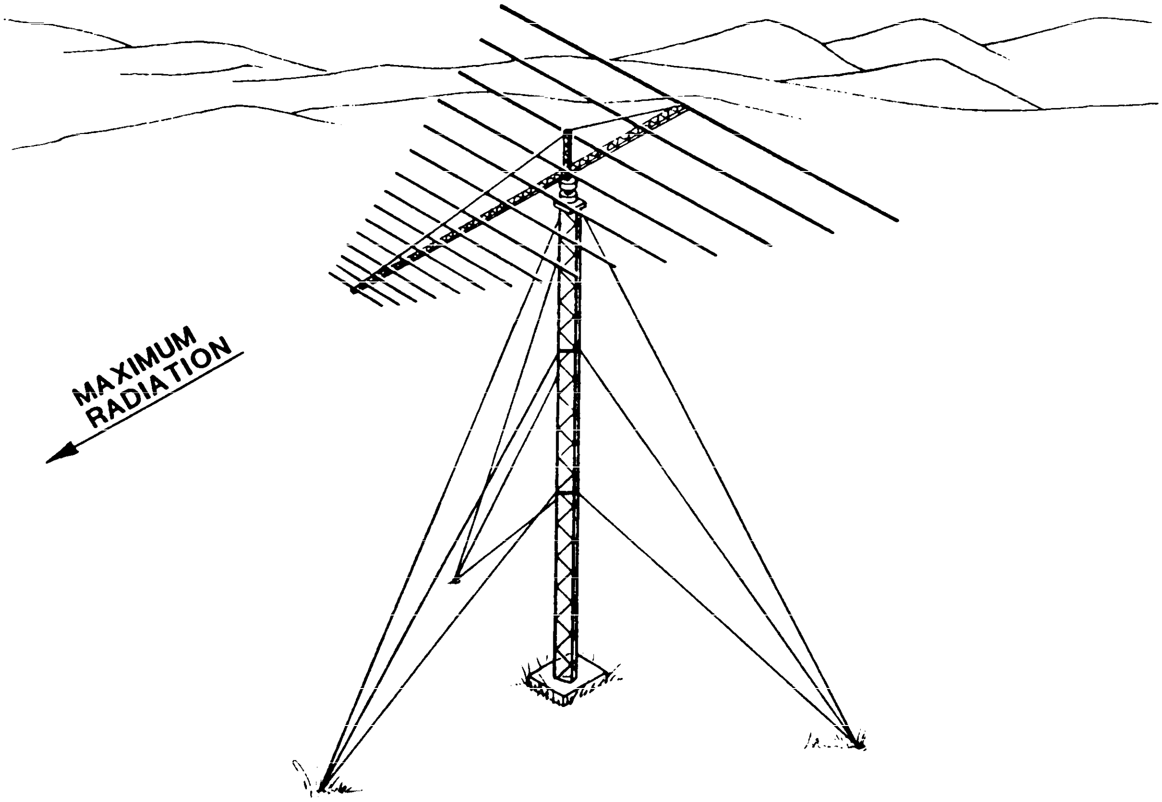


FIGURE 41. Rotatable log-periodic.

4.6.2 **Transmission lines.** Transmission lines connect radio transmitters and receivers to antennas located some distance away. A single, insulated wire makes the connection when the equipment is close to the antenna and, in the present context, is not considered to be a transmission line. The two types of transmission lines in common use in HF radio systems are coaxial and open-wire lines. They are illustrated in figure 42. (Refer to FM 11-65 for a more thorough exposition of HF transmission lines.) For systems engineering, the salient characteristics of transmission lines include their degree of electrical balance, their characteristic impedance, and the attenuation. In certain applications, it is also necessary to know the velocity of propagation along the conductors and whether the line is resonant or nonresonant.

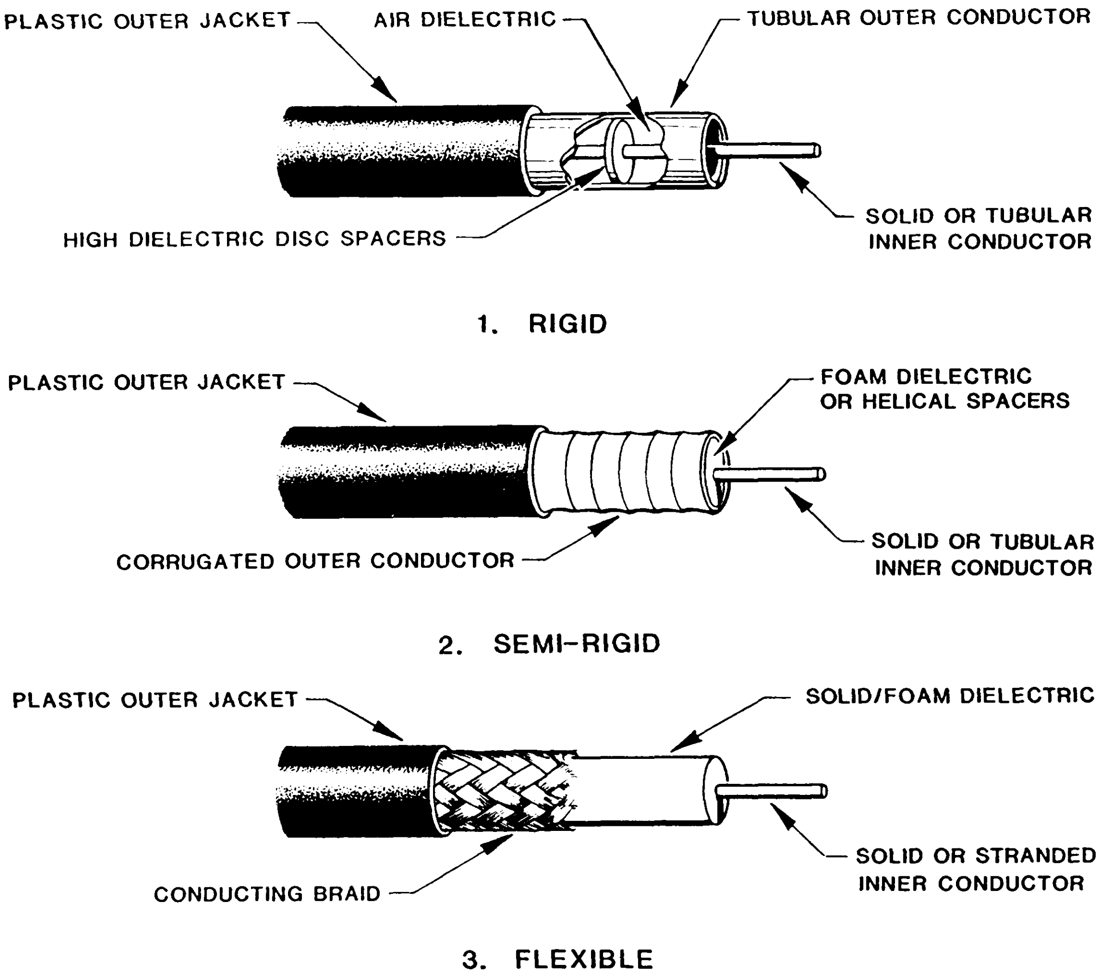
4.6.2.1 **Electrical balance.** A balanced transmission line has two conductors operated at equal and opposite potentials above electrical ground. Such lines radiate little, if any, of the rf energy they carry. In an unbalanced line, one conductor is operated above electrical ground potential while the other is at ground potential. Coaxial transmission lines are generally connected so that the outer conductor is at ground potential. The grounded shield prevents radiation from the line. Thus, they are used as unbalanced lines. Coaxial lines may also be used in a balanced mode for short interconnecting lines. Open-wire lines are operated as closely as possible to a balanced condition. Improper installation, such as in proximity to conducting structures, however, can upset the electrical balance of open wire lines. Proximity to conducting structures has no effect on properly terminated or installed coaxial lines.

4.6.2.2 **Characteristic impedance.** Transmission lines with parallel conductors have distributed series resistance and inductance. They also exhibit distributed capacitance and conductance between conductors. When an alternating current (rf) is applied, the electrical parameters establish a relationship between the applied voltage and the current. This relationship is the characteristic impedance. At a given frequency, it assumes a constant value for a line of infinite length or for a line terminated in the characteristic impedance, regardless of length. The most frequently used coaxial lines, solid coaxial cable, are generally available with characteristic impedances of 50 or 75 ohms. The characteristic impedance of open-wire lines varies with the conductor size and spacing. It generally ranges from 200 to 800 ohms.

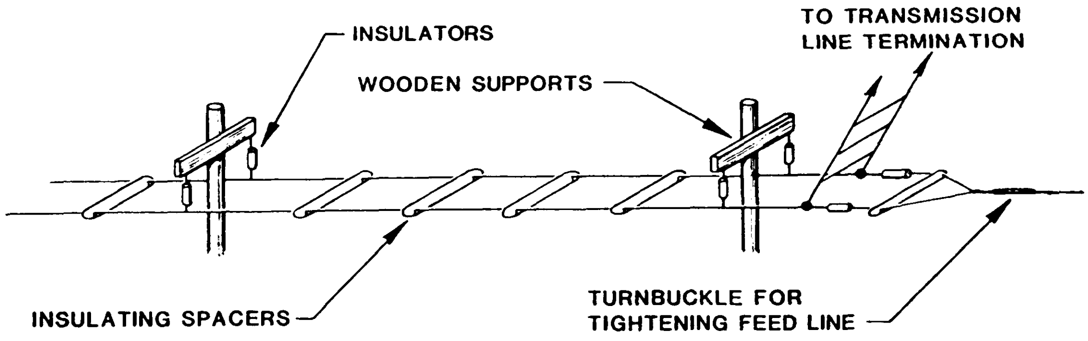
4.6.2.3 **Attenuation.** Attenuation is the loss in signal power that occurs during passage through the transmission line. At rf, the major source of attenuation in the line is the resistance of the conductors, although some loss is attributable to radiation and to leakage between conductors. Transmission lines are generally rated in terms of attenuation constant, which is the attenuation per unit length.

4.6.2.4 **Velocity of propagation.** In some applications, such as in matching devices, it is necessary to determine a signal's wavelength in a transmission line. Wavelength depends on frequency and velocity of propagation. The ratio of the velocity of propagation in the line to that in free space is the velocity of propagation factor. It is always less than one. It is a function of the dielectric constant and is usually given in the line manufacturer's data. The wavelength of a signal in the line, then, is given by its wavelength in free space multiplied by the propagation factor.

4.6.2.5 **Resonant and nonresonant lines.** When a transmission line is terminated in a load equal to its characteristic impedance, all the energy input to the line is absorbed and the voltage-to-current ratio at any point on the line is equal to the characteristic impedance. In most cases, however, the load does not exactly match the characteristic impedance of the line and accepts only a portion of the energy. The rest is reflected back in the line, resulting in waves traveling in both directions along the line. The voltage at any point in the line, then, is the sum of



A. COAXIAL LINE



B. OPEN-WIRE LINE

FIGURE 42. HF transmission lines.

the original signal voltage and the reflected voltage. Thus, voltage loops (maximums) and nodes (minimums) are set up along the line. The ratio of loop voltage to an adjacent node voltage is called the voltage standing wave ratio (VSWR), or often, simply, standing wave ratio (SWR). The VSWR of a line terminated in its exact characteristic impedance would be 1:1. Such a line is referred to as nonresonant. In some instances, such as an antenna operated on harmonically related frequencies, the antenna impedance will vary widely on the different harmonics.

4.6.3 **Matching devices.** There are three impedances involved in energy transfer via transmission lines: the characteristic impedance of the line, the impedance of the source (transmitter in the transmitting direction; antenna in the receiving direction), and the impedance of the load (antenna in the transmitting direction; receiver in the receiving direction). When all three impedances are equal, maximum power is transferred to the load. Moreover, it has been shown that some transmission lines are balanced; others, unbalanced. Sources and loads can also be balanced or unbalanced terminations. Transformation between balanced and unbalanced terminations may be required at one or both ends of a transmission line.

4.6.3.1 Series-fed match.

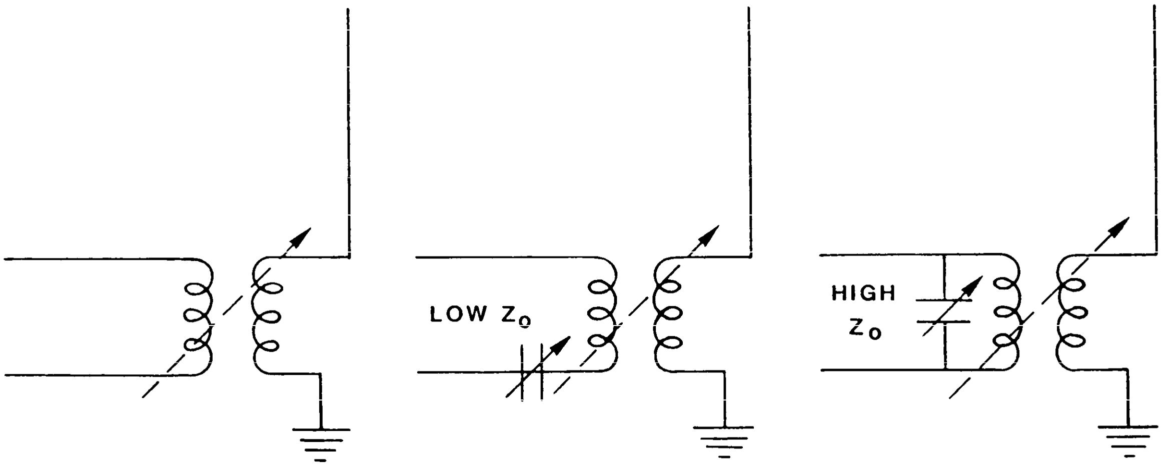
a. Series-fed matching is one method for coupling a balanced transmission line to an unbalanced antenna; for example, an open-wire line to a grounded vertical monopole. The match is accomplished through a transformer by varying the coupling between the primary and secondary windings as required. A tuning capacitor in conjunction with the primary winding simplifies the matching. Such a circuit is illustrated in figure 43A.

b. Series-fed matching of an unbalanced line, e.g., a coaxial line to an ungrounded vertical monopole is accomplished by connecting the outer sheath of the coaxial line to ground at the antenna base and the inner conductor to a base coil, as shown in figure 43B. The point of attachment is adjusted to achieve the impedance match.

c. A matching stub can be used to match a nonresonant two-wire line to a half-wave dipole antenna, as shown in figure 44A. The matching stub is a resonant section, i.e., a quarter-wave section of transmission line. The impedance of the matching stub varies along its length. Therefore, an impedance match can be made by placing the nonresonant line feed point at the matching impedance point on the stub. If the impedance of the antenna is known, a quarter-wavelength section of either open-wire or coaxial line, known as a Q-matching section, can be used to "transform" impedances between the nonresonant line and the antenna, as shown in figure 44B. The characteristic impedance of the Q-matching section must be equal to the geometric mean of the two impedances to be matched. The match may be a step-up (in impedance) or a step-down.

4.6.3.2 Shunt-fed match.

a. An unbalanced coaxial line can be coupled to a grounded vertical monopole through a shunt-fed match, as shown in figure 45. The coaxial line shield is connected to ground at the antenna base. The inner conductor is connected to the point where the antenna resistance matches the line impedance. A capacitor is inserted in series with the short line connecting the antenna with the coaxial line's center conductor. Its purpose is to prevent standing waves from being introduced by the connecting lines natural inductance.

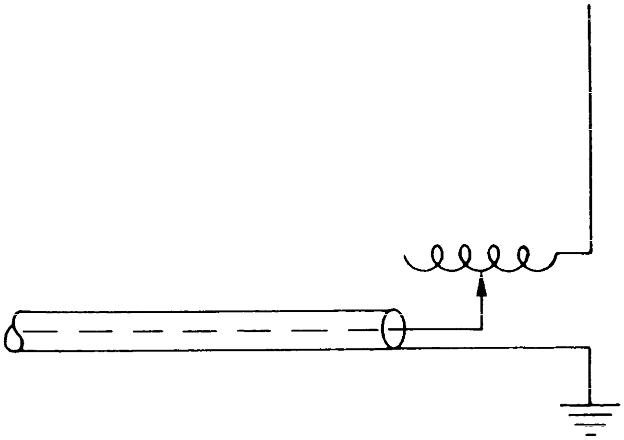


a) BASIC CIRCUIT

b) WITH LOW Z_0 FEEDLINE

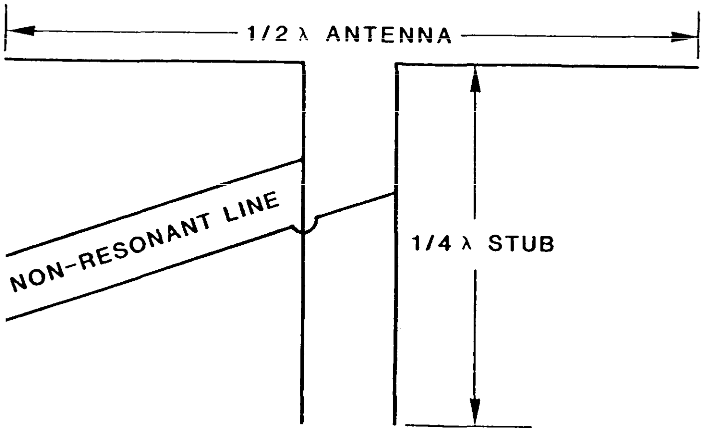
c) WITH HIGH Z_0 FEEDLINE

A. TRANSFORMER COUPLING OF BALANCED LINE TO GROUNDED VERTICAL MONOPOLE

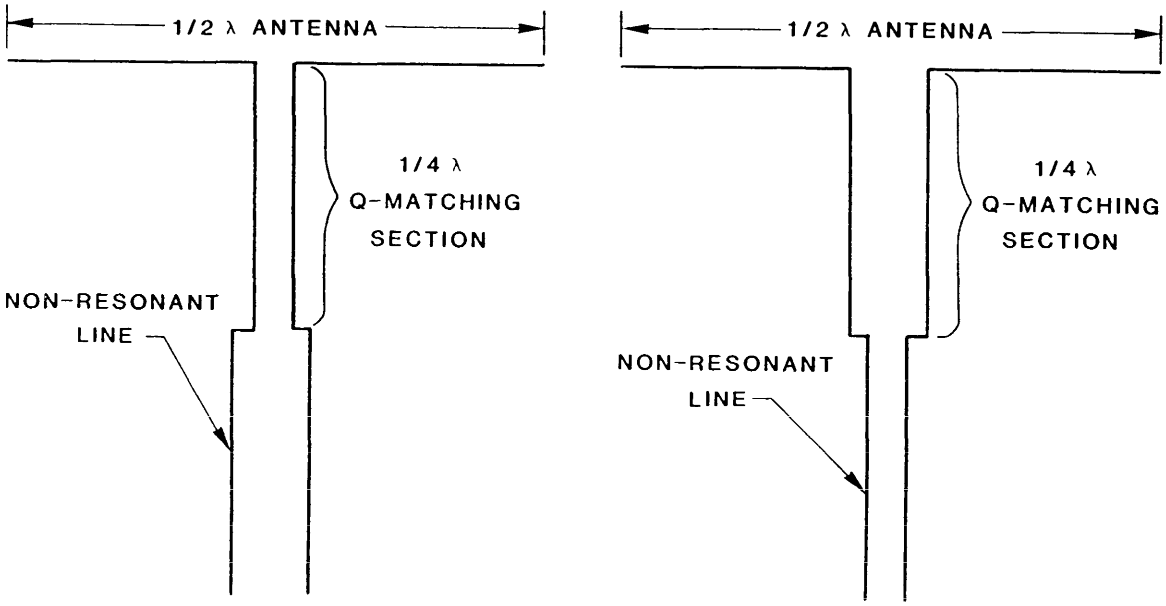


B. SERIES COUPLING OF COAXIAL LINE TO UNGROUNDED VERTICAL MONOPOLE

FIGURE 43. Series-fed matching devices.



A. SERIES COUPLING OF NON-RESONANT LINE TO HALF-WAVE DIPOLE



STEP-DOWN MATCH

STEP-UP MATCH

B. Q-MATCHING SECTIONS

FIGURE 44. Matching stubs.

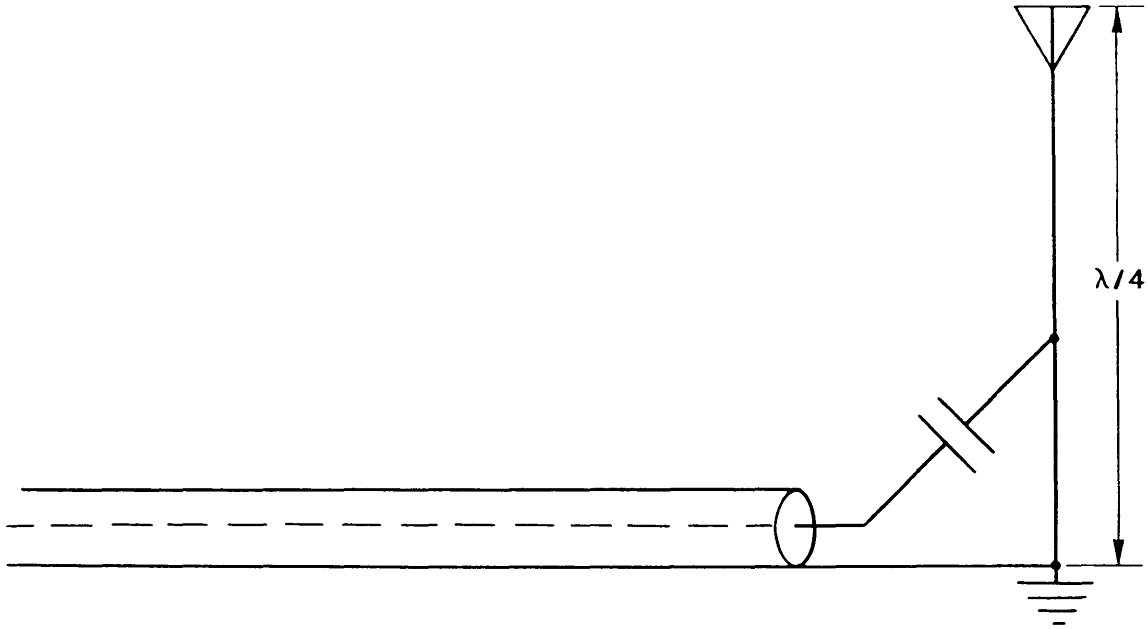


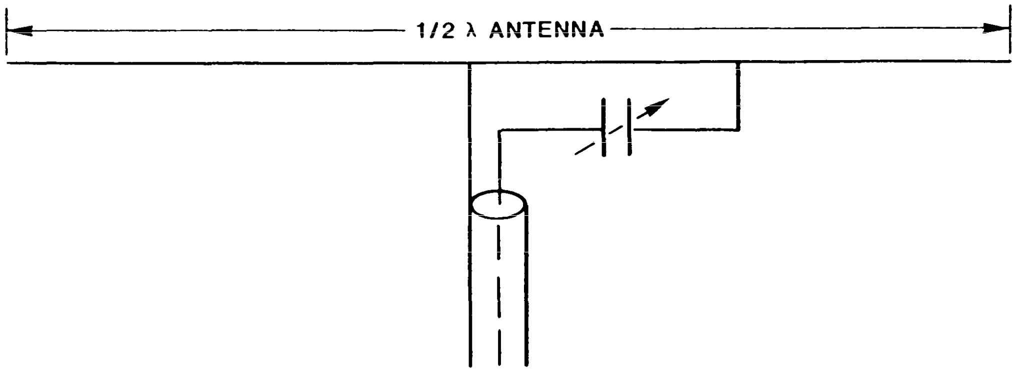
FIGURE 45. Shunt-fed match coupling a coaxial line to a grounded vertical monopole.

b. Shunt-fed matching can also be used with a half-wave dipole antenna, as shown in figure 46. Since the gamma match in figure 46A is an unbalanced feed, some current flows on the outside of the coaxial shield and results in a skewing of the antenna radiation pattern. This skewing is eliminated by a double gamma match, called a T match. The T match is shown in figure 46B. The delta match in figure 46C is used with relatively high-impedance open-wire transmission lines and provides an essentially resistive connection without inductive components.

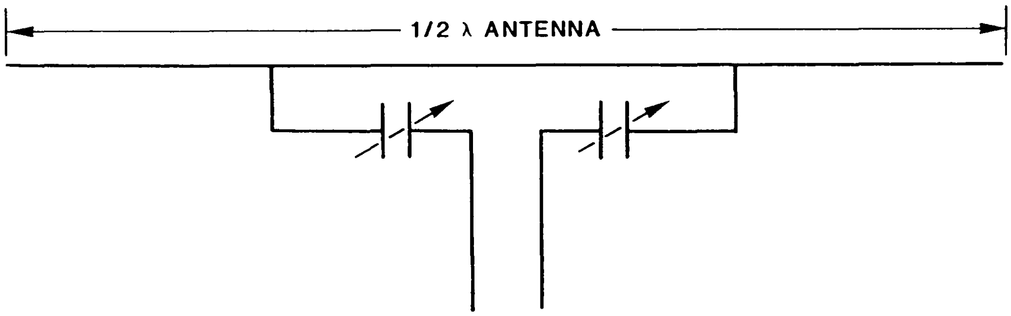
4.6.3.3 **Baluns.**

a. Most HF antennas, with the exception of the vertical monopoles, are balanced antennas. The use of coaxial lines to feed such antennas directly would result in antenna current flowing on the outside of the coaxial shield. Such current flow would distort the antenna radiation pattern. Devices which are used to provide conversion of balanced to unbalanced states are known as baluns. The term balun also encompasses impedance transformers. There are two broad categories of baluns: frequency-dependent, or tuned, and broadband. Since military communications seldom use single operating frequencies, only the broadband baluns are of interest here.

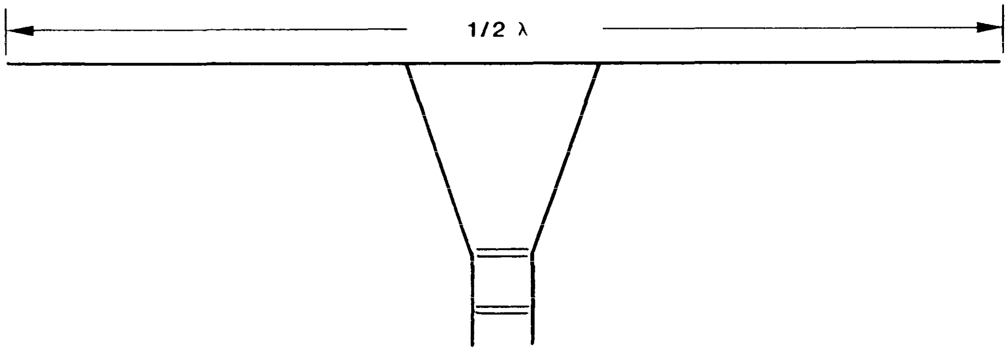
b. Broadband baluns are specially wound transformers with either air or ferrite cores to couple energy between the windings. Air-coupled baluns are generally limited to low and medium power, under 1 kW. The ferrite-core balun power-handling capability is limited only by the properties of the core and the windings.



A. GAMMA MATCHING A COAXIAL LINE TO A HALF-WAVE ANTENNA



B. T MATCHING A BALANCED LINE TO A HALF-WAVE ANTENNA



C. DELTA MATCHING A BALANCED LINE TO A HALF-WAVE ANTENNA

FIGURE 46. Gamma, T, and delta shunt-fed matches.

4.6.3.4 **Coupling to transmitters.** The coupling of transmission lines to transmitters is simplified by the fact that most transmitters are designed to provide a characteristic impedance close to that of some standard transmission line, e.g., 50 ohms for coaxial lines and 300 or 600 ohms for open-wire lines.

4.6.3.5 **Multicouplers and rf patches.** Multicouplers or diplexers enable two or more receivers or transmitters, respectively, to be connected to a single antenna. Rf patch panels are included in all major military installations to permit flexibility in interconnection between receivers or transmitters and the available antennas.

4.6.4 **Antenna grounding systems and counterpoises.** A major factor in design of some antennas is the provision of a suitable grounding system. A low-resistance return path is required for ground-mounted antennas that are series- or shunt-fed, or otherwise fed in such a manner that the ground supplies the return path for current flowing in the antenna. A ground system is also a factor in determining the radiation pattern of other types of antennas. The two basic types of ground systems are radial and ground screens. (FM 11-65 provides a detailed discussion of antenna grounding.) For antennas which must be mounted above ground, and yet require an electrical ground, an artifical ground known as a counterpoise is used.

4.6.4.1 **Radial ground system.** A radial ground system consists of radial wires extending out from the base of the antenna in straight lines. The length of the radials should be approximately a quarter-wavelength at the lowest frequency of the antenna. There should be a minimum of four radials, and they should be equally spread. Near the base of the antenna, the radial system is often augmented by a grid-type ground mat.

4.6.4.2 **Ground screens.** Ground screens consist of copper mesh and are installed near the surface at the base of the antennas. They are rarely used at HF because effective ground screens are too large and unwieldy at these frequencies.

4.6.4.3 **Counterpoises.** Vertical antennas mounted above electrical ground require an artificial ground system. A counterpoise, which is made up of radial, metallic spokes (wires or rods), serves the purpose for building-mounted antennas. For a whip mounted on a vehicle, the metal of the vehicle serves as the counterpoise.

4.7 **Modems.** The fundamental purpose of a digital modem (modulator/demodulator) is to enable transmission of digital signals over an analog channel, e.g., an HF radio link. Recently developed modems, and modems currently under development, perform additional transmission functions. These modems are covered in 4.9.4 and 4.9.5, respectively.

4.7.1 Voice frequency carrier telegraph (VFCT) modems.

a. VFCT modems use FSK of multiple subcarrier frequencies to enable the transmission of multiple teletypewriter signals over a 3-kHz voice channel. The individual teletypewriter signals key the shifting of subcarrier frequencies within the range of the nominal 3-kHz voice channels. The channel bandwidth of the individual teletypewriter signal is roughly proportional to the data rate: the higher the data rate, the larger the bandwidth. In FSK, bandwidth is directly related to frequency shift.

b. The various national and international telecommunications organizations have standardized frequency shifts and the spacing of channel carrier frequencies. The spacing allows for the transmission bandwidth plus guard bands separating the individual channels. MIL-STD-188-100 has standardized the widely accepted modulation scheme for 16 teletypewriter channels. The scheme, based on a frequency shift of ±42.5 Hz with a subcarrier spacing of 170 Hz, is shown in table III. The standardized scheme is intended for signaling rates of 80 baud or less. (A baud is a measure of signaling speed. For binary digital signals, it is equivalent to one bit per second.) To relate the 80-baud signaling rate to teletypewriter speeds and codes, a 100-word-per-minute (wpm) signal using 7.42-unit start-stop code produces a 74.2-baud signaling rate. A 60-wpm teletypewriter speed with a 5-unit synchronous code produces a 45-baud rate.

TABLE III. 16-channel VFCT scheme.

Channel Number	Frequency (Hz)		
	Mark	Carrier	Space
1	382.5	425	467.5
2	552.5	595	637.5
3	722.5	765	807.5
4	892.5	935	977.5
5	1062.5	1105	1147.5
6	1232.5	1275	1317.5
7	1402.5	1445	1487.5
8	1572.5	1615	1657.5
9	1742.5	1785	1827.5
10	1912.5	1955	1997.5
11	2082.5	2125	2167.5
12	2252.5	2295	2337.5
13	2422.5	2465	2507.5
14	2592.5	2635	2677.5
15	2762.5	2805	2847.5
16	2932.5	2975	3017.5

4.7.2 **Digital data modems.** FSK is commonly used for data transmission at rates up to 1200 bits per second (bps). DPSK is often used for 2400 bps. Some modems operating at these rates use QPSK or DQPSK. Some modems are programmable for M-ary PSK such as 2-, 4-, or 8-phase.

4.8 **Interfaces.** HF radio systems interface electrically with communications users in various ways, depending upon system application and overall configuration. In large-scale, complex networks, the user interfaces are accomplished through elaborate patching and/or switching systems and may include transmission links by other media, such as microwave radio or cable. In tactical, transportable systems, the interfaces may be more direct, although still utilizing patching facilities for flexibility. In manpack, vehicular, and most aircraft systems, the user interface is direct through headsets, handsets, or teleprinters. The more elaborate interfaces provide user control and selection of the transmission equipment, while even the direct interfaces provide user controls for operating mode and frequency selection. Network configuration and control is incorporated in the more elaborate interfacing systems.

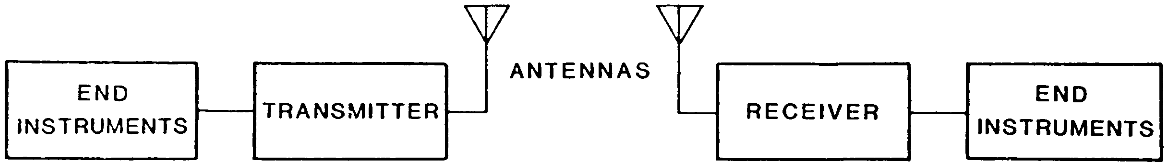
4.8.1 **Basic system configurations.** There are three basic HF radio system configurations: broadcast, simplex, and full duplex. They are shown in figure 47. The broadcast configuration enables a single transmitting terminal to communicate one way with multiple receiving terminals. The end instruments shown in the figure may be microphones on the transmitting end and speakers on the receiving end, teletypewriter sending and receiving units, facsimile equipment, or other electrical signaling devices. The interfaces between the end instruments and the radio equipment are not shown in the figure for the sake of clarity. The simplex configuration allows transmission in both directions, but only in one direction at a time. It uses a single rf channel. The switching circuit enables the transmitter and receiver to access the same antenna in sequence. The full-duplex mode allows transmission in both directions simultaneously. It uses two rf channels: one at frequency f_1 and the other at f_2.

4.8.2 **Operational configurations.** The basic configurations may be applied to a number of operational applications. Strategic long-haul communications terminals may be configured as fixed plant (permanent) or large-scale transportable installations. Tactical communications may utilize transportable, vehicular, and manpack terminals, as well as the special terminals required for ships and aircraft.

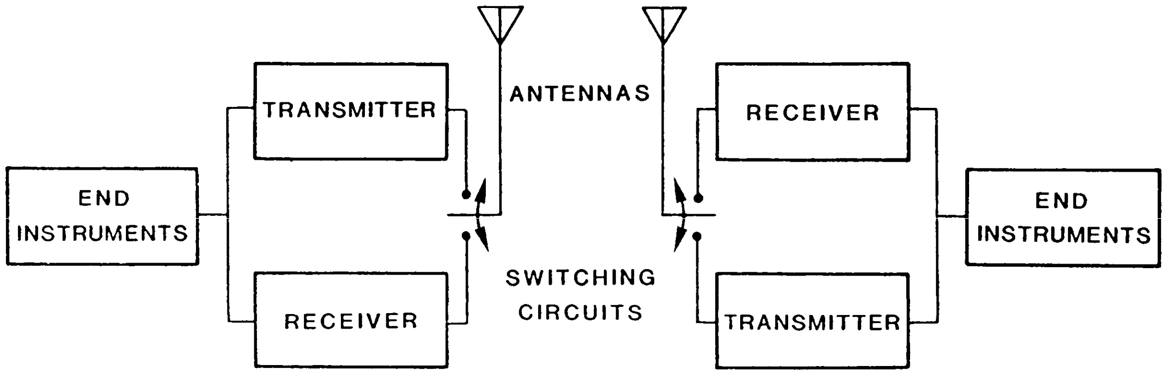
4.8.2.1 **Fixed plant and large-scale transportable installations.**

a. Fixed plant installations may consist of as many as three separate, but interconnected sites. Major installations providing worldwide communications capability use many transmitters and receivers and large numbers of antennas. To prevent spurious emissions from high-power transmitters interfering with reception of the desired signals, the transmitters are commonly housed at one geographical location and the receivers at another. Because of the high-power outputs and high antenna gains involved, the two locations are separated by a considerable distance, generally greater than 10 km. Often, a third location, near or collocated with a telecommunications center or telephone central office, is the site of what is generally referred to as a communications relay center (CRC). The three sites are interconnected by microwave links or landlines. When only two sites are implemented, the receiving site usually serves as the CRC. Figures 48A and B illustrate the 3-site and the 2-site configuration, respectively.

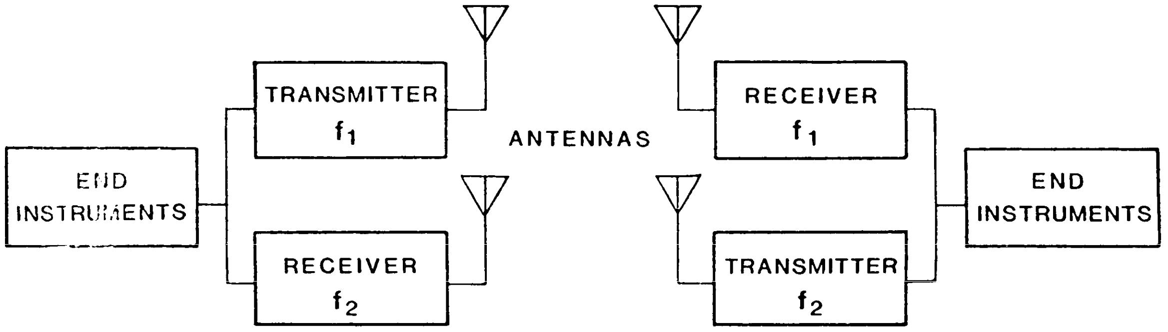
b. Where only one or two transmitters and receivers are involved, they can be collocated at a single site. Large-scale transportable terminals generally involve collocation. Such collocation requires careful attention to frequency selection and the minimization of transmitter spurious outputs. Generally, frequencies must be chosen such that at least 10-percent separation exists between all transmit and receive frequencies that could be in use simultaneously.



A. BROADCAST



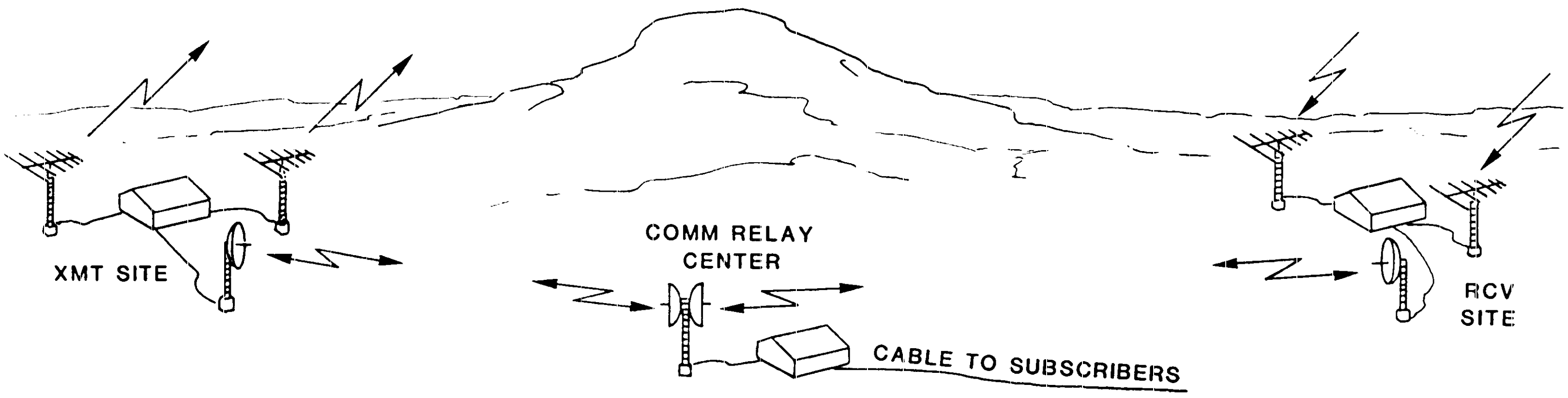
B. SIMPLEX



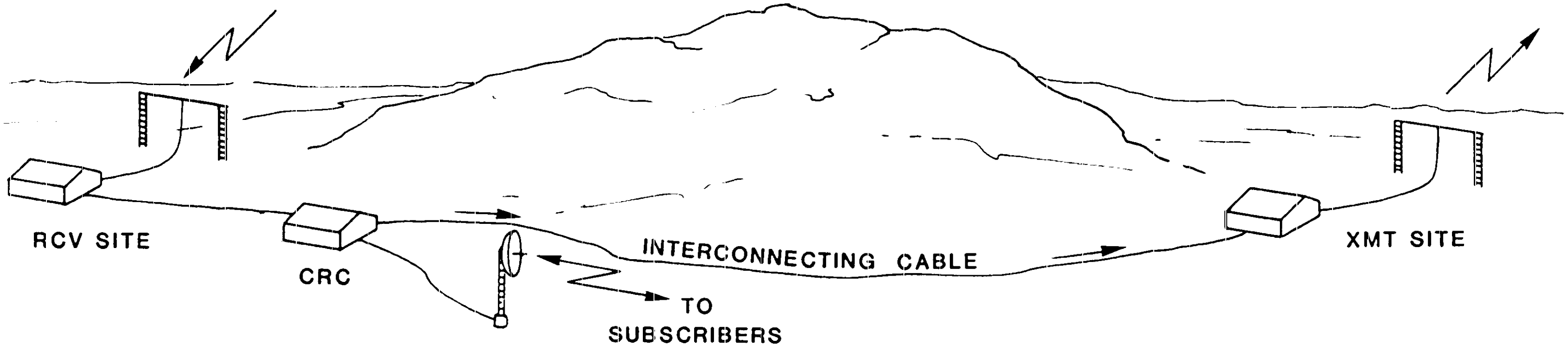
C. FULL DUPLEX

NOTE: INTERFACES OMITTED FOR CLARITY

FIGURE 47. HF radio system configurations.



A. TYPICAL 3-SITE HF CONFIGURATION



B. TYPICAL 2-SITE HF CONFIGURATION

FIGURE 48. Fixed plant and large-scale transportable installations.

c. The AN/TSC-60(V) series and the AN/TSC-99 exemplify the family of large-scale, transportable HF terminals. The AN/TSC-60(V)5 and 7, and the AN/TSC-99, carry the military nomenclature, Communication Central, since they are totally self-contained communications terminals. They include all the required radio equipment, modems (including crypto), RED/BLACK terminations, technical control, and terminal equipment. They also include the primary electrical power distribution subsystem and signal entry ports. Figure 49 is a block diagram of the AN/TSC-60(V)7 Communication Central. Figure 50 is an illustration of AN/TSC-60(V) assemblages deployed in a typical configuration.

4.8.2.2 **Shipboard installations.** The provision of electromagnetic compatibility (EMC) is the most severe problem faced by naval communications involving shipboard radio. The nature of the communications requirements at sea is such that coverage is required over the full 360 degrees of azimuth. The 35-foot whip antenna satisfies this requirement and has become the Navy's standard shipboard HF antenna. EMC becomes a problem because of the need to transmit and receive simultaneously and the need to serve more than one radio link at a time. These needs cannot be satisfied by a profusion of antennas, since limited shipboard area and ship architecture preclude adequate separation of antennas. The classic solution to the problem is a combination of careful frequency management and sophisticated filtering techniques. Rf bandwidths are limited to one percent of the operating frequency and frequency separations of five percent are maintained. Narrowband filtering is accomplished by antenna base tuners, transmitting diplexers and receiving multicouplers, and highly selective IF filters. Figure 51 is a block diagram of a conventional, narrowband, shipboard HF terminal.

4.8.2.3 **Airborne configuration.** EMC is also a major problem in airborne terminal configurations. The problem is compounded by the weight and volume limitations of aircraft, as well as the structural constraints imposed on antennas by high-performance aircraft designs. In practice, the airborne terminals are kept simple at the expense of increased complexity of the ground-based terminals. A typical airborne configuration consists of a lightweight transceiver (for voice operation), which is capable of accommodating an external modem for digital operation; an antenna coupler with automatic antenna-tuning capability; and an antenna suitable to the type of aircraft.

4.8.2.4 **Vehicular and manpack configurations.**

a. Vehicular HF radio terminals are normally installed in tactical vehicles. They consist of receiver-exciter, power amplifier, antenna coupler, and power converter. The antenna is commonly a whip antenna, but the antenna coupler will permit tuning of an external long-wire or connection to a dipole antenna. The AN/GRC-106 family of HF, tactical, vehicular radio sets is typical of this vehicular configuration. It is illustrated in figure 52.

b. The AN/PRC-515 is typical of manpack HF terminals. It consists of receiver-exciter, power amplifier and coupler, pack frame and bag, handset, battery, and whip antenna. It is capable of vehicular mounting and operation, and will also operate with an external long-wire or dipole antenna. The AN/PRC-515 is illustrated in figure 53.

4.8.3 **Typical interfaces.** User circuits accessing HF radio systems exhibit a wide variety of circuit arrangements. Telephone circuits may be 2-wire or 4-wire, and they may use different kinds of supervisory signaling schemes. Digital data and telephone circuits may be carried between telephone central offices and the HF radio complex by metallic cable pairs, or they may be multiplexed into a composite signal for transmission by a microwave radio link.

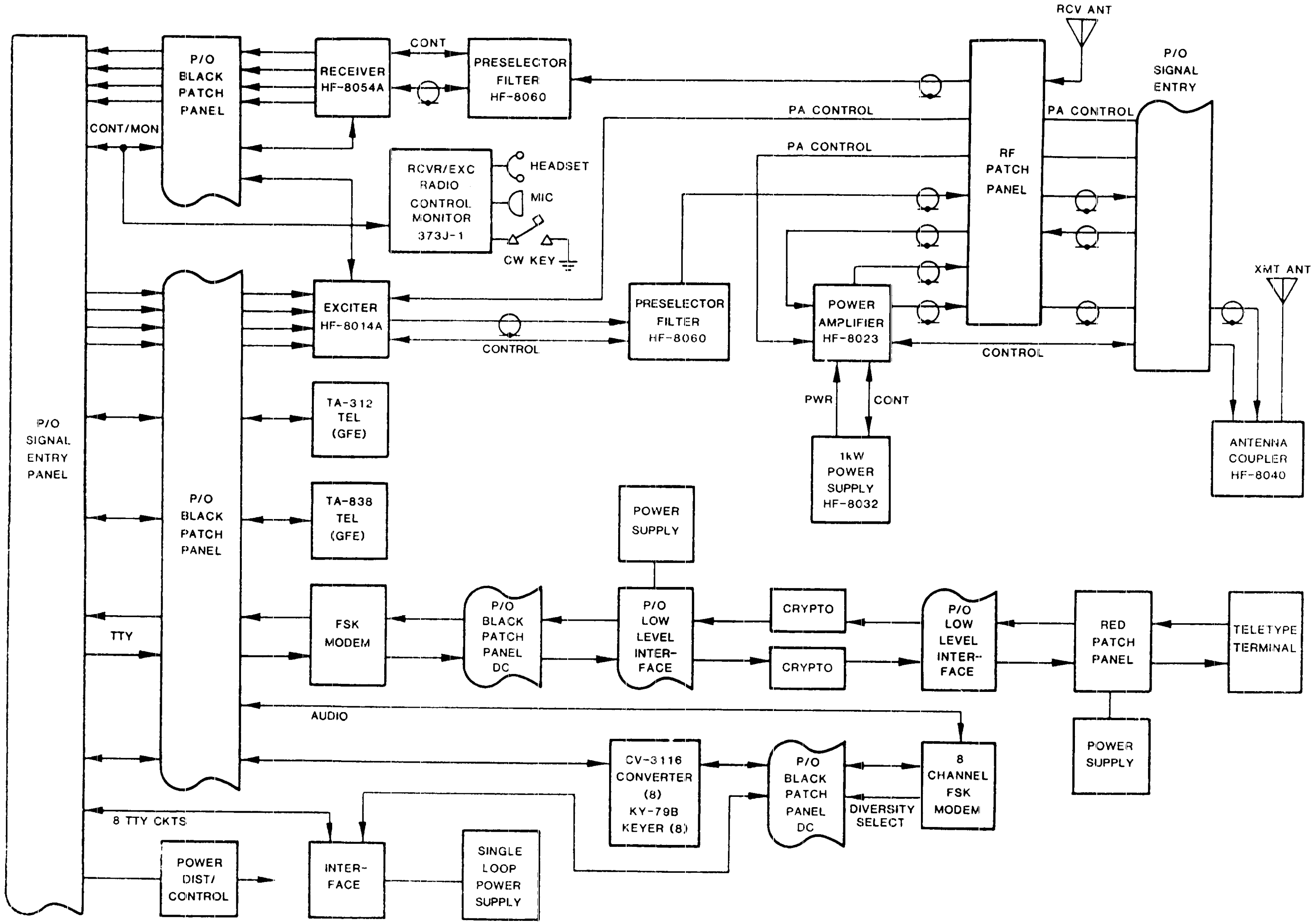


FIGURE 19. Block diagram of AN/TSC-60(V)7 Communication Central.

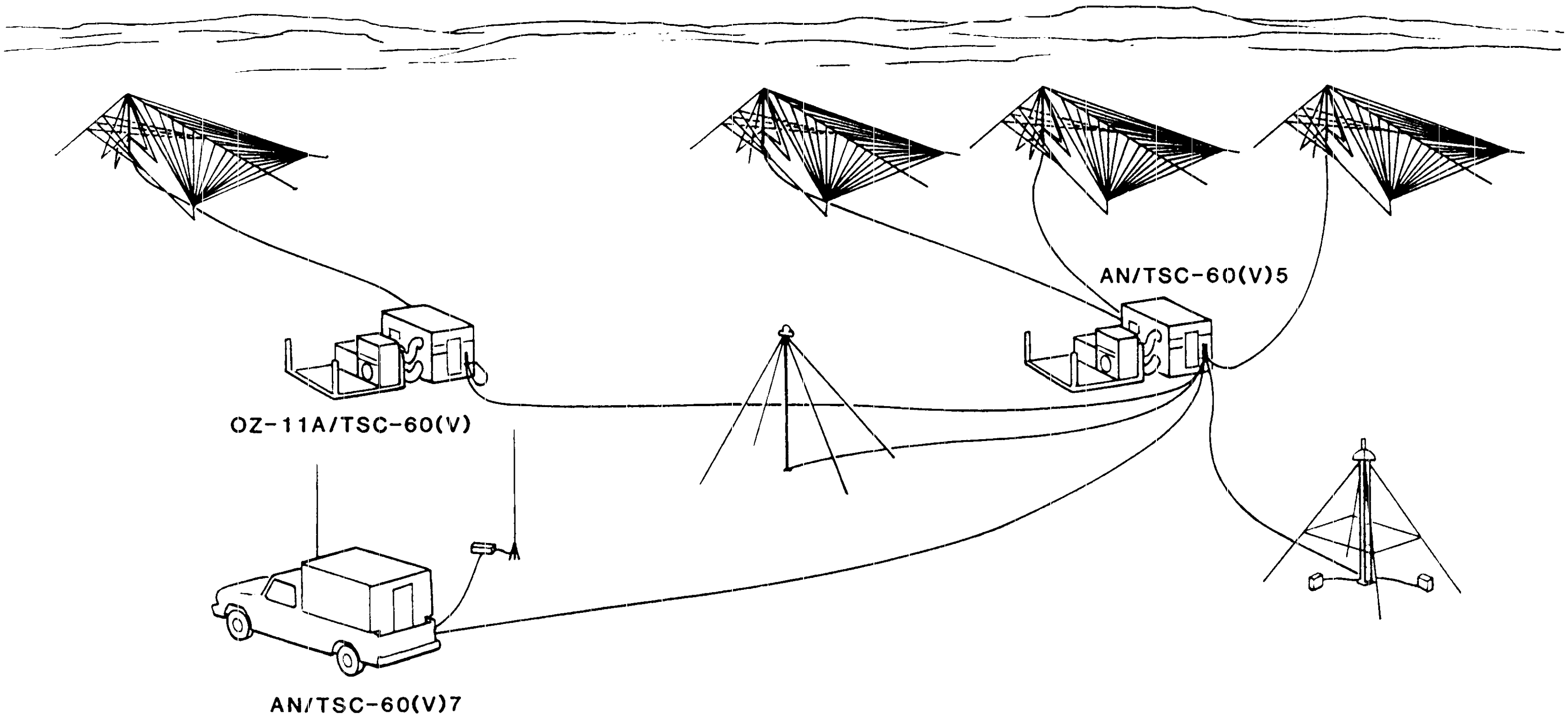


FIGURE 50. Artist's rendering of deployed AN/TSC-60(V) family.

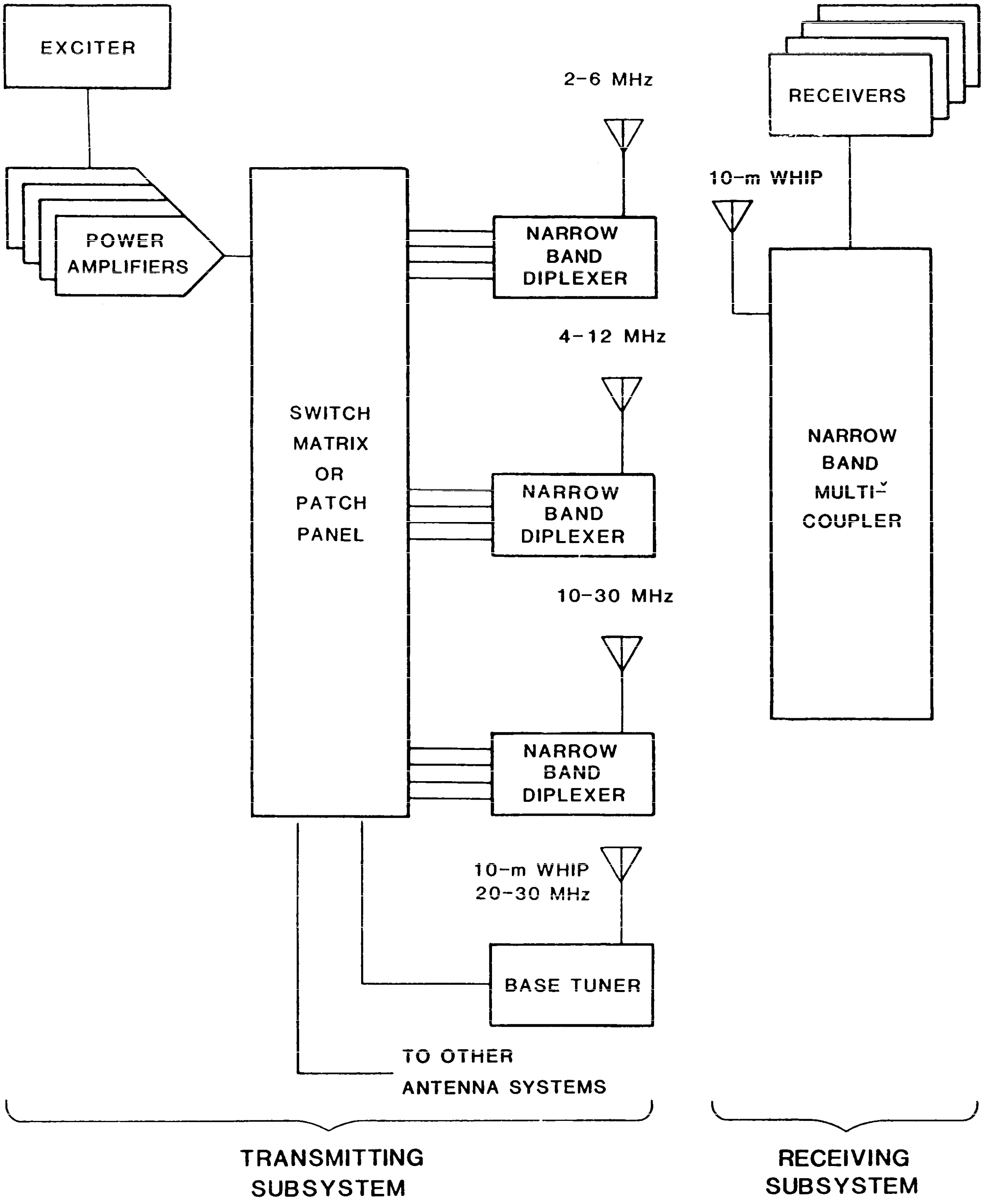


FIGURE 51. Conventional shipboard HF terminal.

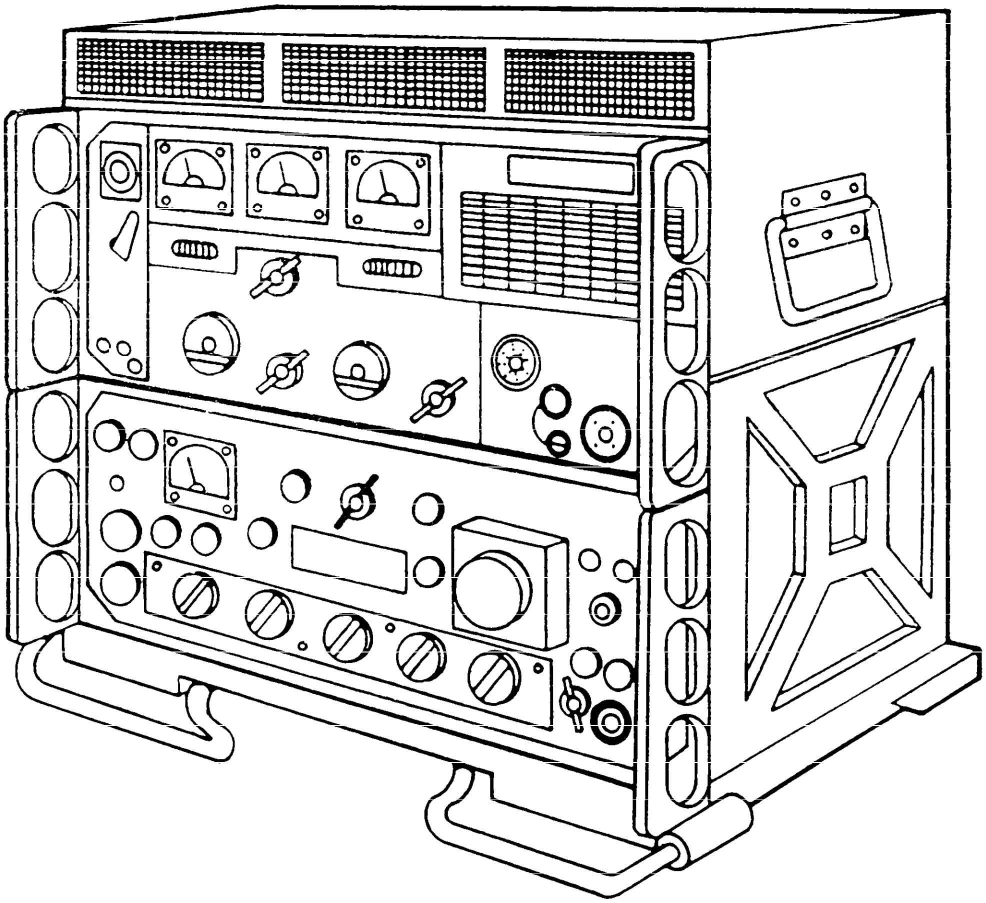


FIGURE 52. AN/GRC-106 vehicular radio set.

4.8.3.1 **Technical control facility interface.**

a. In major fixed plant installations with a 2-site or 3-site configuration, interfacing with system users is accomplished in a technical control facility (TCF) in the CRC. In addition, certain interfacing (primarily for flexibility of operation) is accomplished at the transmitter and receiver sites.

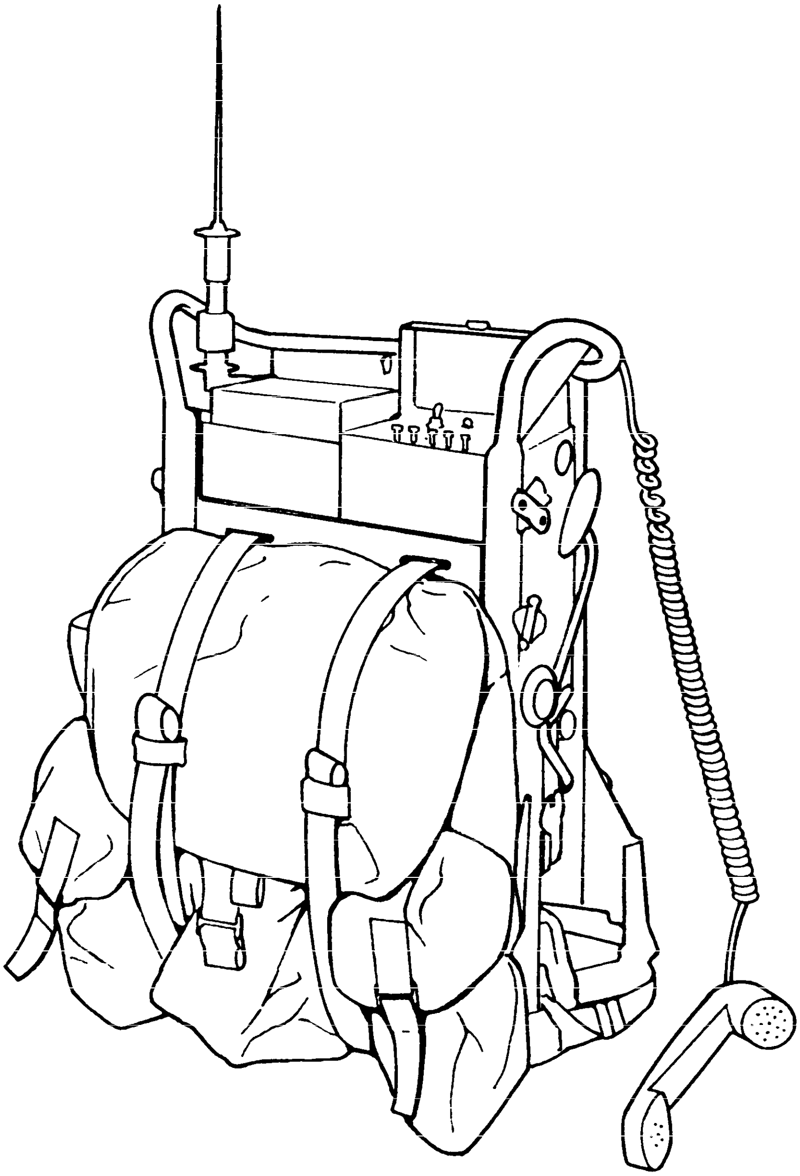


FIGURE 53. AN/PRC-515 lightweight HF packset.

b. Metallic cable pairs which interconnect an HF facility and its users appear at the VF primary patch bay in the TCF, as shown in figure 54. (For an explanation of TCF terms and concepts, refer to MIL-STD-188-310.) Voice signaling and termination equipment provide the proper input and output levels and make any necessary conversions in supervisory signaling schemes for telephone circuits. On the other side of the signaling and termination equipment, the circuits appear at the equal level patch bay. From the other side of the bay, circuits carried by cable pairs between the CRC and the radio sites appear at the VF intersite patch bay for that cable. Circuits carried by microwave radio link multiplex channels appear at

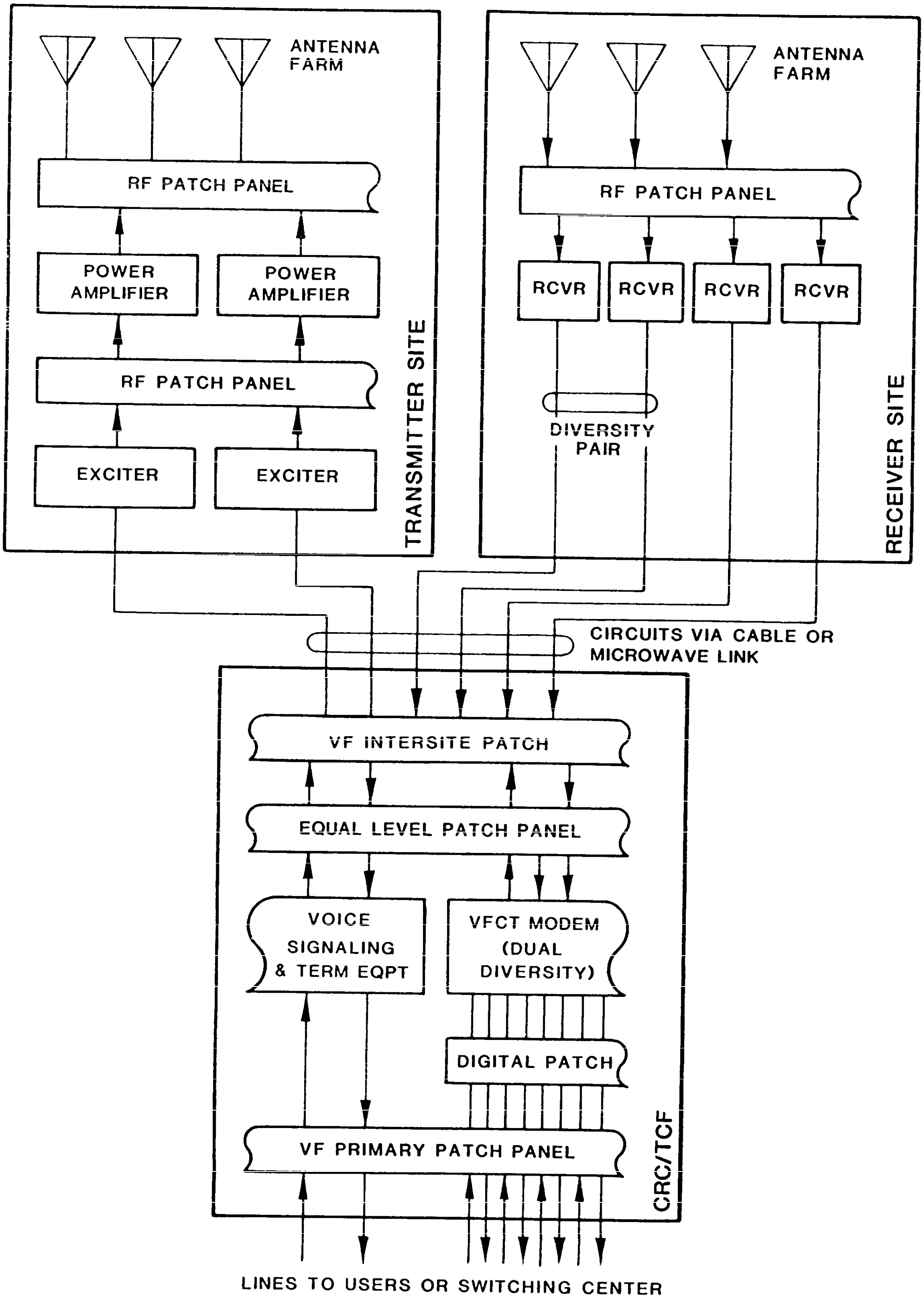


FIGURE 54. HF radio system interfaces in typical three-site configuration.

another equal level patch used for multiplex channels. Teletypewriter or digital data circuits follow the same general routing, except for the inclusion of a digital patch and data modem. In the case of 16-channel teletypewriter, for example, the 16 user lines appear at the digital patch on the user side of the VFCT modem. The FSK tone output of the modem goes to the HF section of the equal level patch bay. Two sets of FSK tones, arriving from two diversity receivers by way of the equal level patch bay, are input to the modem.

c. The send circuits are routed to the transmitter site where they are directly connected to individual exciters. The exciter outputs can be switched between power amplifiers by an rf patch. The power amplifiers, in turn, can be switched among antennas in the antenna farm by another rf patch.

d. At the receiver site, receivers can be switched among antennas at the rf patch. The audio outputs of the receivers are routed to the TCF where they are assigned to appropriate signaling and termination equipment or modems.

4.8.3.2 **Collocated interface.** Where transmitters and receivers are collocated, as in a typical transportable configuration, user lines appear at an audio patch or a DC patch, depending on the nature of the signals. Signaling and termination equipment or data modems are used and the signals on the other side of that equipment appear again at an audio patch. Send circuits are patched to exciters. The exciters are patched to power amplifiers through an rf patch, and the power amplifiers to the transmitting antennas through the antenna patch. In the receive direction, receiving antennas are patched to receivers at the antenna patch and the audio outputs of the receivers appear at the audio patch. This typical arrangement is shown in figure 55.

4.8.4 Remote control interface.

a. With computer-controlled equipment, HF transmitting and receiving installations can be remotely controlled. With an established communications network, as shown in figure 56, and predetermined message priority structure, control can be exercised by system users. By dialing a three-digit code, for example, a user can gain automatic interconnectivity with a desired network location. A programmed priority assigned to the calling user line enables the call to take precedence over calls of lesser priority. Likewise, a special code can have the same effect. Thus, command and control communications can be carried out efficiently without intermediary technical personnel or manual patching and switching. Technical personnel carry out the necessary functions of initial network establishment and function programming, operational monitoring, and routine and emergency maintenance and repair. In a 3-site configuration, they carry out the monitoring function from a console in the CRC.

b. A typical remote control system would include an electronic switching system (ESS) at the CRC of an HF installation. User locations would be interconnected with the CRC and the ESS by dedicated circuits. (A dedicated circuit is a full-period reserved line between two locations.) The ESS is programmed to select the exciter and receiver with the available mode (voice or data) to match the user mode and the appropriate emission type (SSB, ISB, FSK, etc.). The ESS is also programmed to issue appropriate supervisory signals to the transmitter and receiver sites to produce the required interconnections to establish the radio link. An operator's console is included at the CRC for the circuit monitoring and maintenance functions. As shown in figure 57, both traffic and control signals pass between the CRC and the radio sites.

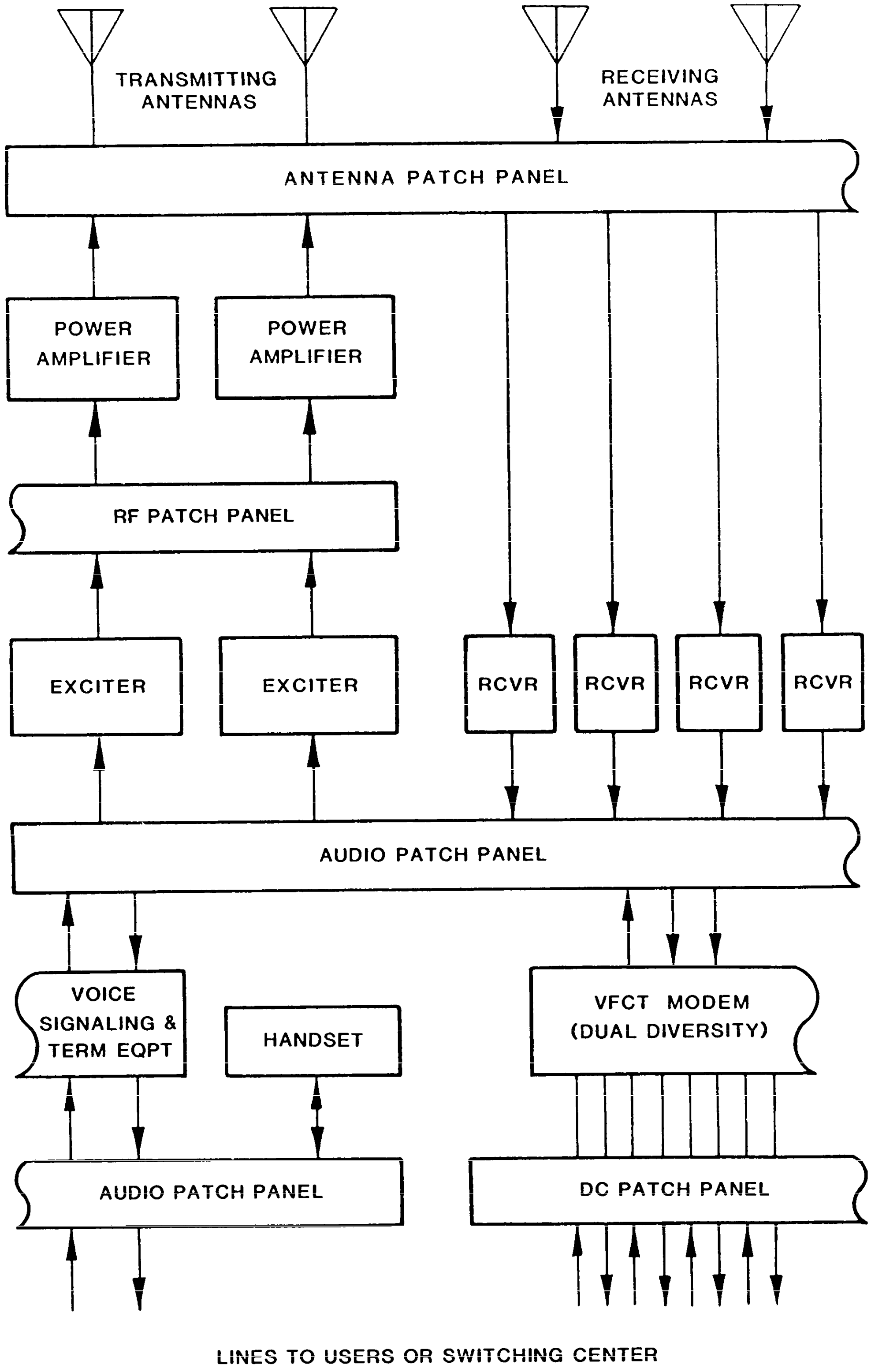


FIGURE 55. HF radio system interfaces in typical transportable or one-site (collocated) configuration.

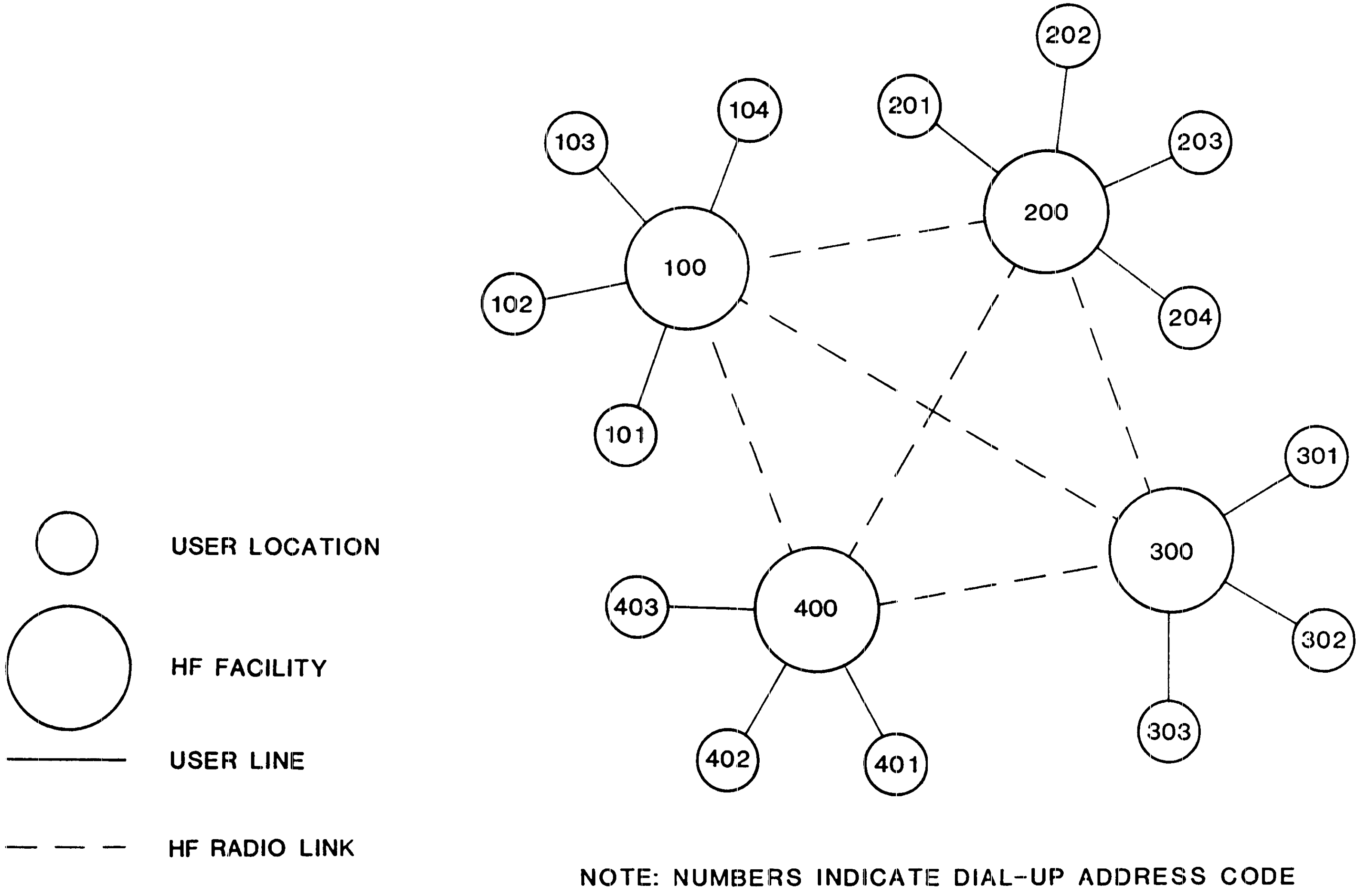


FIGURE 56. Hypothetical user-controlled HF network.

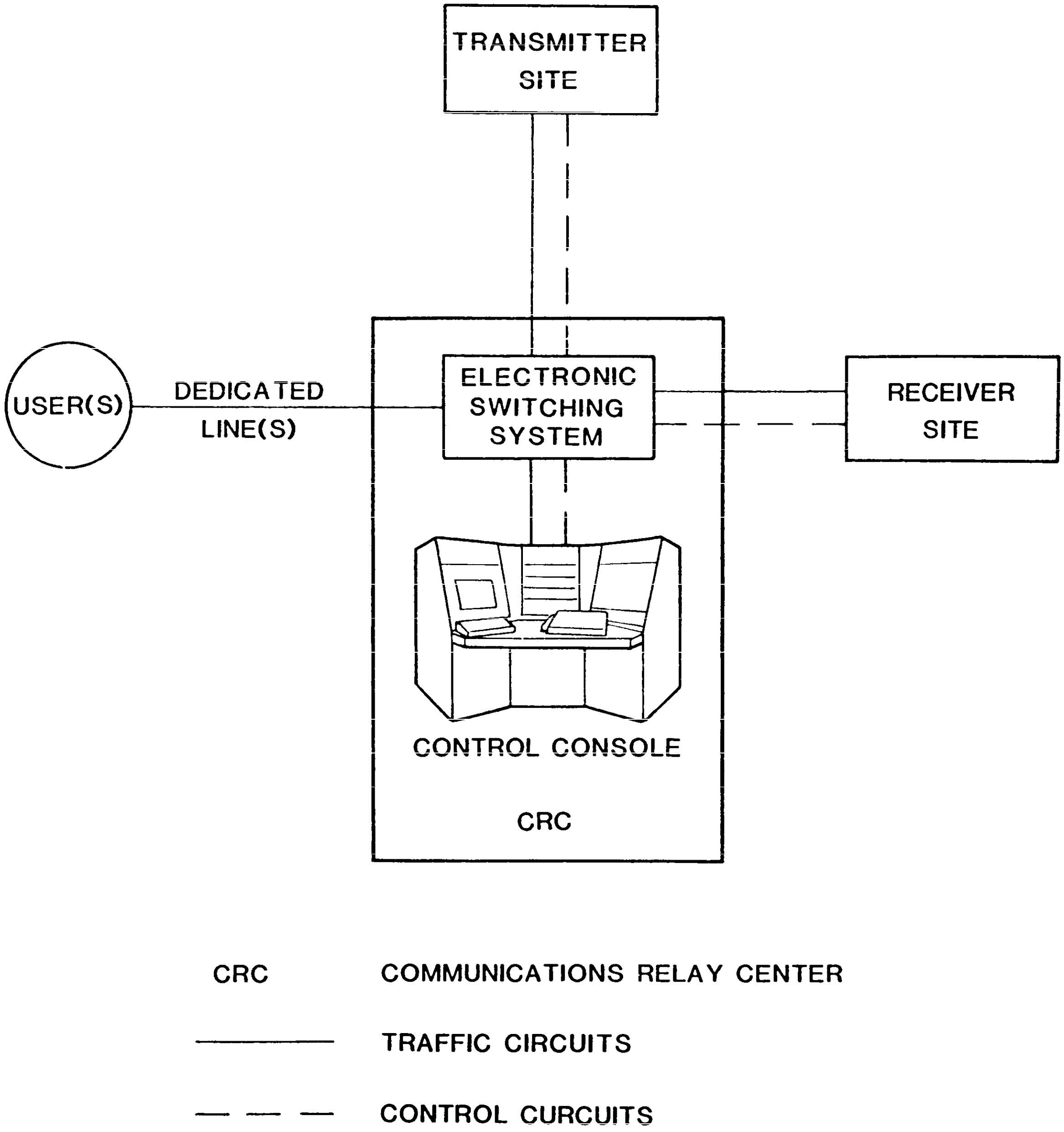


FIGURE 57. Traffic and control circuits in remote-control system.

e. Computer-controlled switching matrices at the radio sites provide for remote selection of transmitting power amplifiers and antennas in the send direction, and antennas in the receive direction. Microprocessor-controlled equipment enables remote selection of frequency and transmitter power output. The patching capability is retained to permit emergency override of the automatic system for emergencies and maintenance purposes. Such an arrangement is shown in figure 58.

4.9 **HF signal enhancement.** It is evident that the ionosphere (see 4.2.2) exists in a state of flux and that radio waves refracted or reflected by it necessarily exhibit certain unstable characteristics. They may return to earth at points other than the intended points. They may vary widely and rapidly in amplitude. And they may be dispersed in time and space. Even so, through the efforts of skilled operators, HF provides a reliable, long-distance communications capability. In system design, provision for diversity operation (particularly on data circuits) can improve communications reliability. Sophisticated error-detection-automatic-correction (EDAC) coding provides greatly reduced error rates in data communications. Computerized ionospheric propagation predictions aid substantially in system design. Ionospheric sounding (see 4.9.3.3) provides data for reliable propagation forecasts and assists in operational frequency management. Automation of the sounding function, in combination with adaptive equipment features, enables real-time link-quality analysis and adaptive response. And the application of spread-spectrum waveforms enables reliable communications in the face of severe interference, including deliberate jamming.

4.9.1 **Diversity.** The signal enhancement brought about by diversity operation is attributable to the fact that different radio paths undergo largely uncorrelated variations. That is, variations such as amplitude fading do not occur simultaneously to an identical extent in two separate paths. The degree of improvement brought about by diversity operation depends on the extent of the lack of correlation between the propagation-induced variations in signals received over two or more paths. The common forms of diversity are space, frequency, polarization, time, and path.

4.9.1.1 **Space diversity.** Space diversity requires two antennas, each feeding a different receiver, spaced sufficiently far apart such that the perturbations in the signals arriving at each are largely uncorrelated. Generally, a spacing of five wavelengths provides reasonable lack of correlation. Of course, wider spacing reduces the correlation even more, but the rate of improvement is usually too small to justify the increased land area and transmission line runs required. The signals at the receiver outputs are routed to a diversity combiner (see 4.5.7). The effect is to fill in the deep fades and, over a period of time, the combined signal will have a higher average value than either of the separate signals.

4.9.1.2 **Frequency diversity.** Signal enhancement due to frequency diversity is based on the assumption that fading does not affect all frequencies equally. It may be implemented through the use of two carrier frequencies or two tones on a single carrier. Both methods are wasteful of the already congested HF spectrum. Carrier-frequency diversity, which provides superior performance to the other method, requires two separate transmitters and two separate receivers, but no additional antennas if diplexers and multicouplers are used. Normally, ground-based frequency diversity installations will employ separate antennas for each transmitter.

4.9.1.3 **Polarization diversity.** Where space is not available to adequately separate two large antennas, polarization diversity provides a compromise solution. By using two receiving antennas — one horizontally polarized; the other, vertically polarized — which can be placed in close proximity to each other, the desired signal can be received over two somewhat uncorrelated paths.

and long paths, space diversity with adequate separation provides better performance on long paths.

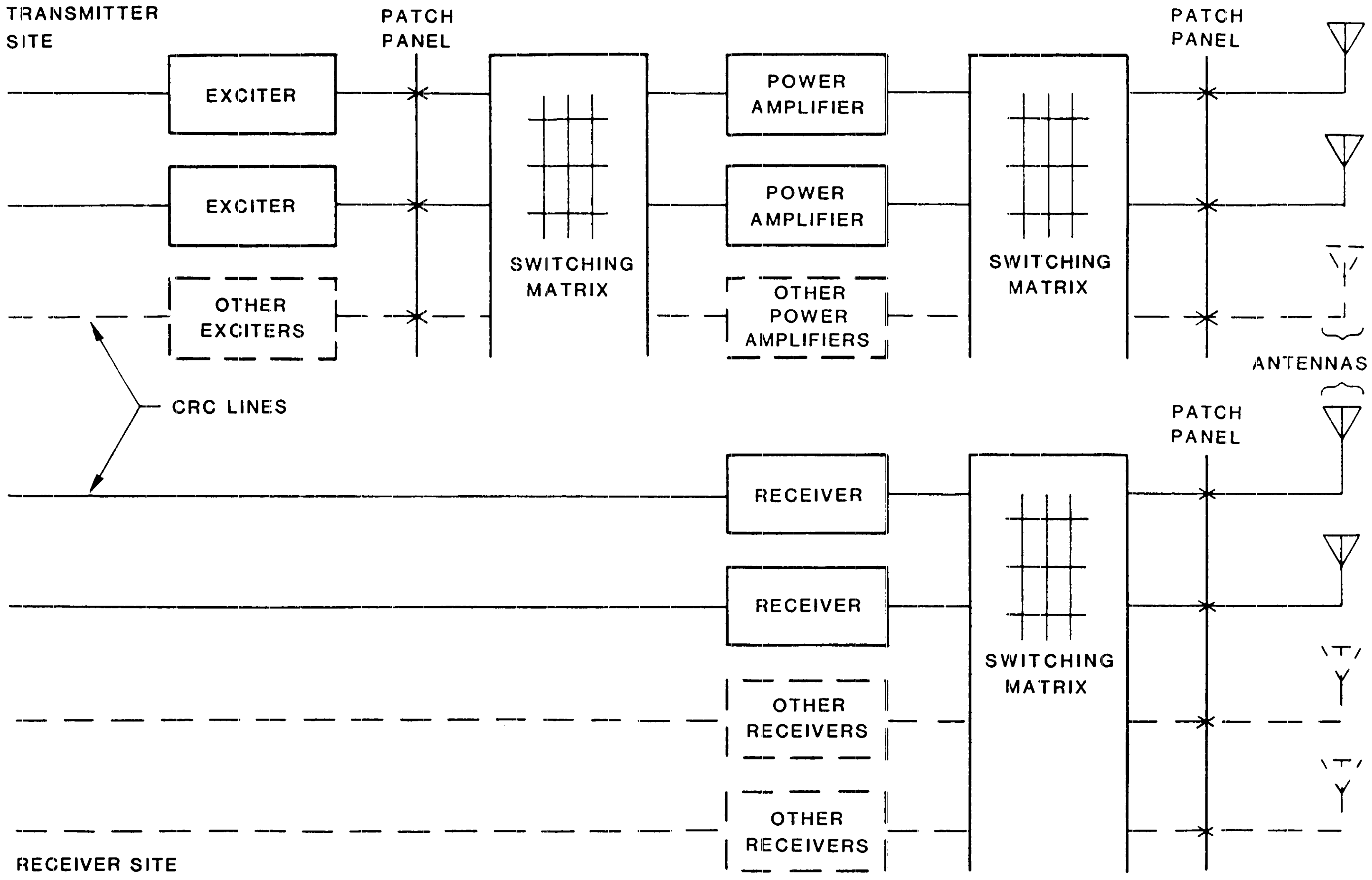


FIGURE 58. Patching and switching at transmitter and receiver sites.

4.9.1.4 **Time diversity.** Time diversity, used in data communications, takes advantage of the fact that error-producing perturbations usually occur in bursts of fairly well defined duration. The time diversity technique places the same information on the same medium two or more times, the times separated by a period longer than the normal duration of an error-producing perturbation. Although this form of diversity requires no additional antennas, transmitters, or receivers, it does require modems capable of repeating message units at the proper intervals and combining the received message units in the proper time sequence. The method provides important signal enhancement even with frequent error bursts, but it does so at the expense of reduced data throughput.

4.9.1.5 **Path diversity.** Path diversity uses geographically dispersed paths, i.e., separate HF radio links, to carry identical signals simultaneously. While it is expensive in terms of HF radio facilities, it provides substantial improvement, particularly in view of the fact that each of the paths can employ its own independent diversity for further improvement.

4.9.2 **Data error control.** A number of methods are available for error control in digital data transmission. They range from simple loop checks and automatic repeat request (ARQ) methods to forward error control (FEC) and error-detection-automatic-correction (EDAC) schemes. All error control is achieved at the expense of reduced data throughput and increased equipment complexity. The error control schemes most frequently used in HF systems are described briefly here. For more detailed descriptions and discussion of coding theory, refer to FM 11-486-24.

4.9.2.1 **Loop check.** The simplest error control method is the loop check. The receiving station sends received data sequences back to the transmitting station, where they are compared with the original sequences for accuracy. If a sequence has errors, it is retransmitted before the next sequence is sent. This method requires a full-duplex configuration. It wastes time and transmission capacity. On the other hand, the return link in a full-duplex system is often underutilized. No special error-control coding is required.

4.9.2.2 **ARQ.**

a. ARQ systems use error-detecting codes. Such codes may be quite intricate and have a high degree of redundancy at the expense of data throughput, or they may be fairly simple with very little redundancy. One commonly used code in HF teletypewriter systems is known as the 3-out-of-7 code. Each teletypewriter character has a 7-bit code: 5 data bits plus two extraneous bits. The seven bits are so arranged that if more or less than three marks, or 1's, are detected at the receiving end, the resulting character is interpreted as an erroneous character. There is a somewhat remote possibility that an error burst could mimic a 3-out-of-7 code character, in which event, an erroneous character would be interpreted as correct. Even so, the code enables a marked improvement in error rate on HF circuits.

b. There are two types of ARQ: "stop-and-wait" and "continuous". The stop-and-wait is the most widely used. In both types, the data message is divided into blocks of predetermined length, say 1000 bits. The blocks are transmitted sequentially. In the stop-and-wait system, the transmitting terminal stops at the end of each block and waits for an acknowledgement (ACK) from the receiving terminal that the block was received without detectable error before transmitting the next block. If the receiving terminal returns a negative acknowledgement (NACK), meaning that an error was detected, the transmitter retransmits the block. In the continous system, the transmitter continues sending blocks, constantly receiving the return ACKs or NACKs. The blocks are individually numbered in sequence, so that if a NACK is returned for a particular block, the transmitter will either retransmit that block or all blocks beginning with that block. The single block retransmission, called selective repeat ARQ, requires extensive logic circuitry and buffering in the transmit and receive terminals. The latter, called pullback ARQ, uses simpler equipment but reduces throughput to a greater extent.

4.9.2.3 **FEC.** Instead of error-detecting codes, forward error control uses error-correcting codes. Such codes require a large number of redundant bits, with consequent substantial reduction in throughput. Although error-correcting codes are not as reliable as error-detecting codes, they have the advantage of not requiring a return path.

4.9.2.4 **Combined ARQ and FEC.** In cases of excessive error rates and retransmission time, ARQ and FEC can be combined to advantage. One combining technique uses a single code structure for both ARQ and FEC functions. The code corrects errors under most conditions and ARQ comes into play only when FEC is inadequate to correct the errors. In another method, a predominantly ARQ system includes some error-correction capability to reduce the number of requests for repeats.

4.9.2.5 **EDAC.** Some of the most advanced HF systems use complex encoding and decoding to provide error-detection and automatic correction. Multistage codes, known as convolutional codes, are used with complex decoding algorithms. An advanced system concept, referred to as robust HF, uses, among other features, a 7-stage convolutional code and a hard-decision, Viterbi decoding algorithm. (A hard decision in this context is simply a 2-level, pulse or no-pulse, decision.) The Viterbi algorithm is based on a trellis structure as opposed to a sequential structure and is named after its designer. Again, FM 11-486-24 provides detailed discussions of coding concepts and terminology.

4.9.2.6 **Bit interleaving.** Bit interleaving is the technique of rearranging bits in an encoded bit stream so that they are dispersed in time. It is effective in assisting the operation of error-correcting codes on burst errors of substantial duration. It is commonly used in conjunction with EDAC.

4.9.2.7 **Packet switching.** Packet switching is a form of store-and-forward message switching intended for real-time machine-to-machine communications in computer networks. Messages are divided into blocks of set length and enclosed in a digital frame structure called a packet. Each packet contains the destination address, other control information, and an error-detection code. The transmitting terminal retains each packet until it receives an ACK from the receiving terminal. If an ACK is not forthcoming in a preset length of time, the transmitting terminal retransmits the packet. Upon reception of the final ACK, the transmitting terminal deletes the packet from storage.

4.9.3 **Adaptive HF.** Historically, skilled operators have adapted HF links to the constantly changing propagation medium. The most experienced operators knew when a frequency would stop propagating and which new frequency (from the assigned frequencies) would permit continued operation. As propagation forecasting became a well-developed science, operators used published frequency charts and broadcast advisories from stations operated by the National Bureau of Standards (NBS). At the present time, day-to-day operations are more likely to use computerized predictions or prediction services, including those available from the U.S. Army Information Systems Engineering Support Activity (USAISESA), Fort Huachuca, Arizona. The published data is more useful for predictions required in system design. In many instances, ionospheric sounding is used to provide real-time data for operations. Advanced adaptive HF systems are now coming into being. Under microprocessor control, they monitor the HF channel and automatically adapt it to the changing propagation medium by changing frequency, adjusting data rates, or changing the modulation type.

4.9.3.1 **Published propagation forecasts.** Propagation forecasts published by the U.S Department of Commerce, available through USAISESA, cover groundwave and skywave propagation in three sets of books. The skywave books are published in two sets: one for intermediate and short distance skywave, the other for air/ground skywave. Also, the DoD Electromagnetic Compatibility Analysis Center (ECAC), Annapolis, MD, publishes quarterly propagation supplements for the U.S. military services.

a. Groundwave propagation charts for selected areas of the world provide predicted distance ranges. Charts are currently available for 24 areas located in the continental United States, Central America, Europe, Africa, and parts of Asia, South America, and Greenland. Predictions in the charts cover all seasons.

b. The Intermediate and Short Distance Skywave (ISD) Books give the MUF, FOT, and LUF. They are useful for propagation predictions over paths up to 2400 km in length. There are 33 ISD books covering the continental United States, Central America, South America, Europe, Africa, Greenland, and parts of Asia. The air/ground skywave (A/G) books give lists of frequencies for air-ground communications within an 8340 km radius of 57 selected ground stations throughout the world.

c. In addition to the groundwave and skywave propagation books, USAISESA issues reports in the form of messages on day-to-day ionospheric activity. The reports cover 7-day periods. They are based on messages and alerts from Global Weather Central, an element of the Air Weather Service at Offutt Air Force Base, Nebraska. The reports review propagation conditions for the prior week and forecast solar and geomagnetic activity for the next 7 days (short-term forecast) and the next 30 days (long-term forecast). The reports include narrative descriptions of propagation conditions over polar, auroral, and low, mid, and equatorial latitudes.

4.9.3.2 **Computer prediction models.** Computer prediction models serve a number of purposes, ranging from analysis of proposed communications links to electromagnetic compatibility (EMC) assessment and the effects of nuclear blasts. Table IV lists the most prominent of the current models. A number of computer prediction models and computerized prediction services are available through USAISESA; among them PROPHET, Ionospheric Communications Analysis and Prediction Program (IONCAP), MINIMUF, and MINIMUF BASIC. Predictions are also available from the Air Force Communications Command (AFCC), Naval Electronics Systems Command (NAVELEX), and ECAC.

a. **PROPHET.** PROPHET is the name of a group of HF computer models designed for field use. The programs in the group define the propagation constraints and provide data for propagation planning. The data are intended to improve HF link effectiveness, to assist in achieving a low probability of intercept and location by the enemy, and to reduce vulnerability to jamming. All models in the group are designed for programmable calculators. The models require ongoing software and engineering support which is provided by the Army Master Prediction Support System (AMAPSS), a USAISESA system.

TABLE IV. Computer prediction models for HF.

Model	Acronym	Agency
High frequency communications assessment model	HFCAM	ECAC
HF electromagnetic compatibility	HF EMC^2	NOSC
HF maximum usable frequency evaluation	HFMUFES-4	ITS
Ionospheric comm analysis and prediction program	IONCAP	ITS
Minicomputer model for predicting MUF in HF comm	MINIMUF-3.5	NOSC
Effect of nuclear burst on HF communications	NUCOM-II	SRI
Propagation forecasting and assessment system	PROPHET	NOSC
Quiet-time lowest usable frequency	QLOF	NOSC
HFMUFES-4 ionospheric propagation model	RADARC	NRL
Sudden ionospheric disturbance grid	SIDGRID	NOSC
HF skywave propagation model	SKYWAVE	ITS
X-ray flare and shortwave fade duration model	XRAY FLARE	NOSC

ECAC — Electromagnetic Compatibility Analysis Center

ITS — Institute for Telecommunications Sciences

NOSC — Naval Ocean Systems Command

NRL — Naval Research Laboratory

SRI — Stanford Research Institute

b. **IONCAP 11-year propagation analysis.** IONCAP was developed by the Institute for Telecommunications Sciences (ITS), the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce. It includes an 11-year propagation analysis, the purpose of which is to provide data for HF system design that will permit a specified level of performance over the extremes of sunspot activity experienced in the solar cycle. Program users input transmitter and receiver locations, transmitter power output, required signal-to-noise ratio, frequency limitations, and estimated man-made noise levels. The program contains the necessary ionospheric physics data. The program can assume either isotropic (theoretical point source) antennas or models of antennas from either internal or external sources. Special output routines can be invoked to provide the required frequency range, the range of required take-off angles, the required overall system gain, and low-end cutoff frequencies. The data are intended to provide system designs that will yield 90 percent circuit reliability for 90 percent of the hours over the 11-year solar cycle.

c. **IONCAP point-to-point propagation prediction tables.** Program users input transmitting and receiving location coordinates, antenna types, required signal-to-noise ratio, desired month, sunspot number, man-made noise level, and the available frequency complement. The program outputs a table of reliabilities as a function of frequency and time. The reliabilities are presented to indicate the percentage of undisturbed days during a month that the required signal-to-noise ratio is met or exceeded. The charts are available on a one-time basis or as a recurring monthly or quarterly report.

d. **MINIMUF.** MINIMUF is a PROPHET program for predicting MUF using small-scale microcomputers. The original version was developed by the Naval Ocean Systems Center (NOSC). It has only 80 program steps and permits the use of only a few input variables: transmitter and receiver location, time, date, and sunspot number (SSN). It assesses propagation by way of the F layer only with a linear MUF/SSN relationship. It is reasonably accurate for frequencies between 2 and 30 MHz and distances from 800 km to 8000 km. To extend its usefulness, MINIMUF is also available in the BASIC programming language. Later versions, though longer and more complex, include such accuracy improving routines as a nonlinear MUF/SSN relationship.

4.9.3.3 Ionospheric sounding.

a. Sounding of the ionosphere provides research data for the various propagation forecast publications and data for frequency selection at the time of the sounding. A sounder is, in effect, an HF test link. It consists of a transmitter and receiver and uses its own or the operating system antennas. A step-sounder transmitter emits signals at discrete frequencies over a range of frequencies. Chirpsounders(R) sweep the frequency range. The time delay between transmission and reception on each frequency is translated into ionospheric layer height. An oscilloscope-type display, known as an ionogram, shows height as a function of frequency, thus, giving a display of available skywave transmission modes. The groundwave return is also displayed. Some modern sounding equipment has added a printout capability to the display.

b. There are two basic classifications of ionospheric sounding, depending on the location of the sounding equipment with respect to the ionosphere: bottomside and topside. Bottomside sounding is accomplished from stations below the ionosphere, generally ground stations. Topside sounding is accomplished from satellites above the ionosphere. Both types use either vertically incident or obliquely incident radio waves.

c. Vertical-incidence sounders use collocated sounding transmitters and receivers. They direct the signals vertically to the ionosphere. An algorithm is used to convert the vertical-incidence data for use on oblique paths.

d. Oblique sounders, using a transmitter at one end of a circuit and a receiver at the other end, provide more accurate results for the usual oblique radio path.

4.9.3.4 **Frequency management using sounding.** Ionospheric sounding provides an up-to-date basis — in some cases, real-time — for frequency management of HF links and networks. Used in conjunction with spectrum analyzers, they display received power level as a function of frequency and enable selection of clear (not in use) frequencies that will propagate in the desired manner. (Modern spectrum analyzers are microprocessor-controlled receivers that monitor the frequency band and provide a display of spectrum occupancy and noise conditions across the band.) The AN/TRQ-35(V) Tactical Frequency Management System is an example of the combination of ionospheric sounding and spectrum monitoring to provide timely data for frequency management, usually in conjunction with a propagation prediction program such as PROPHET.

4.9.3.5 **Link quality analysis.** Link quality analysis (LQA) is a means for providing current data on the actual conditions of assigned frequencies over operational links. Whereas sounding provides data on which frequencies are propagating, LQA provides data on the signal-to-noise ratio or error rate performance they will provide. LQA uses the same transmitter, receiver, and antennas used for traffic, thereby providing performance analysis of the active link. It monitors in-traffic frequencies and performs tests on unused assigned frequencies.

4.9.4 **Advanced adaptive HF systems.** Advanced adaptive HF systems automatically monitor the propagation channel and change frequencies and data transmission rates to adapt to the channel characteristics. The radio equipment is designed to operate under microprocessor control. System control is generally provided by advanced modems. This subsection describes the most used features made possible by advanced adaptive monitoring and control:

a. Selective calling and scanning.

b. Automatic LQA (ALQA).

c. Automatic interconnectivity.

d. Automatic relaying.

e. Code combining.

4.9.4.1 **Selective calling and scanning.** Selective calling, or automatic link establishment (ALE), is based on the assignment of discrete addresses to the individual stations in a network. To initiate a call, the user selects the desired address and keys the transmitter, generally through an automatic keying device such as a dual-tone multifrequency (DTMF) telephone handset or data terminal. The transmitter repeatedly transmits the address on each of the assigned frequencies in turn until the addressee responds. The response occurs within seconds (see 4.9.4.3), since all receivers in the network are continuously scanning the preset channels for their addresses.

4.9.4.2 **ALQA.** ALQA uses the selective calling and scanning signals. Each transmitter in the network assigned to call origination service uses a computer data base containing data on the quality of all links in the network. The address and response signals provide link data for updating the link quality data base. The ALQA updates are made periodically through either network-wide broadcasts or roll calls.

4.9.4.3 **Automatic interconnectivity.** When a user initiates a call, as in 4.9.4.1 above, the transmitter selects the best frequency for the call from the link quality data base. Moreover, each transmitter station has the capability to monitor the spectrum or the assigned frequencies and recognize frequencies already in use. Thus, if a frequency identified as best by the link quality data base is already in use, the transmitter automatically selects the next best frequency from the data base. Since link quality is not always reciprocal, a "handshaking" process between the transmitter and receiver microprocessors establishes the optimum frequency for reciprocal operation. Interconnectivity is automatically assured.

overhaul events required to occur throughout the maintenance

4.9.4.4 **Automatic relaying.** In cases of difficult transmission, significant improvements in connectivity can be achieved through automatic relaying. If a transmitter cannot contact a desired receiver directly because of ionospheric conditions or jamming, a preprogrammed microprocessor, using ALQA and spectrum monitoring, can automatically select an alternate receiving station and relay the transmission through that station to the desired receiving station.

4.9.4.5 **Code combining.** Code combining provides a means for error-free communications. The technique consists of combining data packets from different transmissions. Single packets are retransmitted as many times as necessary, up to a pre-established threshold point, so that when they are combined and decoded, the resultant is error-free. Data throughput, of course, is reduced in accordance with the number of packet retransmissions required.

4.9.5 **High performance systems.** High performance HF systems are designed to provide reliable communications under adverse propagation and interference conditions without the intervention of skilled operating personnel. They combine some or all of the signal enhancement techniques described thus far in this section. Notable among the high performance systems currently under development are Regency Net, Advanced Narrowband Digital Voice Terminal , and Navy High Frequency Anti-Jam and Newlook.

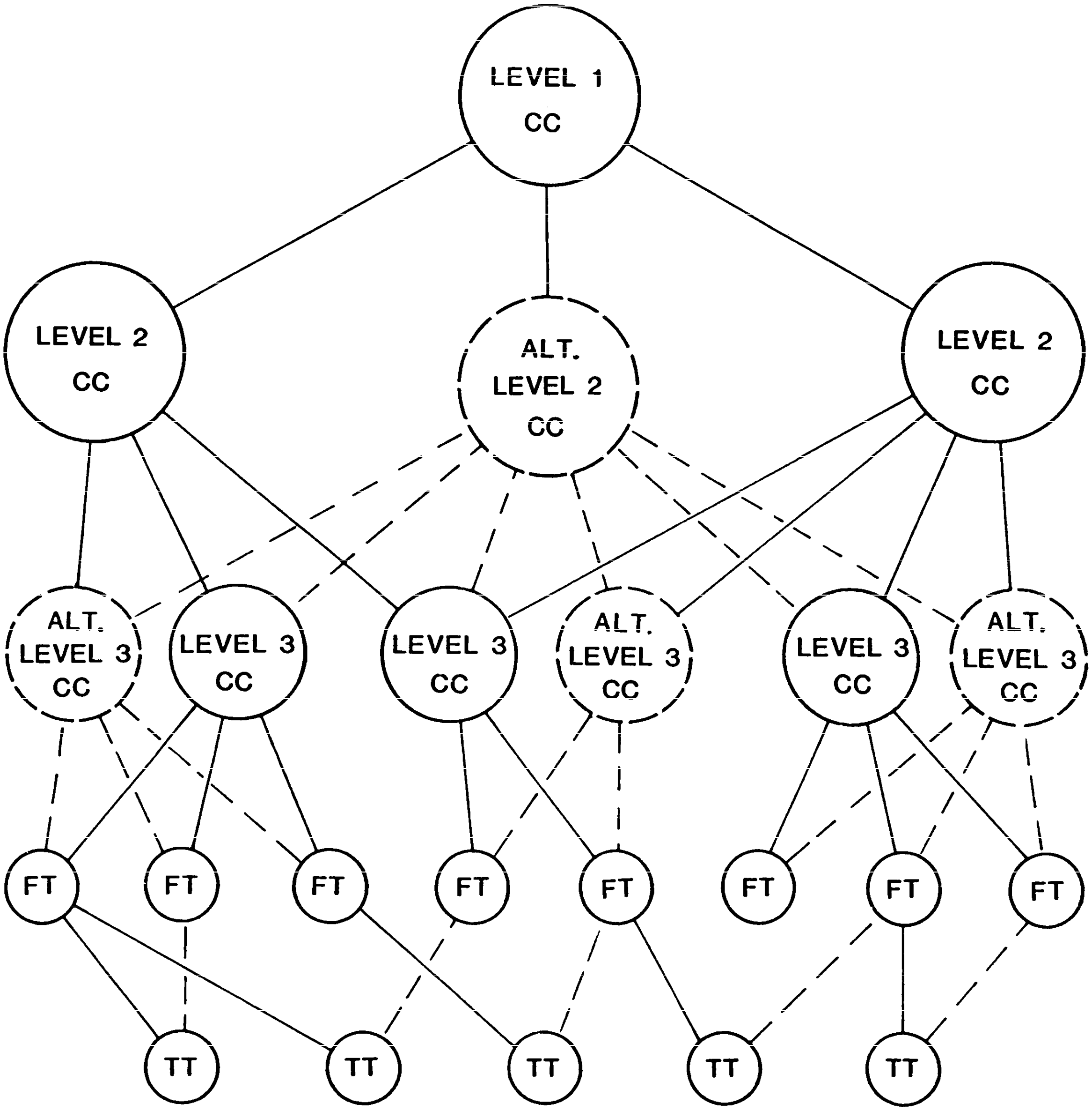
4.9.5.1 **Regency Net.** The purpose of Regency Net is to provide reliable, jam-resistant record (digital data) traffic. It uses a combination of techniques lumped together under the name, robust HF.

a. Robust HF takes advantage of signal-enhancement techniques and elaborate network architecture. Basically, it uses frequency-hopping spread spectrum with a specially designed "energy" receiver, sophisticated coding and decoding for synchronization, error detection and automatic correction (EDAC), real-time ALQA to activate adaptive features, and a tree-structured network (see figure 59) with redundant routing. Robust HF systems are not affected by multipath or interference from atmospheric or man-made noise. They perform well against even extensive jamming.

b. The modulation format is frequency-hopping spread spectrum, using assigned frequencies over the entire range from LUF to MUF. The frequency-hopping format uses FSK to enable detection by the bandpass-filtering, envelope-detection method. If significant energy is present in the bandpass for a given frequency, the receiver interprets it as a signal at that frequency. Consequently, if a frequency-following jammer is being used, energy will be present in the bandpass (at possibly greater magnitude than the desired signal energy) and the receiver will automatically interpret the presence of the energy as the desired signal. The decision time-slot is made sufficiently narrow so that time-dispersion by multipath has no effect. As long as energy exists during the time-slot, the receiver will interpret it as a signal and cut off further reception of energy arriving later from the same signal.

c. The basic encoding scheme is 7-stage convolutional coding. A hard-decision Viterbi algorithm is used for demodulation. (Refer to FM 11-486-24 for explanation of coding and decoding techniques.) ALQA controls adaptive decoding by code combining.

4.9.5.2 **Advanced Narrowband Digital Voice Terminal (ANDVT).** The purpose of the ANDVT is to enable the transmission of encrypted, digitized voice signals over HF links. It uses a signal compression scheme called linear predictive coding (LPC) and a 39-tone, bit-packing, modulation scheme.



ALT.	ALTERNATE
CC	COMMUNICATIONS CENTER
FT	FORCE TERMINAL
TT	TEAM TERMINAL

FIGURE 59. Example of tree-structured network for robust HF.

a. LPC encodes a voice signal as numbers derived from the instantaneous spectral characteristics of the signal. While the numbers bear no analog relationship to the voice signal, they are used in demodulation to produce an analog signal resembling the original voice signal. At the present stage of development, LPC compresses a 3-kHz voice signal into a 2.4-kbps digital data stream. The algorithm which brings this about uses a linear mathematical relationship to predict the value of each successive sample it is digitizing. Once the data is encoded by LPC, it is encrypted by combining it with a string of numbers generated by a "key" generator. Upon reception, the bits are synchronously detected and the stream is decrypted by the same key used for encryption. The inverse of the LPC process converts the resulting numbers to the original voice signal.

b. Transmission of the 2.4-kbps encrypted LPC signal would normally require 6 kHz or more of bandwidth using AM, binary FSK, or biphase PSK. For HF transmission, it is desirable to fit the signal into a 3-kHz transmission bandwidth. ANDVT does this using a modulation scheme which achieves a 1-Hz/bit packing density. The 2.4-kbps bit stream is split into a number of parallel data streams of lower rate. Each of the slower streams modulates one or more of 39 tones within the 3-kHz bandpass. The modulated tones are then applied as a composite signal (similar to that used by VFCT) to modulate the exciter stage of the transmitter.

4.9.5.3 **High Frequency Anti-Jam (HFAJ).**

a. Navy shipboard HF systems face the severe problem of providing EMC with minimum sacrifice of system performance. Moreover, conventional shipboard HF terminal configurations are not compatible with the broadband requirements of the newer, enhanced-waveform, anti-jamming systems. Finally, the time required to change frequencies precludes the use of automated adaptive techniques based on rf channel-scanning. To eliminate these drawbacks to effective use of modern HF techniques, the Navy is engaged in the HFAJ research and development program.

b. The HFAJ is aimed at providing a wideband system in which the key elements are: highly linear transmitting power amplifiers, rapid-tune whip antenna base tuners and couplers operating under microprocessor control, and a programmable modem. The modem is to be capable of multichannel fleet broadcast and interoperation with TADIL A, Link 11, the data mode of the ANDVT, and MIL-STD-188-200 digital data. The HFAJ also includes the development of an anti-jam modem. Figure 60 is a block diagram of the proposed HFAJ wideband system.

4.9.5.4 **Newlook.**

a. The Newlook development program is aimed at providing reliable, wartime communications over ground-to-ground, ground-to-air, and air-to-ground HF links. The system will use ALQA adaptivity to enable operation under conditions of disturbed ionosphere (caused by solar flares or nuclear explosions), as well as the normally constantly changing ionosphere. According to system philosophy, however, adaptivity concentrates all system resources to determine and execute the one strategy most likely to succeed. Diversity, on the other hand, dilutes or augments system resources for the execution of many strategies, with a high probability that one or more of them will succeed. Consequently, Newlook also makes use of frequency, time, and space diversity.

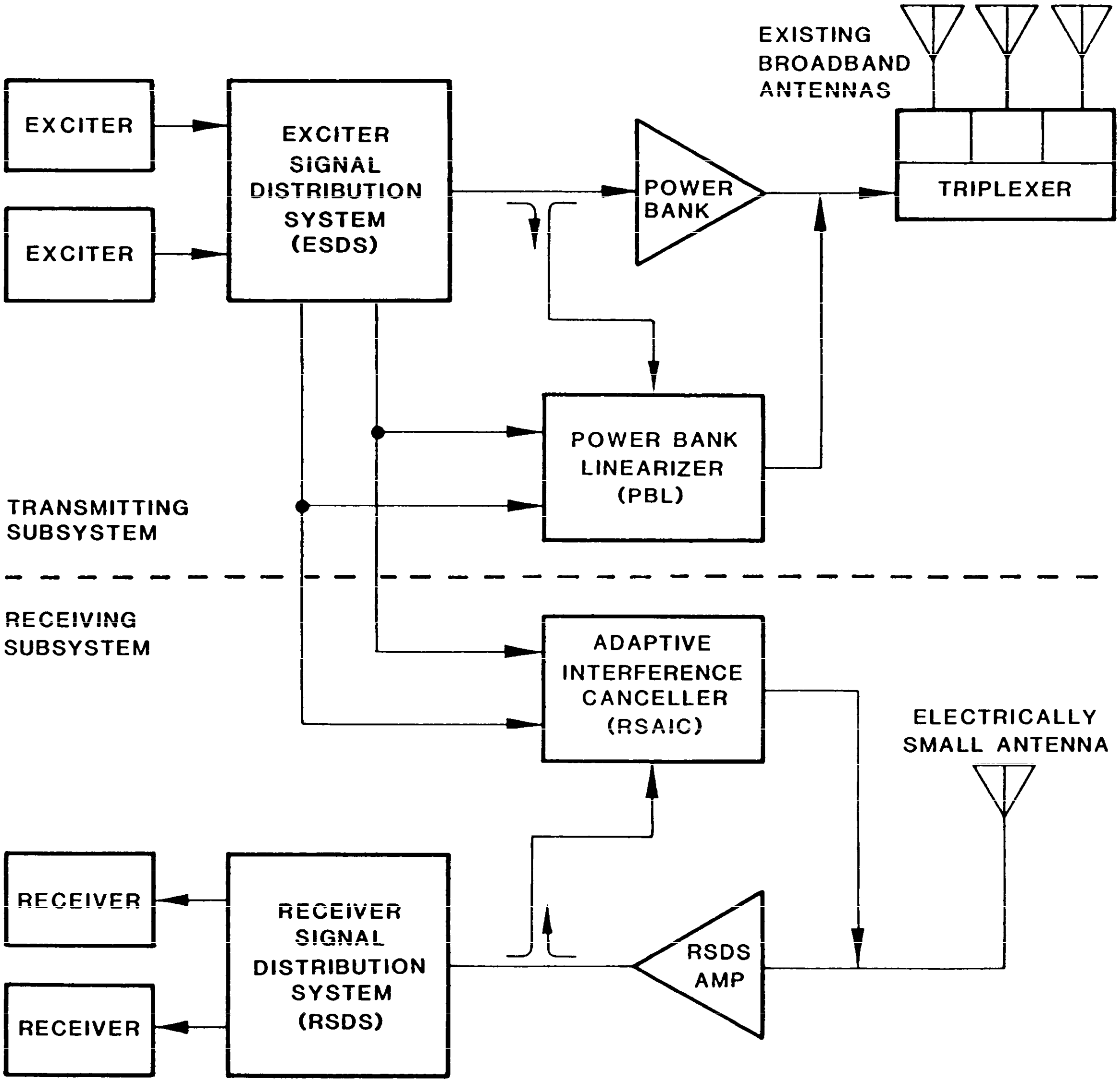


FIGURE 60. Navy High Frequency Anti-Jam (HFAJ) shipboard terminal configuration.

b. The system uses quaternary FSK to send two data bits per frequency in a frequency-hopping signal format. Coding and decoding algorithms are designed for EDAC. The system uses a network structure that provides multiple relays and enables path diversity. A companion program, Stresscom, is aimed at producing a transceiver to interoperate with the Newlook system.

4.9.5.5 **High performance modems.**

a. In addition to the major development programs, there are currently available a number of high performance modems which incorporate many of the features of the major systems.

b. The trend in high performance modems is to combine many features. Thus, a single modem will multiplex data signals of various rates, originate transmissions to selected locations, establish connectivity over station-to-station links or broadcast networks, automatically poll receiving stations, change modulation type, change the order and type of diversity, accommodate a variety of signal formats and protocols, perform ALQA, accomplish bit-interleaving for time-dispersion of signals, and operate EDAC schemes.

c. An important function provided by many modems is interoperability. Different communications applications among the three services, other agencies, and cooperating foreign military services use different waveforms and different communications protocols. Illustrative of the diversity of formats are: the AN/FGC-54 (KINEPLEX) 12-tone, 2400-bps data; the Navy fleet broadcast (VECT); the MIL-STD-188-200 16-tone PSK; the Navy Tactical Data System (NTDS); the Airborne Tactical Data System (ATDS); the Tactical Digital Information Link (TADIL); and the STANAG (NATO) 5511 Link 11. Because of the lack of standardization among the systems of the various organizational entities, the responsibility for interoperability falls upon the operating elements and is accomplished through complex modems. MIL-STD-188-148 is the DoD interoperability standard for anti-jam HF communications systems. All new equipment procurements and all systems modifications for anti-jam HF systems are required to be able to operate in the MIL-STD-188-148, Tri-Service Waveform Mode.

5. DETAILED ENGINEERING

5.1 **Overview.** HF radio system design consists primarily of the detailed engineering of individual radio links. Individual links can be formed into communications networks through the development of network topology (layout and interconnectivity) and implementation of network controls. A procedure for detailed link engineering is given in the flow diagram of figure 61. The procedure entails analysis of the communications requirements, consideration of the constraints on system design, synthesis of a link to meet the requirements, and prediction of link performance.

5.2 **Communications requirements analysis.** The communications requirements to be satisfied by a particular link may be stated explicitly in terms of geographical locations, numbers and types of channels, requirements to interoperate with other links or systems, and performance criteria. However, it is often necessary to derive a statement of the communications requirements from an analysis of the military mission to be served by the communications.

5.2.1 **Geographical location.** The geographical locations of the communications systems users broadly establish the radio terminal locations and, thereby, establish the important link design parameters of path length, operating frequency range, atmospheric noise level, ground conductivity, and antenna selection.

5.2.1.1 Path length.

a. Path length determines the major system power loss factor — propagation distance loss — that must be offset by the transmitter power output and antenna gains. In the broadest sense, it determines the predominant propagation mode: groundwave or skywave. Together with the ionospheric makeup over a skywave path at a given time, it determines whether propagation will occur by way of a single hop or multiple hops. The propagation mode and number of hops influence the choice of transmission equipment, particularly antennas.

b. For short links over suitable terrain, assume groundwave propagation. The most suitable terrain is the ocean. Sea water has the highest conductivity of any natural terrain substance and oceans do not have terrain obstructions. The least suitable terrain, for HF groundwave propagation at least, is mountainous or jungle. High-angle skywave is indicated for both. Use vertically polarized antennas for groundwave propagation to minimize ground absorption of signal energy.

c. For long links assume skywave propagation. Determine the great circle distance for long links using calculation services or computer programs provided by USAISESA. Both require the latitude and longitude to the nearest minute of the two terminal sites.

5.2.1.2 Operating frequency range.

a. The geographical location of the radio path is an important factor in determining the range of operating frequencies. For link design associated with long-term planning, determine the range of suitable frequencies for the entire 11-year sunspot cycle by calculating the limits corresponding to the sunspot maxima and minima. Charts published by USAISESA give MUFs for sunspot numbers of 10 and 110, a sufficient spread for most engineering purposes. If a link is to operate full-period, as is usually the case, include consideration of diurnal and seasonal effects on frequency propagation.

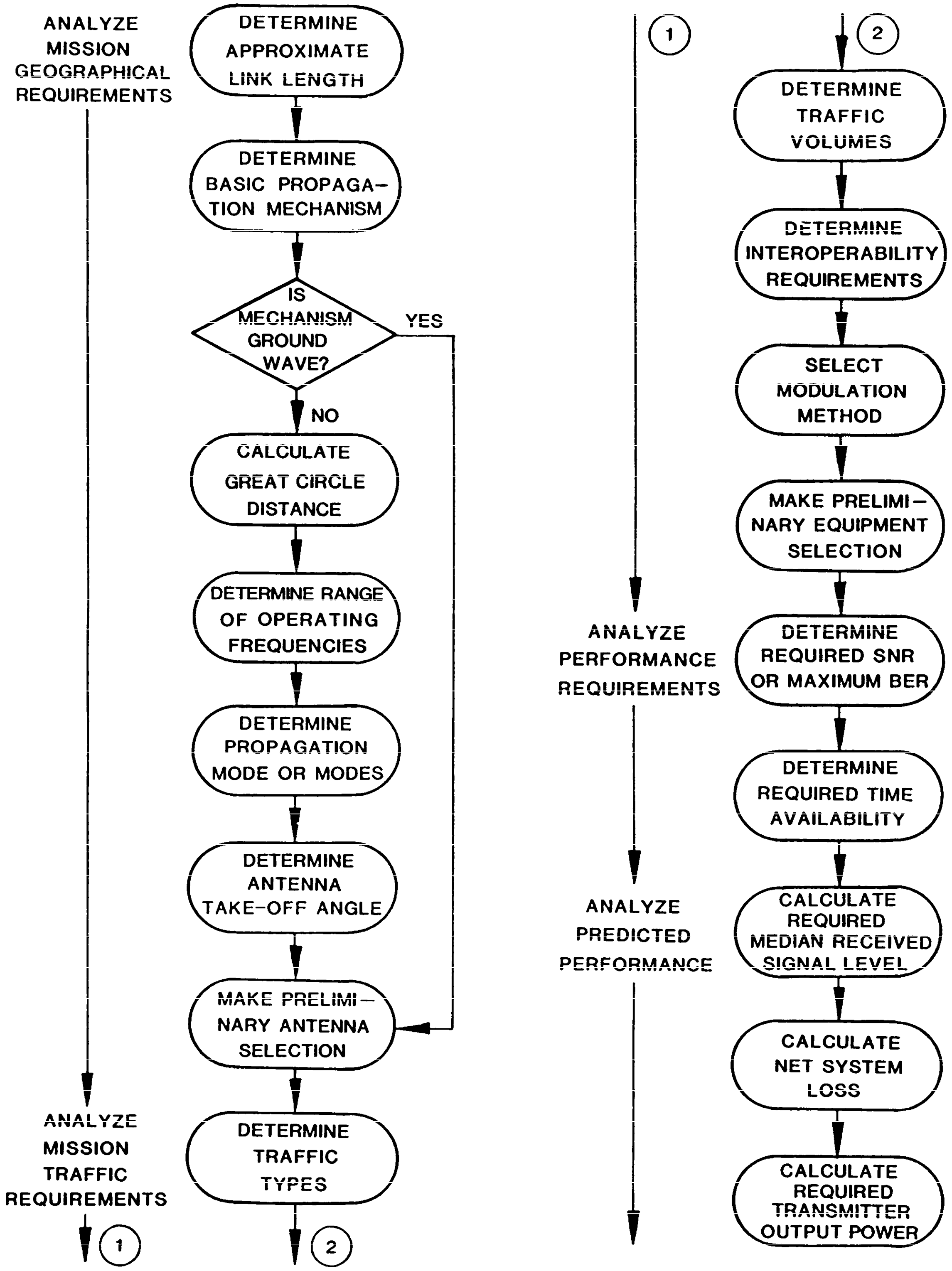


FIGURE 61. HF radio link detailed engineering procedure.

b. In the design of links with a limited life span, determine the range of suitable frequencies in accordance with the prevailing sunspot number for the period of interest, again taking into account the times of day and the seasons.

5.2.1.3 **Atmospheric noise.** The geographical location of the radio path determines the level of atmospheric noise that will be encountered during a given time period. (Determination of atmospheric noise levels is part of the performance analysis, 5.4.)

5.2.1.4 **Man-made noise.** The exact site location of link terminals is often critical from the point of view of ambient man-made noise. Certain site locations may be ruled out by the inability to mitigate overwhelming man-made noise levels.

5.2.1.5 **Ground conductivity.** In groundwave links, the nature of the site terrain determines the ground conductivity. The site location, for multihop skywave links, determines the location of the ground reflecting points and, hence, the terrain and ground conductivity at these points.

5.2.1.6 **Antenna type selection.** The exact site location and local radio horizon of link terminals often influence antenna choices, since they define the land area available for antennas and the effect of surrounding topography on take-off angles. (Refer to table II (4.6.1) for general antenna characteristics. Antenna selection from the point of view of antenna gains is part of the performance analysis, 5.4.)

5.2.2 **Traffic requirements.** Ultimately, communications traffic requirements must be stated in terms of numbers and types of channels and traffic routing (for network configuration). Channel requirements influence the choice of modulation method and link terminating equipment, e.g. modems, multiplexers, signaling and terminating devices, and end instruments.

5.2.2.1 **Number of channels.** Since the HF spectrum is such a limited resource, the amount of bandwidth allocated per link is also limited. Hence, traffic volume for a link can be converted directly into numbers of channels without resort to the distribution and grade-of-service calculations involved in high-capacity media. For new link design, historical data on traffic in similar systems is often the only means for estimating traffic volume. In existing systems slated for upgrading, traffic records and measurements can provide the basis for channel estimation.

5.2.2.2 **Channel types.** The nature of a military mission generally dictates the types of traffic that will be involved and, consequently, the channel types. Command and control functions rely primarily on voice communications in which voice characteristics recognition is of significant importance. Administrative functions imply teletypewriter communications involving hard copy. In modern management information services, computer data communications are used. Battlefield communications rely heavily on voice, with some teletypewriter and digital data requirements. Naval fleet communications involve voice, teletypewriter, and computer data communications. Air-to-ground HF communications are generally limited, at present, to voice and low speed digital authentication codes, but in the future may include teletypewriter and computer data.

5.2.2.3 **Modulation.** The modulation type must be selected on the basis of performance in terms of the time availability of a specified signal-to-noise ratio (SNR) or digital data bit error ratio (BER). For skywave links, the choice must take into account fading and the bandwidth restrictions caused by multipath propagation. For radio links to be employed in warfare communications, modulation types are required that resist enemy jamming and produce signals that are difficult to detect and intercept. Table V summarizes the following modulation selections.

a. For single-channel voice, use SSB. It provides the best SNR performance of the modulation types available to HF radio.

b. For multichannel voice, use ISB. It is the only available means for multiplexing voice channels for HF radio transmission.

c. For single-channel teletypewriter, use FSK. For a given power budget and noise environment it provides superior BER performance to the alternative ICW. For compatibility with existing systems, use a frequency shift of either 850 Hz or 170 Hz, depending on the system.

d. For VFCT, use FSK with a frequency shift and multiplexing scheme corresponding to those of an existing system. Where compatibility with older systems is not an issue, use DPSK to take advantage of the improved BER performance and spectral efficiency.

e. For digital data, including time-division multiplexed (TDM) signals, use DPSK. For maximum spectral efficiency, use DQPSK.

f. For warfare communications, use frequency-hopping spread spectrum compatible with the particular network or system with which the link must interoperate.

TABLE V. Selection of modulation techniques.

Traffic Type	Modulation Type
Manual or machine telegraph	ICW
Single-channel voice	SSB
Multichannel voice	ISB
Single-channel teletypewriter	FSK
Multichannel teletypewriter	FSK (VFCT)
Computer data and TDM	DPSK, DQPSK
Warfare communications	Frequency-hopping spread spectrum

5.2.3 **Interoperability.** Military missions may require interoperability with the HF radio systems of other services and other nations. MIL-STD-188-141, Interoperability and Performance Standards for High Frequency Radio Equipment, addresses interoperability by reference to appropriate national and international standards and agreements. All new HF anti-jam equipment procurements and all HF anti-jam system upgrade programs are required to meet the requirements of MIL-STD-188-148, Tri-Service Waveform Mode.

5.2.3.1 **Tactical Digital Information Link (TADIL) A.** Interoperability standards for systems or links intended as part of TADIL A are given in MIL-STD-188-203-1, Subsystem Design and Engineering Standards for Tactical Digital Information Link (TADIL) A.

5.2.3.2 North Atlantic Treaty Organization (NATO) Standardization Agreements (STANAGs).

a. **Single-channel systems.** STANAG 4203, Technical Standards for Single Channel HF Radio Equipment.

b. **Naval gunfire support systems.** STANAG 5009, Minimum Military Characteristics of Radio Frequency Equipment for Naval Gunfire Support of Shore Forces.

c. **Shore-to-ship broadcast systems.** STANAG 5031, Minimum Standards for Naval HF, MF, and LF Shore-to-Ship Broadcast Systems.

d. **SSB voice systems.** STANAG 5032, Basic Technical Characteristics for SSB Single Channel Voice Communications Between 1.5 and 30 MHz in the Mobile Services.

e. **Maritime air communications systems.** STANAG 5035, Introduction of an Improved System for Maritime Air Communications on HF, LF, and UHF.

5.2.3.3 **Quadripartite Standardization Agreements (QSTAGs).** QSTAGs are intended to provide for interoperation among American, British, Canadian, and Australian (ABCA) armed forces. In particular, interoperation among HF combat net radio equipment is covered by QSTAG 263A, Standards to Achieve Interoperability of ABCA Armies High Frequency Combat Net Radio Equipments.

5.2.4 **Performance.** Military standards have been promulgated to establish uniform performance standards for all types of communications systems. In addition, military communications systems benefit from design in accordance with interface standards established by the Electronic Industries Association (EIA). For interoperability with the national and commercial systems of other nations, the recommendations of the International Telecommunications Union (ITU) are often invoked as design standards. To ensure state-of-the-art performance, the recommendations of the National Telecommunications and Information Administration (NTIA) are observed where possible. In particular, the following military standards are applicable to the design of military HF radio systems:

a.	MIL-STD-188-100	Common Long Haul and Tactical Communication System Technical Standards
b.	MIL-STD-188-110	Equipment Technical Design Standards for Common Long Haul/Tactical Data Modems
c.	MIL-STD-188-114	Electrical Characteristics of Digital Interface Circuits
d.	MIL-STD-188-141	Interoperability and Performance Standards for High Frequency Radio Equipment

e.	MIL-STD-188-200	System Design and Engineering Standards for Tactical Communications
f.	MIL-STD-188-317	Subsystem Design and Engineering Standards and Equipment Technical Design Standards for High Frequency Radio
g.	MIL-STD-188-323	System Design and Engineering Standards for Long Haul Digital Transmission System Performance

5.2.4.1 Voice channel performance.

a. MIL-STD-188-100, MIL-STD-188-200, and MIL-STD-188-323 provide general design criteria for 3-kHz telephone (voice) channels, such as those traversing HF radio links. The standards do not, however, cite specific HF system performance criteria. Such criteria are included in MIL-STD-188-141.

b. For the present, military HF radio system design uses the following voice-channel performance criteria:

(1) Recommendation 339-5, *Bandwidths, Signal-to-Noise Ratios and Fading Allowances in Complete Systems*, Recommendations and Reports of the CCIR, 1982.

(2) Technical Report No. 4, U.S. Army Radio Propagation Agency, Fort Monmouth, NJ, 1964.

These criteria, based on speech articulation tests, provide "good commercial quality". Specifically, the criteria are based on a 29-dB SNR in a 3-kHz voice channel.

c. Since radio signals propagated by way of the ionosphere are subject to fading, the time availability of the SNR is an important design parameter. The above criteria suggest a time availability of 90 percent.

5.2.4.2 Teletypewriter and digital data channel performance.

a. The situation with regard to teletypewriter and digital data channel performance criteria is similar to that of voice channels. MIL-STD-188-114 addresses digital interface criteria but no standard is available covering teletypewriter or digital data channel performance.

b. For teletypewriter channels, a character error rate of 0.1 percent (one error in 1000 characters) constitutes good performance, according to the above criteria (5.2.4.1b). For system design purposes, character error rate is most easily treated by translating it to bit error ratio (BER). If bit errors are taken to occur independently of each other, the character error ratio, P_c, in a system using start-stop teletypewriter code is related to the BER by

$$P_c = [1 - (1 - \mathrm{BER})^{17}] \times 10^2 \tag{5-1}$$

With synchronous, 5-unit teletypewriter code, the relationship is

$$P_c = [1 - (1 - \mathrm{BER})^{5}] \times 10^2 \tag{5-2}$$

In ionospheric radio systems, errors in adjacent bits generally do not occur independently so that these relationships are somewhat pessimistic. For the start-stop code, a more realistic relationship is

$$P_c = [1 - (1 - BER)^7] \times 10^2 \qquad (5\text{-}3)$$

The three relationships are plotted in figure 62.

c. For data transmission at 600, 1200, or 2400 bps, a commercially acceptable BER is 10^{-5}.

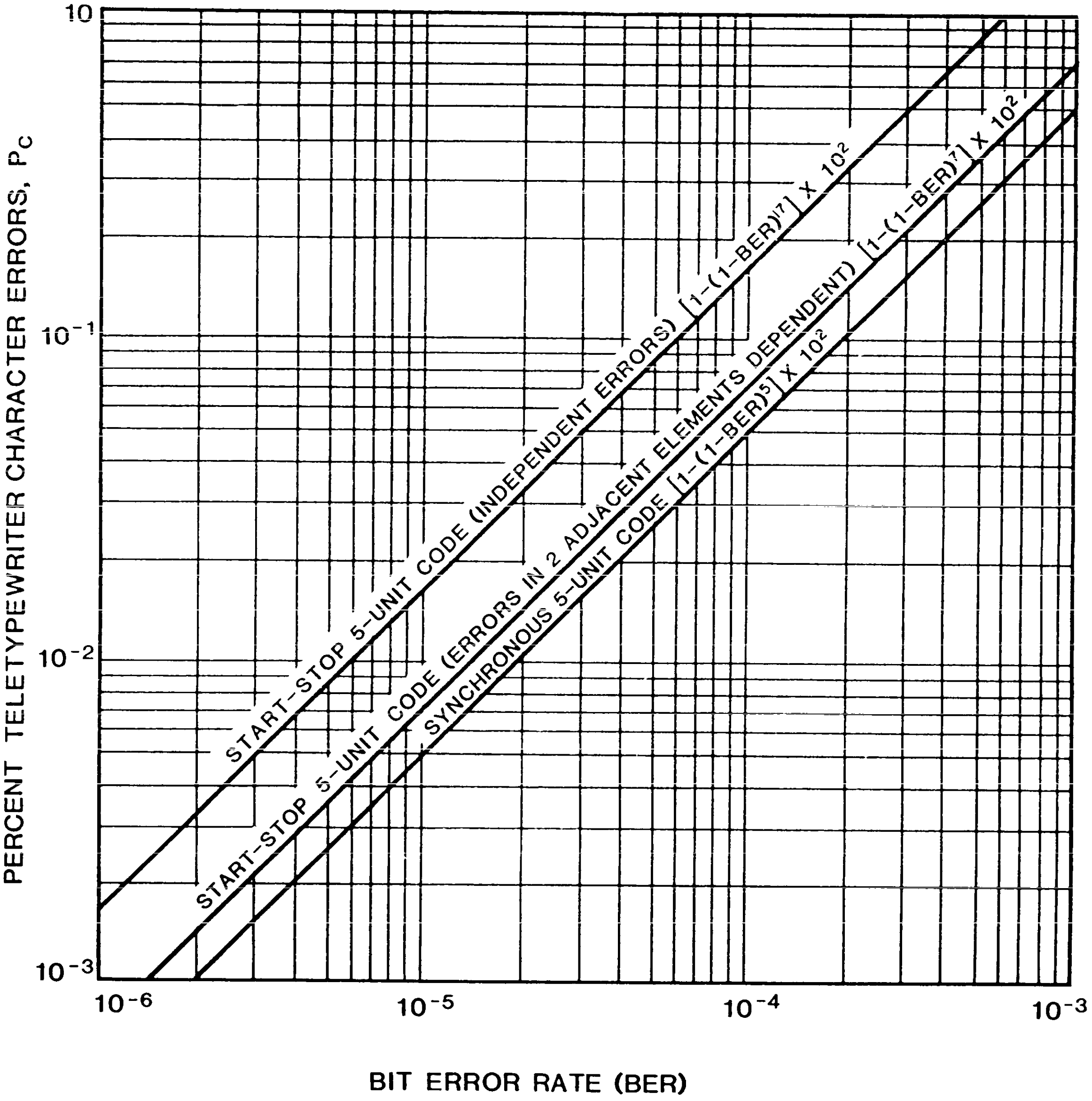


FIGURE 62. Percentage teletypewriter character errors vs. BER.

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5.3 **System design constraints.** All military system design efforts, whether HF radio or other, must take into consideration the practical constraints imposed by economics in general, and military circumstances in particular. The major constraints circumscribing military HF radio system design are:

a. Funding limits.

b. Specification of certain equipment types and models.

c. Government procurement practices.

d. Personnel resources.

e. Training.

f. Time available for construction.

g. Space available for construction.

5.4 **System synthesis and performance calculations.** This engineering stage consists of designing a hypothetical HF system (synthesis) and calculating the performance it will provide. Comparision of the calculated performance with the performance requirements determines whether or not the design is adequate. The synthesis and calculation processes are reiterated until an adequate design is produced. An HF Power Budget Worksheet is included as appendix A to assist in the processes. Appendix B contains sample, filled-in worksheets for typical situations. The procedure involves the following steps:

a. Select the modulation type and diversity scheme appropriate for the required traffic and calculate the signal power level at the receiver input terminals that will provide the required SNR or BER.

b. Make a tentative antenna selection and calculate the net transmission loss.

c. Calculate the transmitter power output level that will offset the transmission loss and provide the required signal power level at the receiver input terminals.

d. If the transmitter output level required is unreasonably high, reconsider the antenna selection. If a better antenna selection is possible, repeat the calculation of transmission loss and transmitter power output level with the new antenna selection. If no better antenna selection is possible, reconsider the path geometry. In some cases, it may not be possible to implement a direct point-to-point link; an intermediate relay may be required.

5.4.1 **Calculation of required received signal level.** Symbols for the variables and constants used in the ensuing equations are listed in table VI and shown in the appropriate equipment areas in figure 63.

a. The required received signal level, P_r, is defined as the median peak envelope power (PEP) of the received signal at the receiver input terminals. It can be calculated in dB using the equation

$$P_r = [(SNR + M_f - I_d - I_c) + F_m] + (10 \log kTb + F_a) - G_p + M_d \qquad (5\text{-}4)$$

(Refer to table VI for the meanings of the symbols.)

TABLE VI. Symbols for variables and constants in HF link performance calculations.

Symbol	Meaning	Unit
b	Message channel 3-dB bandwidth	Hz
B_{rf}	Rf bandwidth of frequency-hopping signal	Hz
F_a	Atmospheric noise factor	dB
F_o	Crest factor of composite multichannel signal	dB
F_m	Multichannel load factor	dB
G_p	Process gain	dB
G_r	Gain of receiving antenna	dB
G_t	Gain of transmitting antenna	dB
I_c	Diversity combiner gain over selection combiner	dB
I_d	Diversity improvement in fading range	dB
k	Boltzman's constant (1.38×10^{-23})	J/K
L_a	Ionospheric absorption loss	dB
L_b	Basic free space (distance) loss	dB
L_g	Ground reflection loss	dB
L_l	Transmission line loss	dB
L_s	System loss (net)	dB
L_p	Propagation path loss	dB
M_d	Design margin	dB
M_f	Fading margin	dB
N_a	Atmospheric noise level	dBW
P_n	Noise power, referred to receiver input	dBW
P_r	Median received signal level	dBW
P_t	Transmitter power output level	dBW
R	Digital data transmission rate	bps
T	Antenna and receiver noise temperature (290 K)	K

b. The parameters in equation (5-4) are grouped to show their interrelationship.

$$[(SNR + M_f - I_d - I_c) + F_m]$$

is the signal term, and the parameters within the first-order parentheses apply to the fading characteristics of the signal and diversity action.

Likewise,

$$(10 \log kTb + F_a)$$

is the noise term. G_p and M_d apply to both signal and noise.

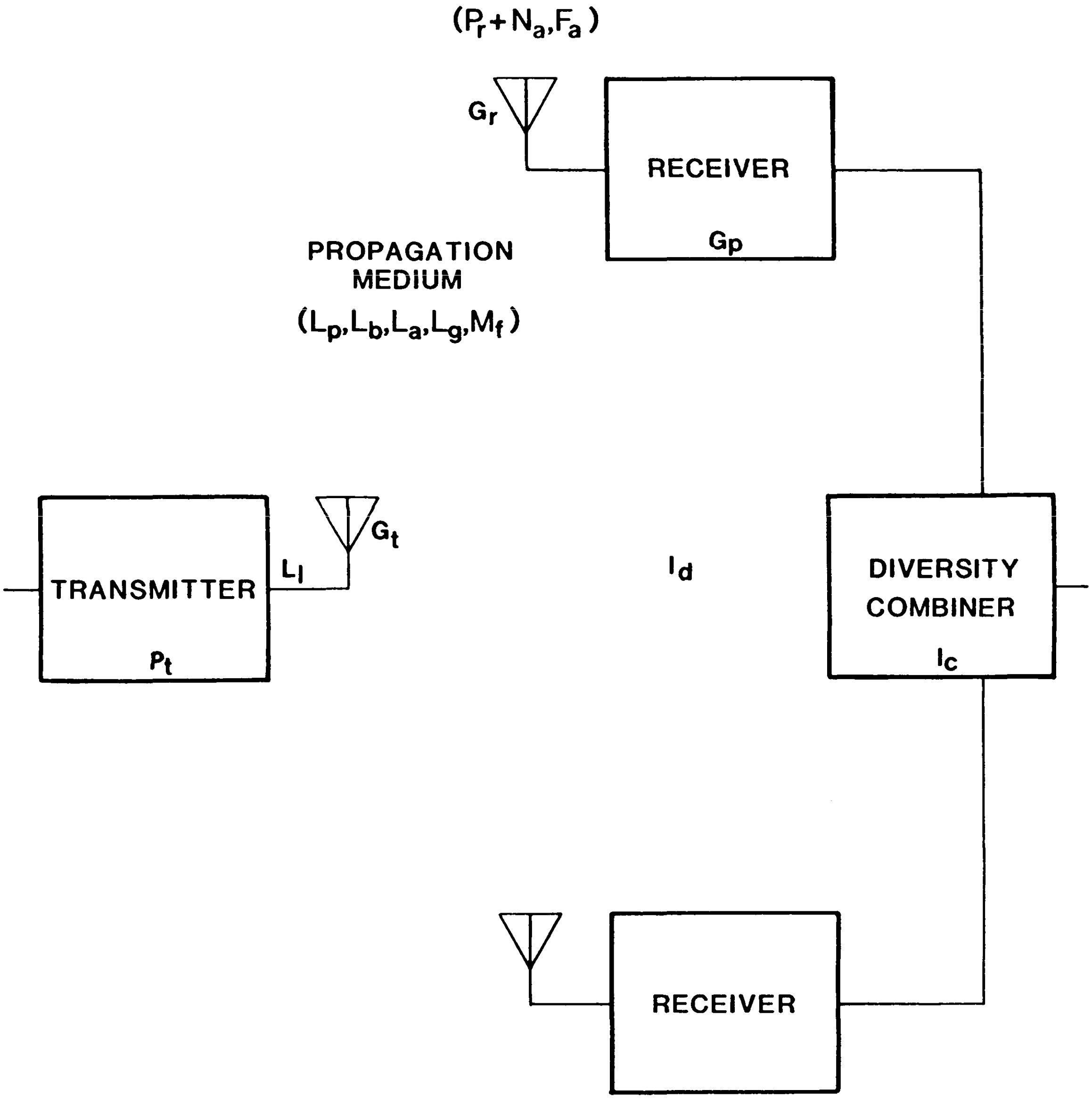


FIGURE 63. Parameters involved in system performance analysis.

5.4.2 **Determination of fading margin.** For voice channels, a fading margin, M_f, must be applied to skywave links to allow for variations in the received signal level. For digital channels, the statistics of fading are taken into account in the error rate analysis.

5.4.2.1 Voice channels.

a. For voice-channel performance calculations, the assumption of Rayleigh fading is most often used. (Rayleigh fading is the term applied when the amplitude distribution of the received signal approximates a Rayleigh statistical distribution.) With Rayleigh fading, an 8-dB margin for fading will enable a given signal level to be met or exceeded 90 percent of the time. Since Rayleigh fading pertains to the distribution of signal levels within a time period on the order of an hour, 90 percent of the time refers to 90 percent of an hour. For other percentiles, refer to figure 64.

b. If dual diversity with selection combining (4.5.7c) is used, figure 64 shows that the margin required for 90-percent time availability is approximately 3 dB. This is 5 dB better than with no diversity. The 5 dB is referred to as the diversity improvement factor, I_d. The diversity improvement given by figure 64 is based on the assumption that the fading does not occur simultaneously for the two signals, i.e., that the amplitude distributions, with respect to time of the two signals, are uncorrelated. As a practical matter, some correlation generally exists. For space diversity, the most commonly used diversity in HF radio practice, an antenna separation of approximately five wavelengths provides sufficient lack of correlation for the values given in figure 64.

c. Equal-gain and maximal-ratio combining provide additional improvement in fading margin over selection combining. The combiner improvement, I_c, is approximately 1 dB for equal-gain and 1.5 dB (round off to 2 dB for most applications) for maximal-ratio.

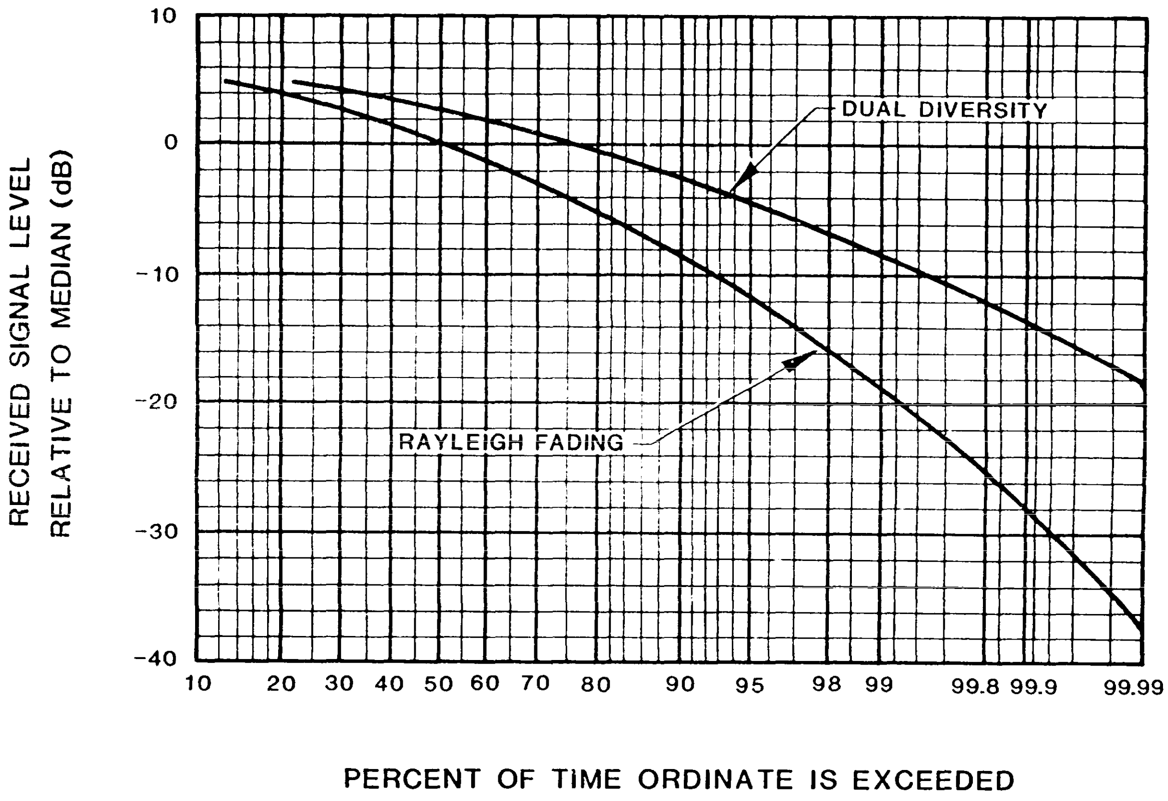


FIGURE 64. Rayleigh fading and dual diversity improvement.

5.4.2.2 **Digital data channels.** To determine the required SNR for digital data channels, use the curves in figure 65. These curves give SNR as a function of BER for FSK with no diversity and with dual diversity. Fading margin and diversity improvement are taken into account in the curves. Therefore, M_f, I_d, and I_c are all taken as zero for use in equation (5-4). Since the curves are for FSK, a correction factor is required for DPSK; for the BERs of interest in most HF system designs (10^{-4} to 10^{-6}), subtract 6 dB from the SNR given by the curves.

5.4.3 **Determination of noise power level.** In HF radio, man-made noise and atmospheric noise are the controlling noise components. Man-made noise problems may not be resolvable and can preclude the use of a particular site. Atmospheric noise can be predicted using noise charts available through USAISESA. The charts give noise levels relative to the level of the thermal noise of the antenna, referred to the receiver input terminals.

$$\text{Thermal noise} = kTb \qquad (5\text{-}5)$$

Therefore, atmospheric noise power level, N_a, is given in dB by

$$N_a = F_a + 10 \log kTb \qquad (5\text{-}6)$$

where F_a is read, in dB, from the atmospheric noise charts. (It should be noted that the IONCAP computer program includes atmospheric noise and may be used without reference to the noise charts.)

5.4.4 **Multichannel load factor.** In multichannel systems, the combination of instantaneous channel signal powers may overload transmitter circuits. To prevent overload, the individual channel levels must be adjusted to lower values than those of a single channel. The values are determined statistically and are different for voice and digital data channels. The term applied to the adjustment is multichannel load factor, F_m.

5.4.4.1 **F_m for voice channels.** In ISB systems, where multiple voice channels are multiplexed into one signal, F_m represents the statistical ratio of the PEP of the composite signal to the PEP of a single-channel signal. Table VII gives F_m for up to four voice channels.

5.4.4.2 **F_m for digital data channels.**

a. Multichannel load factor applies only to frequency-division multiplexed (FDM) digital data channels. Time-division multiplexed (TDM) channels use only one tone and are treated as single-channel systems from the point of view of F_m.

b. In FDM systems, such as VFCT, the average power of the composite signal is N times as high as the average power of a single channel signal, where N is the number of channels. PEP for multichannel signals is higher than average power by a statistically derived factor known as the crest factor, F_c. For five or fewer channels, the PEP can be taken as N^2 times the average power, and the crest factor as N^2/N, or 10 log N in dB. For larger numbers of channels, the composite signal resembles Gaussian noise and the crest factor takes on a Gaussian statistical value. For a PEP of a Gaussian signal that is not exceeded more than 1 percent of the time, the crest factor is 6.6 dB. It has been found experimentally that the Gaussian signal can be peak-clipped at that level without harmful distortion or increased bit errors. With 6 dB of peak-clipping, the crest factor can be taken as 7 dB for as many as 20 channels (where the peak-clipping tests were run):

$$F_c = 10 \log 20 - 6 = 7 \text{ dB} \qquad (5\text{-}7)$$

In practice, F_c is taken as 7 dB for $N \geq 6$. Table VIII gives F_m, rounded off to whole dBs, for commonly encountered numbers of FDM data channels. Figure 66 provides the same information graphically.

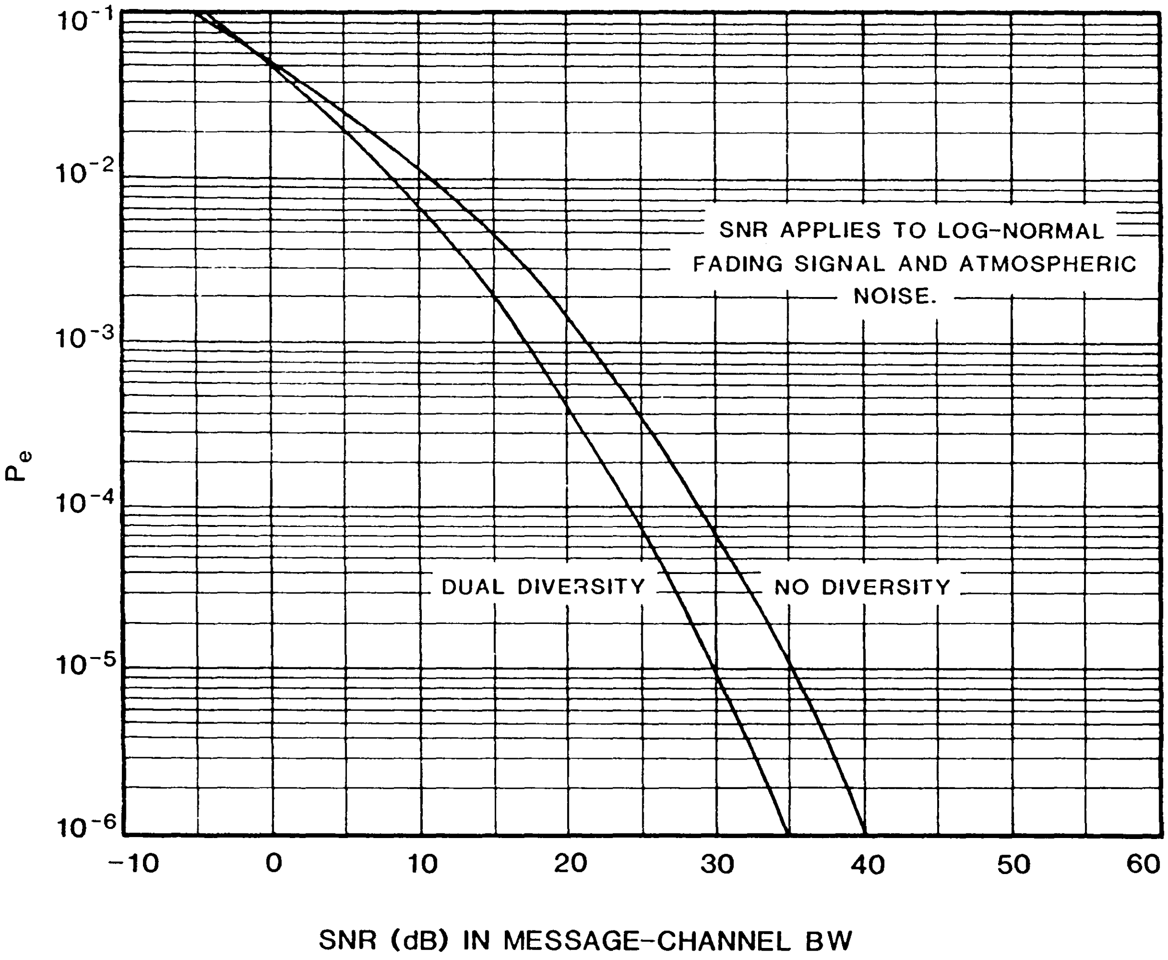


FIGURE 65. Bit error ratio as a function of SNR for noncoherent FSK.

TABLE VII. Multichannel load factor for voice channels.

Number of Channels	F_m (dB)
1	0
2	2
3	2
4	3

TABLE VIII. Multichannel load factor for digital data channels.

Number, N, of Channels	10 log N (dB)	F_c (dB)	F_m (dB)
2	3	3	6
3	5	5	10
4	6	6	12
5	7	7	14
6	8	7	15
10	10	7	17
12	11	7	18
15	12	7	19
16	12	7	19
20	13	7	20

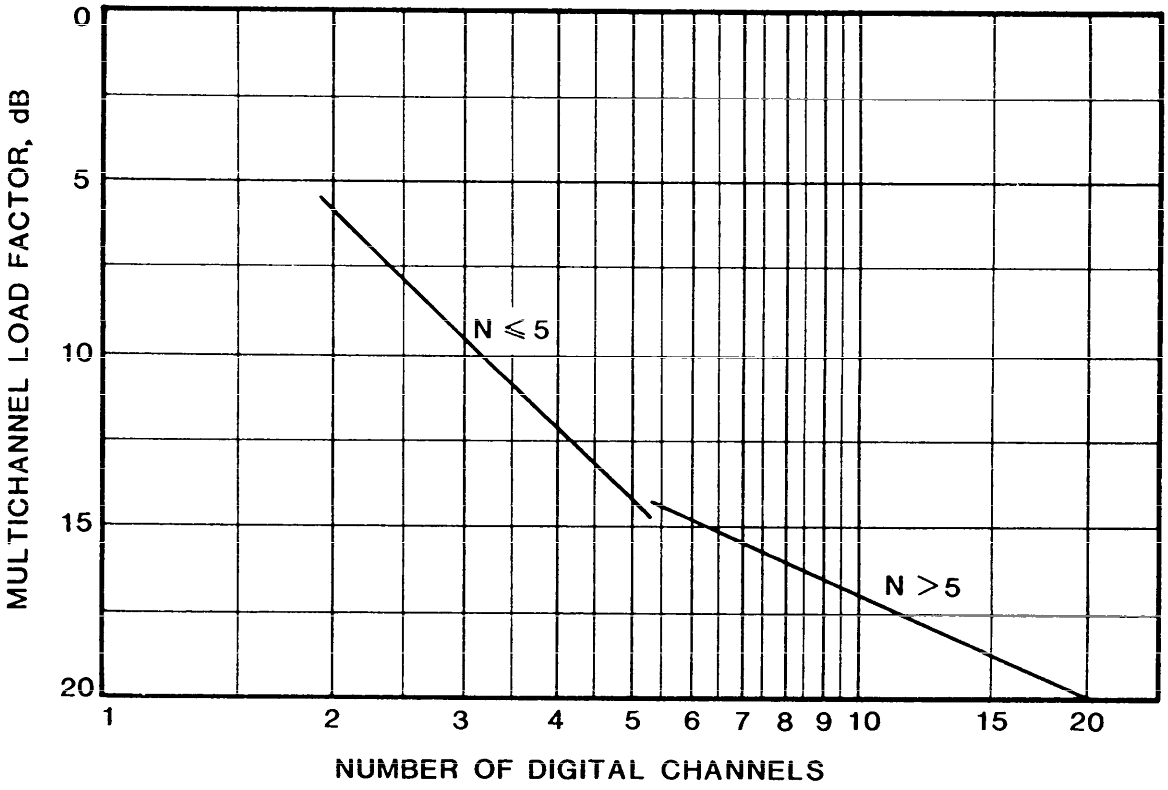


FIGURE 66. Multichannel load factor for digital channels.

The quantity J/S is sometimes called the jamming margin. As seen from equation (5-9), it refers to the margin between the desired SNR and G_p. To find the G_p required to provide a certain jamming margin, rewrite the equation as follows:

$$G_p = SNR + J/S \tag{5-10}$$

To illustrate the application of equation (5-10) in determining the spread spectrum bandwidth required for frequency-hopping transmission, assume an SNR requirement of 10 dB and a known J/S of 20 dB (i.e., the jamming signal is 100 times as powerful as the desired signal). From the equation, G_p is 30 dB. Now, assume a data rate of 1200 bps. Applying equation (5-8),

$$G_p = 30 \text{ dB} = 10 \log (B_{rf}/1200) \tag{5-11}$$

Solving for B_{rf}

$$B_{rf} = 1200 \times \text{antilog } (30/10) = 1.2 \text{ MHz} \tag{5-12}$$

5.4.6 **Design margins.** Statistical uncertainties with regard to the parameters involved in determining the required SNR and BER necessitate the inclusion of a design margin for conservative system design. For voice channels, a standard deviation of 5 dB is associated with the determination of the 29-dB SNR through articulation tests. Consequently, a design margin, M_d, of 5 dB should be included in voice channel performance calculations. For digital data channels, there are uncertainties concerning the probability distributions of both signal and noise levels used for the curves of figure 64. An M_d of 4 dB is suggested to compensate for these uncertainties. Conservative system design for both voice and digital data would include an additional 3-dB margin to account for any failure of the system or equipment to operate in accordance with design expectations. Thus, design margins of 8 dB and 7 dB are recommended for voice and digital data channels, respectively. Although these are recommended values, the design engineer may use discretion in assigning M_d to each case, depending on the purpose of the calculation and the individual circumstances.

5.4.7 **Computation of system loss.** System loss, L_s, is defined as the net loss incurred in signal transmission. It consists of propagation path loss, L_p, antenna gains, G_t and G_r, and transmission line loss, L_l, as illustrated in figure 63 and the following relationship:

$$L_s = L_p - G_t - G_r + L_l \qquad (5\text{-}13)$$

5.4.7.1 **Propagation path loss.**

a. For skywave paths, L_s is best computed by use of one of the computer programs available for this purpose, such as IONCAP. L_p comprises several loss components: basic free space (distance) loss, ionospheric absorption, ground reflection loss, polarization-mismatch loss, and defocusing loss. Polarization-mismatch loss is generally included in the plot of antenna gain as a function of take-off angle. Focusing or defocusing effects are taken into account in the assumed fading statistics. Hence, the factors needed to determine L_p are free space loss, L_b; absorption loss, L_a; and ground reflection loss, L_g. L_p then, is given by

$$L_p = L_b + L_a + L_g \qquad (5\text{-}14)$$

b. For groundwave paths, L_p is highly dependent on ground conductivity, which varies widely with location. Groundwave charts available through USAISESA give total groundwave propagation losses for paths in specific geographic locations.

5.4.7.2 **Antenna gains.** For link synthesis and performance calculation purposes, antenna gains can be read from radiation profiles, such as that in figure 67, as a function of take-off angle. For certain antennas, manufacturer's data sheets provide the needed gain information. For antennas close (less than 0.15 wavelengths) to finitely conducting ground, the gain patterns may be calculated by the Numerical Electromagnetics Code. Such patterns may be obtained from USAISESA.

5.4.7.3 **Transmission line loss.** For most computations involved in system design, it is adequate to assume a transmitting transmission line loss, L_l, of 2 dB. If a more precise value is required, calculate the loss on the basis of line length and rated attenuation per unit length. Receiving antenna transmission line loss is not usually included in the design computations. This is because atmospheric noise is usually the controlling noise. Therefore, the SNR is established at the antenna. Since both signal and noise are attenuated the same amount by the transmission line, the SNR at the receiver input terminals is the same as at the antenna output and the receiving L_l is not a factor in SNR calculation.

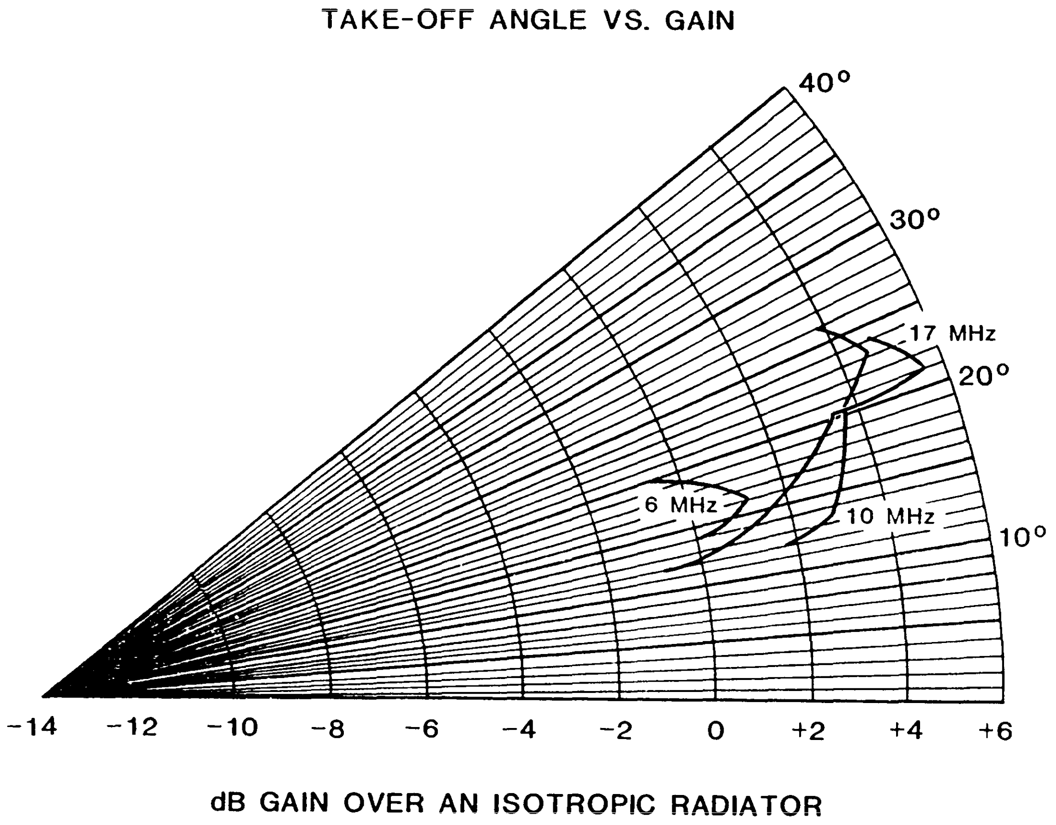


FIGURE 67. Antenna gain and take-off angles.

5.4.8 **Transmitter power output level calculation.** The required transmitter power output level, P_t, is calculated as the sum of the required received signal power level, P_r, and the system loss, L_s

$$P_t = P_r + L_s \qquad (5\text{-}15)$$

When P_r is in dB relative to one watt (dBW), P_t is also given in dBW.

5.5 **Site surveying.** Along with the preceding analysis of the communications requirements and system synthesis, site surveying provides the basis for detailed engineering of the communications facilities. It entails tentative site selection, physical survey, and documentation.

5.5.1 **Tentative site selection.** The site survey process begins with the selection of tentative sites from maps. It involves at least the following considerations:

a. Location from the point of view of mission requirements.

b. Location with respect to clearances for projected antenna take-off angles.

c. Proximity and magnitude of known man-made noise sources.

d. Construction required.

e. Practicability of site support.

f. Feasibility of land acquisition.

5.5.2 **Physical survey.** The physical survey is conducted on-site. Ideally, the survey is performed by a team composed of a communications engineer, a civil engineer, an electrical engineer, and, in some cases, a mechanical/structural engineer. The purposes of the survey are to augment and verify the information gained in the tentative site selection and to gather further information for facility engineering. The survey employs conventional land surveying techniques, photography, and radio noise measurements.

5.5.3 **Documentation.** Site survey documentation should include all the information needed for final site selection and for the early phases of facility engineering. Additional surveys should be anticipated for the development of specific information required in facility engineering. Appendix C provides guidance for the preparation of a site survey report and, hence, for the conduct of the survey itself.

5.6 **Frequency coordination.** Radio-frequency spectrum, especially in the HF range, is a limited international resource. Consequently, frequency coordination is an essential function in planning for the use of this resource. To achieve the necessary coordination, a hierarchy of international and national agencies has responsibility for frequency allocation and management. Further information regarding the specific process of frequency management and the securing of specific frequency assignments can be obtained from the frequency management coordinators or offices of the cognizant military command. It should be noted that formal host government permission must always be obtained through prescribed frequency management channels during the early design stages of any new facility.

5.6.1 **International agencies.** The International Telecommunications Union (ITU) is the parent organization for the two international frequency management and allocation agencies:

a. World Administrative Radio Conference (WARC).

b. International Frequency Registration Board (IFRB).

5.6.2 **U.S. Government agencies.** Frequency management within the U.S. is conducted at the national level by the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA). The NTIA is advised by the Interdepartment Radio Advisory Committee (IRAC). The FCC manages frequencies for the private sector and state and local governments. The NTIA manages frequencies for the Federal Government sector.

5.6.3 **U.S. military agencies.** The Military Communications-Electronics Board (MCEB) coordinates frequency management for the Department of Defense . Each military service maintains a frequency management staff and a network of frequency coordinators. Overseas, bilateral agreements between the U.S. and host countries govern frequency coordination matters. Frequency management within the U.S. forces overseas is under the control of the highest command, usually a unified command such as Commander-in-Chief, Pacific (CINCPAC). The unified command provides frequency management guidance to the component commands, such as Commander-in-Chief, U.S. Army, Europe (CINCUSAREUR).

5.6.4 **Requests for frequency assignments.** The Joint Chiefs of Staff (JCS) publication ACP 190, U.S. Supplement-1 (B), Annex D, establishes the format for frequency requests by U.S. military services. Specific procedures for preparing and submitting requests are also contained in the publication. The information required in frequency assignment requests includes emission designations, location data, equipment data, and antenna data.

5.6.4.1 **Emission designations.** Modulation, or its absence, in large part determines the nature of the emissions from radio transmitters. In 1979, the WARC adopted a method for designating emissions which superseded an earlier method. It is now contained in the International Telecommunications Union (ITU) Radio Regulations, effective in 1982.

5.6.4.1.1 **Bandwidth.** The emission designator begins with an expression denoting the computed or measured emission bandwidth. The expression consists of three numerals and a letter. The numerals give the bandwidth, with the letter replacing the decimal point and denoting the unit of bandwidth. Table IX gives the bandwidth-unit designators. Using this table, a 3-kHz bandwidth, such as that of a voice channel transmitted by SSB modulation of a carrier, would have the bandwidth expresssion, 3K00. A 12.58-kHz bandwidth resulting from 4-channel ISB modulation using a 6.29-kHz subcarrier would be expressed as 12K6, rounding off the last two digits to fit the total of three numerals. For internal use, the designator may be expanded to five numerals and one letter, e.g., 12K580.

TABLE IX. ITU bandwidth-unit designators.

Unit	Frequency Range	Designator
Hz	0.001 through 999 Hz	H
kHz	1.000 through 999 kHz	K
MHz	1.000 through 999 MHz	M
GHz	1.000 through 999 GHz	G

5.6.3.1.2 **Basic emission characteristics.** The emission designation uses a three-symbol code following the bandwidth expression to designate the basic emission characteristics.

a. The first symbol denotes the type of modulation of the main carrier. For CW (ICW or MCW), the designator is A. For SSB, the designator is J; for ISB, B. For FSK, the designator is F. For PSK, DPSK, and QPSK, all of which are phase modulation, the designator is G. (The complete set of emission designations can be found in the 1982 issue of the ITU Radio Regulations.)

b. The second symbol denotes the nature of the signal modulating the main carrier. A telegraph channel is designated by the numeral 1 if no modulating tone is used (ICW) and 2 if a modulating tone is used (MCW). A single voice channel is categorized under the designation system as "a single channel containing analog information" and is designated by the numeral 3. The combination of voice channels and digital data channels normally conveyed by ISB is categorized as a "composite system with one or more channels containing quantized or digital information together with one or more channels containing analog information". It is designated by the numeral 9. FSK and various forms of PSK are categorized as "a single channel containing quantized or digital information without the use of a modulating subcarrier". The designator, as with telegraph, is the numeral 1.

c. The third symbol denotes the type of information to be transmitted. Telegraphy intended for automatic reception — that is, teletypewriter communications — is designated by the letter B; facsmile, by the letter C; data transmission, telemetry, and telecommand, by the letter D; and telephony, by the letter E. The letter W denotes a combination of information types.

d. Thus, the expression denoting the characteristics of an SSB voice channel is J3E, and the complete emission designation, assuming a 3-kHz voice channel, is 3K00J3E. Likewise, the complete emission designation for an ISB system of three voice channels and one data channel, using 6425-Hz subcarriers, is 12K9B9W. Table X gives the designators for the emission characteristics most commonly used in military HF radio.

e. The emission designation method includes two additional symbols: one to represent certain details of the emitted signals and the other, the type of multiplexing, if any, employed. These fourth and fifth symbols are optional. For military HF radio, the symbols most commonly used in the fourth position would be:

(1) B, for 2-condition code with elements of the same number and duration without error-correction.

(2) C, for 2-condition code with elements of the same number and duration with error-correction.

(3) D, for 4-condition code in which each condition represents a signal element (of one or more bits).

(4) E, for multicondition code in which each condition represents a signal element (of one or more bits).

(5) F, for multicondition code in which each condition or combination of conditions represents a character.

The symbols most commonly used in the fifth position would be:

(1) C, for code-division multiplex, which includes bandwidth expansion techniques.

(2) F, for frequency-division multiplexing (FDM).

(3) T, for time-division multiplexing (TDM).

(4) W, for combination of FDM and TDM.

5.6.4.2 **Location data.** The locations of the transmitter and receiver sites by city, state, and country are required. When the operating unit that controls the station(s) is located at some place other than at the station(s), that location must also be provided. Transmitting and receiving antenna locations must be given in degrees, minutes, and seconds of geographical coordinates.

TABLE X. Expressions denoting emission characteristics in common military HF radio usage.

Modulation	Type of Service	Designator
AM	Single-channel telephony	A3E
AME	Single-channel telephony	R3E
SSBSC	Single-channel telephony	J3E
SSBSC	Single-channel facsimile	J3C
ISB	Two or more data channels	B7D
ISB	4-channel telephony and data	B9W
FSK	Single teletypewriter channel	F1B
FSK	Single digital data channel	F1D
FSK	Two or more digital data channels	F7D
MCW	Aural telegraphy	A2A
NBFM	Single-channel telephony	F3E
PSK*	Single teletypewriter channel	G1B
PSK	Single digital data channel	G1D
PSK	Two or more digital data channels	G7D
Frequency-hopping spread spectrum**	Two or more data channels	F7D
Frequency-hopping spread spectrum	Quantized single-channel telephony	F1E

* The same expression applies to DPSK and QPSK.

** Frequency-hopping spread spectrum is a form of frequency modulation.

5.6.4.3 **Equipment data.** The nomenclature and quantities of the transmitters and receivers are required. When the equipment is part of a nomenclatured system, that nomenclature must be provided.

5.6.4.4 **Antenna data.** Transmitting and receiving antenna types must be specified. For manufactured antennas, the military nomenclature or manufacturer's identification is required. The orientation and polarization of fixed antennas are required and rotatable antennas must be identified as such.

5.7 **Facility design.** The design of new HF radio facilities involves the civil and electrical engineering disciplines, and, in some instances, mechanical/structural engineering. Where existing facilities are to be used, design rests largely on existing and available structures, site configuration, and electrical power. In both cases, facility design involves site planning, construction planning and coordination (especially of antenna towers), the provision of electrical power, grounding system design, and protection against destructive transient voltages.

5.7.1 **Site planning.** Site planning for new installations involves the provision of:

a. Access roads and parking areas.

b. Water supply.

c. Sewerage.

d. Cable trenches.

e. Antenna support foundations.

f. Security fencing.

g. Area lighting.

h. Site grading for drainage.

For existing installations, the site survey will have determined the adequacy of the site with regard to these items and the need for any upgrading.

5.7.2 **Construction planning and coordination.**

5.7.2.1 **Planning.** For new construction involving buildings, the following basic data must be developed:

a. Floor space requirements.

b. Floor loading.

c. Access requirements for equipment entry.

d. Environmental control requirements.

e. Equipment-generated heat dissipation requirements.

Provisions must be included for maintenance areas, administrative offices, storage, and, in some cases, personnel housing. Interior lighting adequate for the various operating and maintenance activities must be provided.

5.7.2.2 **Coordination.** Federal, state, and local governments, both in the U.S. and host countries of overseas commands, regulate the construction of facilities and structures through laws and codes. Civil engineering staffs generally have the assigned responsibility for securing the necessary construction permits and assuring construction in conformance with the laws and codes.

5.7.2.2.1 **Construction in the U.S.** In the U.S., military construction on Federal property, although usually exempt from local codes, requires the approval of the Garrison/Installation Commander and the Facility Engineer/Corps of Engineers. In the interest of air safety, however, tower construction and erection must conform to the height restrictions and marking requirements of Federal Aviation Administration (FAA) Regulation (FAR), Part 77. This requires that a notice be filed with the FAA before construction or alteration of any tower over 61 m, or of a greater height than an imaginary surface extended outward and upward by a factor given by the following slopes:

a. 100 to 1 for a horizontal distance of 6096 m from the nearest point of the nearest runway of more than 975 m in length.

b. 50 to 1 for a horizontal distance of 3048 m from the nearest point of the nearest runway of 975 m or less in length.

c. 25 to 1 for a horizontal distance of 1524 m from the nearest point of the nearest landing or take-off area of a heliport.

The FAA may require lighting and marking of towers in accordance with FAA Advisory Circular AC 70/7460-1 as a condition for construction. Painted hazard markings on most towers are usually seven equal-width alternate bands of white and aviation surface orange, starting and ending with the color orange.

5.7.2.2.2 **Construction overseas.** Host nations generally require compliance with national standards when the construction is intended to remain in place after withdrawal of U.S. forces, e.g., Deutsche Industrie Normenauschuss (DIN) in the Federal Republic of Germany. Coordination procedures vary by nation and approvals may take years.

5.7.3 **Electrical power system planning.** Detailed engineering of electrical power systems for telecommunications facilities is provided by MIL-HDBK-411, FM 11-486-7/T.O. 31Z-10-22, and the National Electrical Code. The basic information for the engineering process must be developed in terms of military power system classifications and telecommunications facility load categories.

5.7.3.1 **Power system classifications.** Table XI gives the military classifications for primary, auxiliary, and uninterruptible electrical power.

5.7.3.2 **Load categories.** Figure 68 shows the several load categories applied to telecommunications facility power systems. Load estimating within these categories requires determination of the connected and demand loads. The connected load is the total load that would be imposed by all communications-electronics equipment, lighting, motors, and environmental control equipment if they were operated simultaneously. Demand load is defined as the maximum coincident power required to serve a connected load. It differs from the connected load because all connected equipment is seldom operated simultaneously.

5.7.4 **Grounding system design.** The grounding system for a telecommunications facility provides for personnel safety, equipment protection, and electrical noise reduction. The provision of personnel safety involves low-impedance grounding and bonding between equipment, metallic objects, piping, and other conductive objects. Equipment protection involves low-impedance grounding and bonding between electrical devices, equipment, and other conductive objects. Electrical noise reduction involves minimization of impedance to earth ground throughout the facility by bonding to an earth electrode network. It also involves minimization of noise pickup through shielding. Grounding system design also includes the provision of a lightning protection subsystem and an equipment fault-protection subsystem. Guidance for detailed engineering of grounding, bonding, and shielding is provided by MIL-HDBK-419.

TABLE XI. Classes of electrical power.

Power Class	Operational Power Requirement	Characteristics
Primary power, class A	Includes all utility, technical, and critical technical operational loads resulting in a steady-state operational requirement.	Steady-state power, subject to various voltage and frequency deviations, transients, and occasional complete power failure.
Auxiliary power, class B	Same as class A, capable of indefinite operation; should have 15 days fuel supply available. Auto system operational at −10% or +10% voltage variation after 5-sec delay. Covers extended outages that may last for days.	Supplement to primary power. Subject to complete loss of synchronized power for approximately 20 sec during automatic power transfer after primary power loss.
Auxiliary power, class C	Provides auto-start power plant to provide rapid restoration of power to the technical load. Starts on voltage variation of ±10% or on frequency variation of ±3.3% with an adjustable time delay of approximately 5 sec. Minimum fuel supply of 7 days. Covers outages of relatively short periods (hours).	Supplement to primary power. Assumes load in shortest practicable time after failure of primary power (10 to 60 sec).
Uninterruptible power system (UPS) and no-break power, class D	Provides continuous uninterruptible power and prevents the occurrence of transients and surges on the critical technical load.	Automatically assumes load when required and automatically shifts load back when primary power becomes available. No power interruption, and minimum voltage and frequency deviations.

5.8 **Electromagnetic compatibility.** Electromagnetic compatibility (EMC) is defined as the ability of communications-electronics equipments, subsystems, and electromechanical devices to interoperate in the intended environment without suffering or causing degradation by unwanted electromagnetic radiation or response. Electromagnetic interference (EMI) results when electromagnetic energy causes an unacceptable or undesirable response, malfunction, degradation, or interruption of the intended operation of an electronic equipment subsystem or system. MIL-STD-461 provides standards governing the EMI characteristics of equipment. MIL-STD-462 provides instructions for measurement of EMI. Planning for HF systems at new or existing facilities requires an EMC study. The three military services have EMC agencies which conduct such studies. In addition, the DoD Electromagnetic Compatibility Analysis Center (ECAC), Annapolis, MD, provides assistance to the U.S. military components.

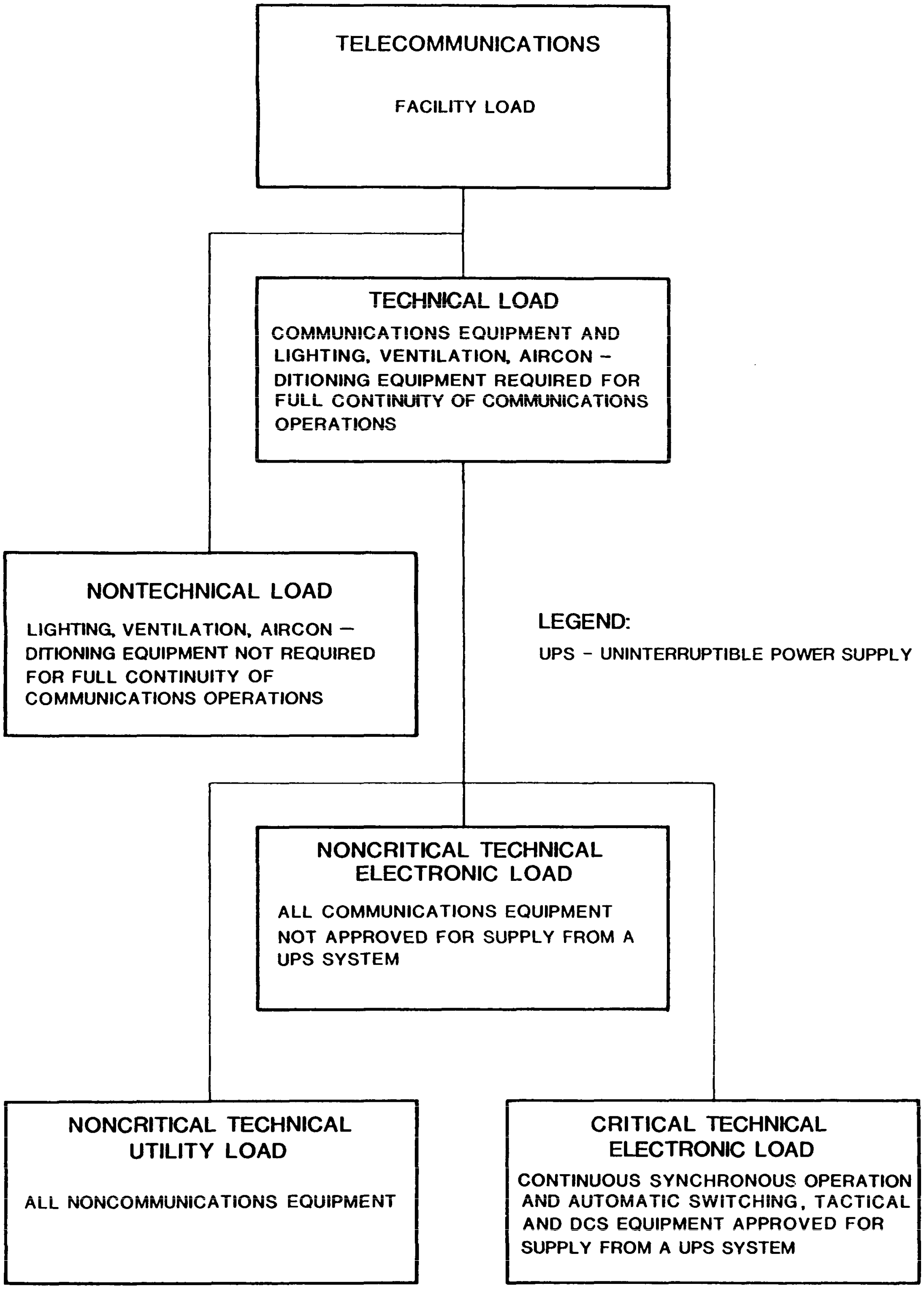


FIGURE 68. Categories of telecommunications facility loads.

5.9 **Equipment testing.** The primary purpose of initial equipment testing is the assurance that the equipment operates within the requisite parameters. This testing also establishes initial values, thus allowing critical comparisons with later tests as the equipment and systems age. A further purpose is to ensure that any equipment after maintenance, repair, or adjustment, functions properly and causes no degradation of the system. The test procedures given are generic rather than oriented to specific equipment. Some manufacturer's technical application notes also contain general test procedures, with technical manuals for individual equipment providing details on specific measurements.

5.9.1 **Receiver tests.** These tests should normally be performed with the receiver in its usual operating position.

5.9.1.1 **Sensitivity.** Connect the equipment as shown in figure 69.

a. For SSB or CW, the signal generator is unmodulated.

b. For AM, the signal generator is modulated 30 percent at 1000 Hz.

c. With the signal generator output set at a level which slightly exceeds the receiver-under-test threshold, tune the receiver for a maximum reading on the ac voltmeter.

d. Set the signal generator for zero output. Adjust the receiver audio output control for a 0-dBm reading on the ac voltmeter. Note: Any convenient level can be used that does not result in overload or limiting.

e. Increase the signal generator output until the ac voltmeter indicates a 10-dB increase. The output level of the signal generator is then the signal level, in microvolts, required to achieve a 10-dB signal-plus-noise-to-noise, (S + N)/N, sensitivity.

f. Compare the measured sensitivity with the manufacturer's specifications or with previous measurements. Typical values are 0.35 μV for SSB and 1.5 μV for AM.

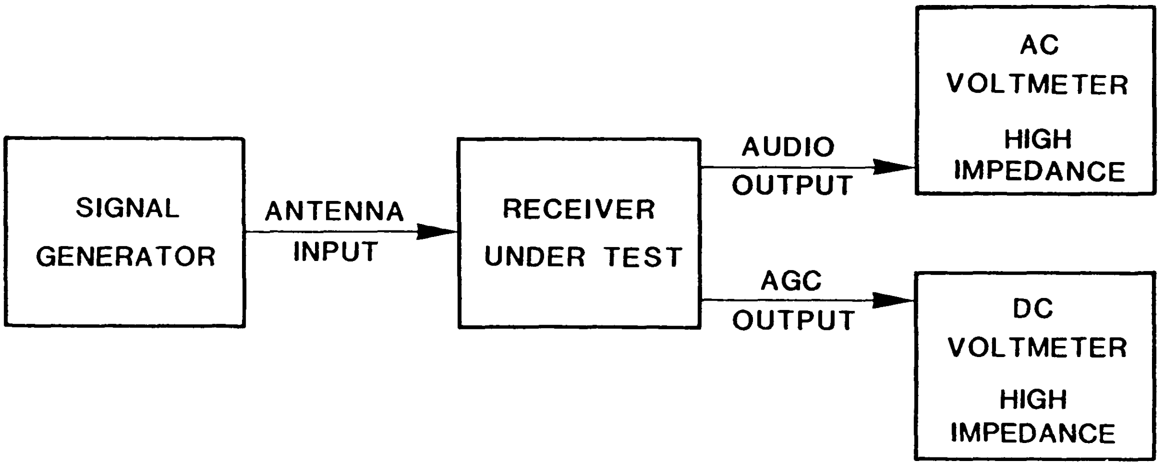


FIGURE 69. Receiver sensitivity and AGC action test setup.

5.9.1.2 **AGC action.** Connect the equipment as shown in figure 69.

a. Starting from zero output, increase the signal generator output until the dc voltmeter reading just begins to change from the threshold reading. Note: A digital dc voltmeter may give false readings due to noise.

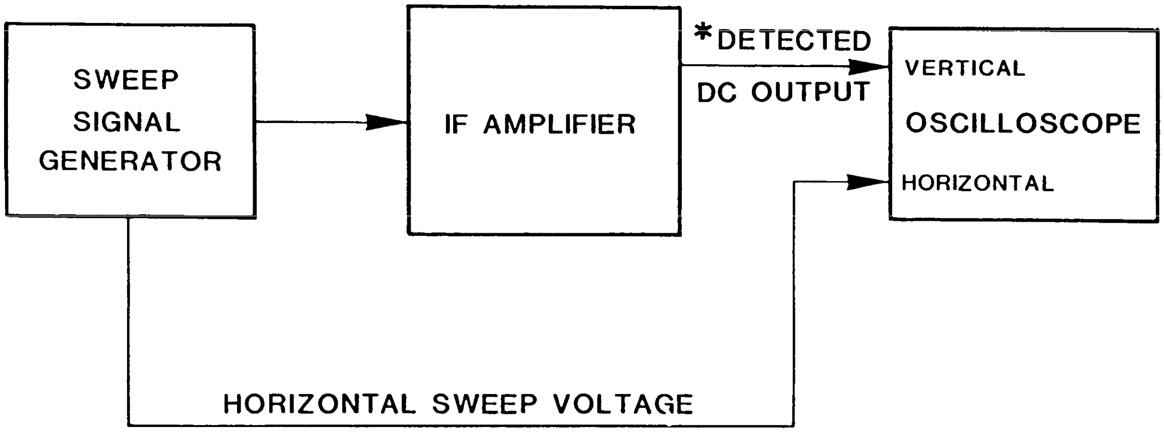
b. Record the signal generator output level. This is the AGC threshold value. Compare this with the manufacturer's specifications or previous measurements.

c. For the AGC linearity test, modulate the signal generator at 30 percent at 1000 Hz for an AM receiver. For SSB or CW, the signal generator is unmodulated.

d. Increase the signal generator output level to the upper limit of the receiver specification while watching the ac voltmeter for output level. The linearity figure is the increase in receive output level for the full input range. Typical specifications are: 3-dB increase for 1 μV to 1 V, 6 dB for 100 dB (−110 to −10 dBm), 6 dB for 5 μV to 0.05 V.

e. Compare the measurement with the manufacturer's specifications or previous measurements.

5.9.1.3 **Selectivity.** A storage oscilloscope is recommended for this procedure. Otherwise, if it is not used, and the signal generator sweep speed is too fast, a distorted picture of the IF passband results. If the sweep speed is too slow, the picture is difficult to view due to the relatively short retentivity of the oscilloscope screen. Connect the equipment as shown in figure 70.



*IF THE DIODE DETECTOR OUTPUT IS NOT AVAILABLE, CONNECT THE IF OUTPUT THROUGH A CRYSTAL DETECTOR PROBE OR ASSEMBLY TO THE OSCILLOSCOPE.

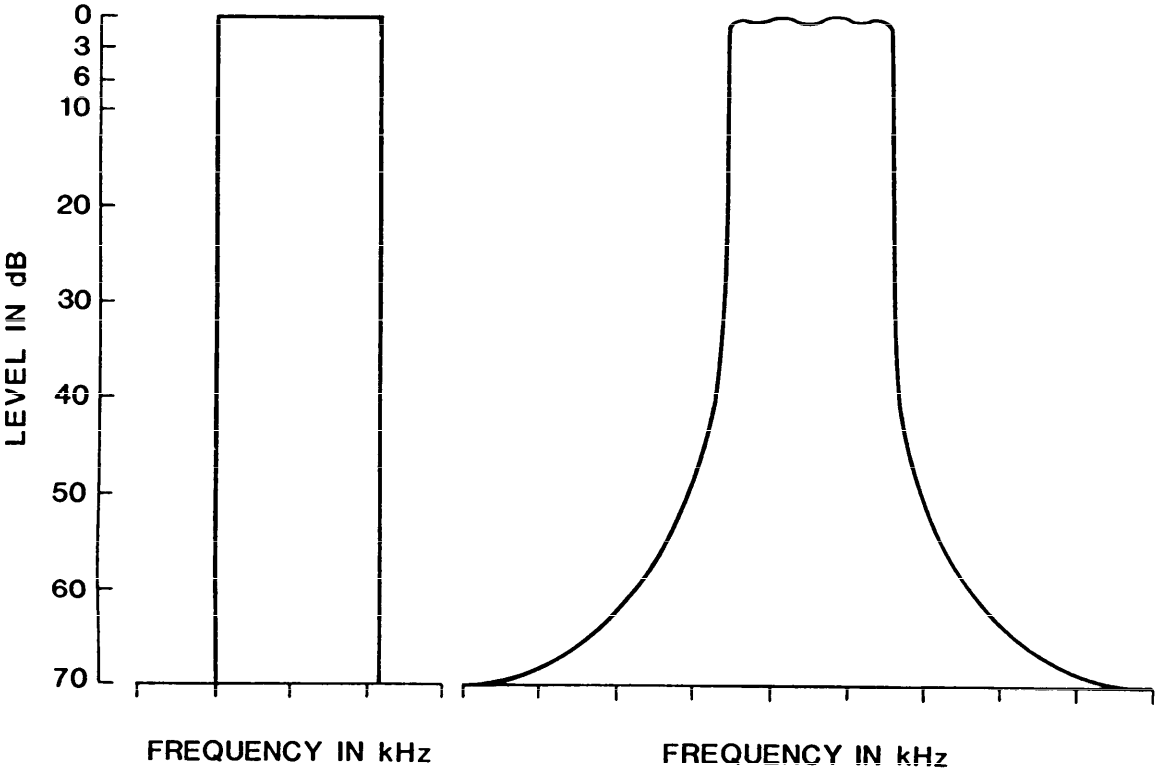
FIGURE 70. Receiver selectivity test setup.

a. Disable the AGC.

b. Keep the signal generator output low enough to prevent overload and a resultant distorted output.

c. Compare the IF passband picture with the shapes shown in figure 71.

d. Calculate the shape factor. This is the ratio of the bandwidth measured at two points on the slope, usually at the 60-dB and the 6-dB points. The ideal passband has a shape factor of 1.0 (figure 71A). A typical passband has a shape factor of about 2.0 (figure 71B). Typical figures are: for SSB, 2.5 kHz at 6 dB and 4.5 kHz at 60 dB; for AM, 6.5 kHz at 6 dB and 14.0 kHz at 60 dB.



A. IDEAL IF PASSBAND B. REALIZABLE IF PASSBAND

FIGURE 71. Receiver ideal and realizable IF passbands.

5.9.1.4 **Frequency stability.** The simplest method of testing frequency stability does not require test equipment.

a. Tune the receiver to one of the WWV frequencies (2.5, 5, 10, 15, and 20 MHz) and place it in a zero beat condition. Use the BFO and the "S" meter. Monitor for the number of hours or days required to confirm stability or to show drift.

b. If operational conditions are such that the above is impractical, remove the receiver to the maintenance area. Connect a signal generator to the receiver and adjust to a zero beat condition. The signal generator must have a stability at least five times better than the receiver under test.

5.9.2 **Transmitter tests.** To prevent equipment damage, the transmitter power amplifier or rf exciter must be connected to an antenna or a dummy load for all of the following tests.

5.9.2.1 **Linearity and intermodulation distortion (IMD).** Connect the equipment as shown in figure 72. This test setup is for SSB transmitters only.

a. Tune the transmitter for full rated output into the dummy load.

b. Observe the output waveform for distortion. Compare the waveform obtained on the output oscilloscope with the waveform on the input oscilloscope. Adjust the exciter drive as necessary to achieve the proper output waveform (figure 73).

c. Observe the spectrum analyzer display for the proper output waveform as shown in figure 74A. Third order IMD should be at least 30 dB below the 2-tone output level.

d. Compare the spectrum analyzer display with the manufacturer's specifications or previous tests.

5.9.2.2 **Power output and gain.** Connect the equipment as shown in figure 72.

a. Tune the transmitter for full rated output into the dummy load. For initial testing, adjust the exciter drive as necessary to achieve the proper output waveform (5.9.2.1b and figure 73). For periodic or return from maintenance testing, adjust the exciter drive for the same output waveform as the initial or acceptance test.

b. For the rf amplifier, record the input power (I × E), the dc plate current, and the plate voltage.

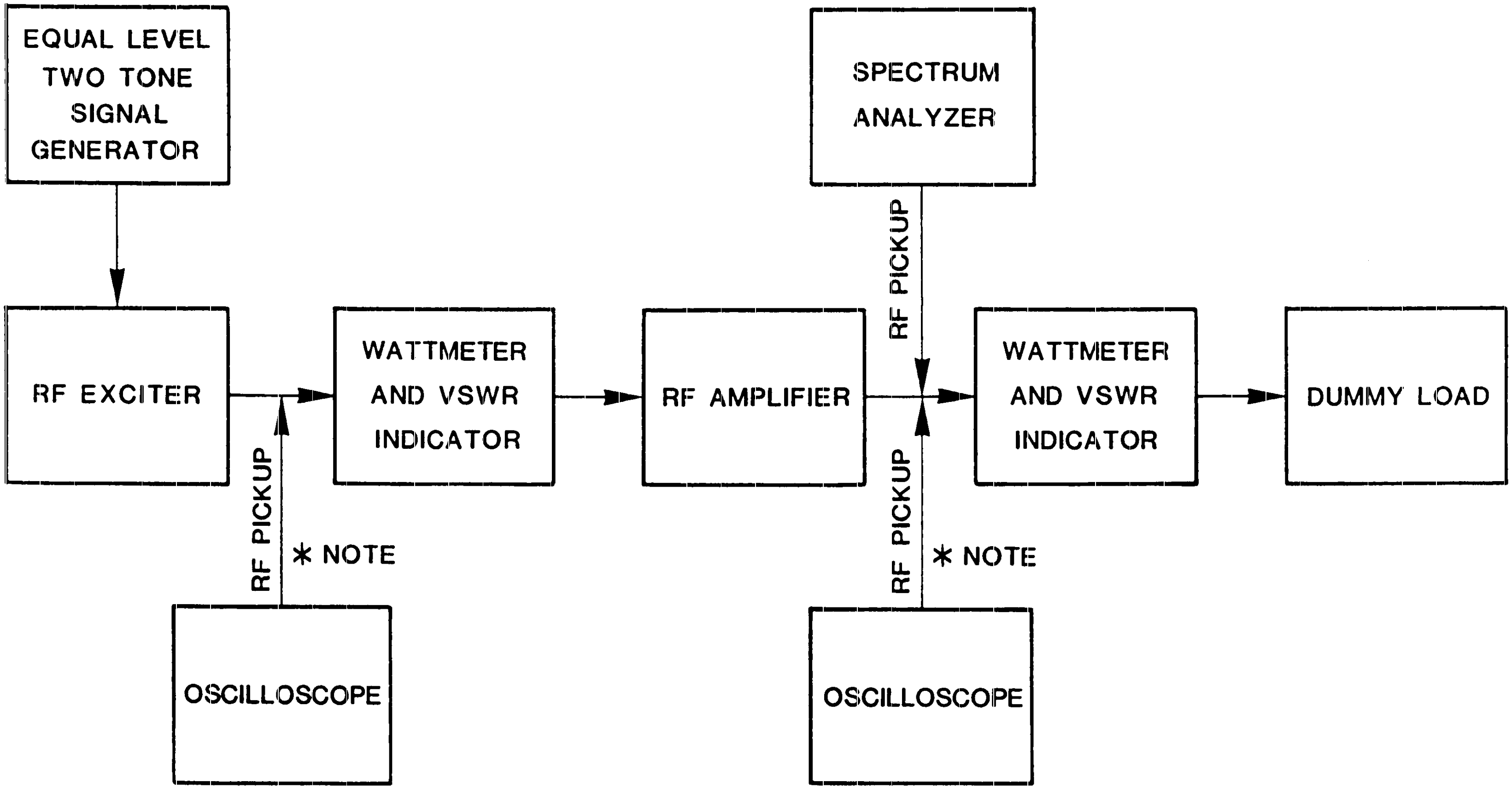
c. Determine and record the output power into the dummy load.

d. Determine and record the rf amplifier gain from:

$$\text{Gain (dB)} = 10 \log P_o/P_i \qquad (5\text{-}16)$$

where P_o is the output power and P_i is the input power.

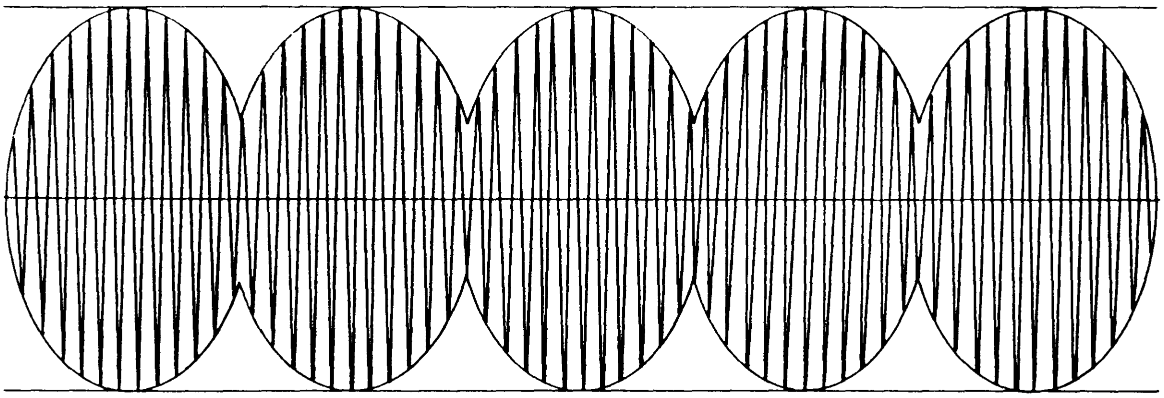
e. Compare the results with the manufacturer's specifications or previous tests.



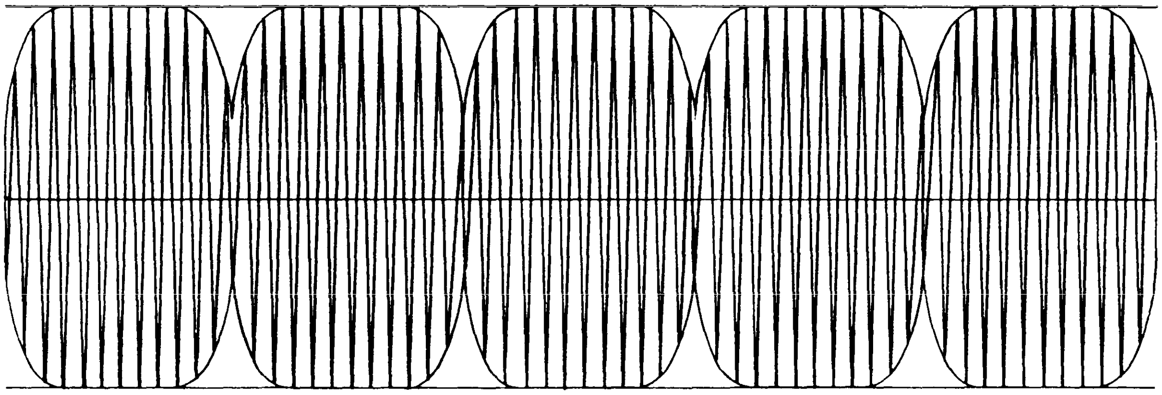
*** NOTE:**

THE PICKUP PROBES FOR THE OSCILLOSCOPES SHOULD BE CONNECTED DIRECTLY TO THE VERTICAL PLATES, BYPASSING THE VERTICAL AMPLIFIERS. IF SUFFICIENT PICKUP VOLTAGE IS NOT AVAILABLE AT THE RF OUTPUT, A SPLITTER OR TEE CONNECTER MAY BE USED.

FIGURE 72. Transmitter linearity, IMD, power output, and gain test setup.



A. PROPER ADJUSTMENT



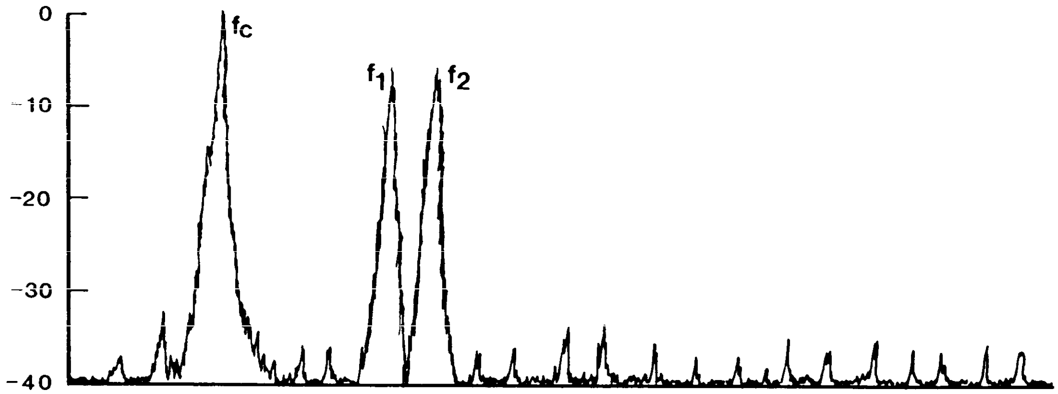
B. OVERDRIVEN WITH RESULTANT FLAT TOPPING

FIGURE 73. Transmitter waveforms.

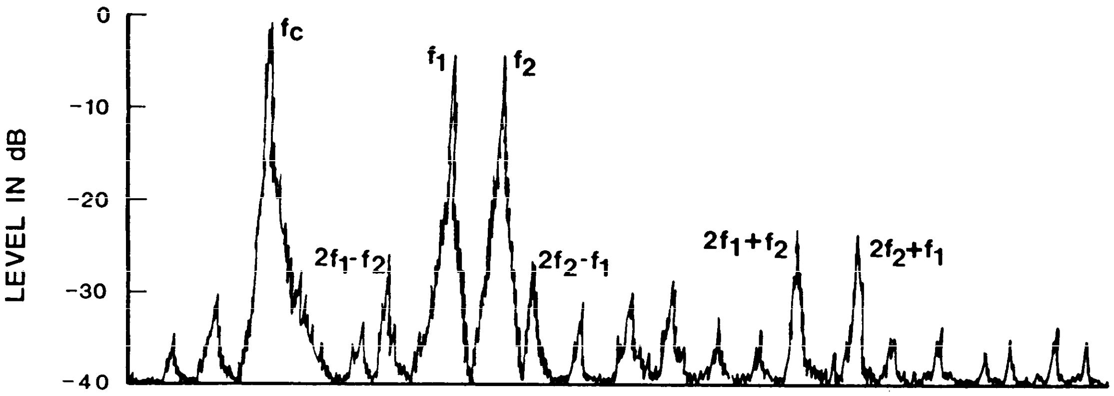
5.9.2.3 **Carrier and unwanted sideband suppression.** Connect the equipment as shown in figure 75.

a. Tune and load the transmitter to full rated output into the dummy load. Adjust the signal generator to full carrier output using a single tone.

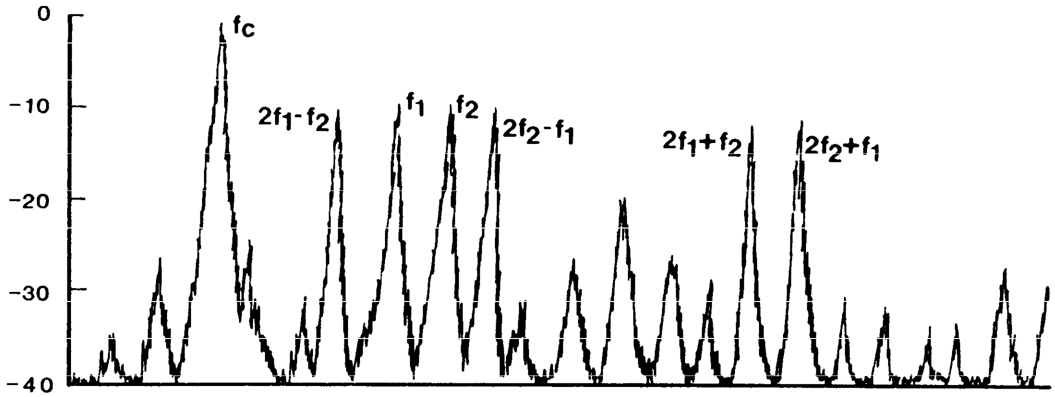
b. Referring to figure 76, set the spectrum analyzer display of the f_c + tone signal for a 0 dB waveform peak.



A. LOW IMD



B. INCREASED IMD



C. SERIOUS IMD AND SPLASH

FIGURE 74. Transmitter distortion products (spectrum analyzer).

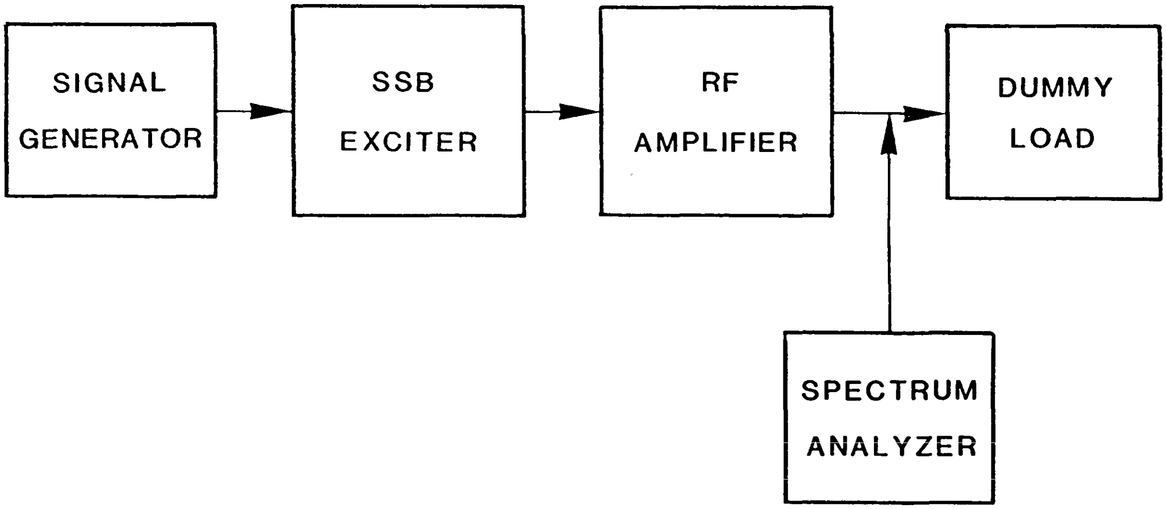


FIGURE 75. Transmitter carrier and unwanted sideband suppression test setup.

c. Remove the signal generator input. Adjust the balanced modulator for a minimum carrier, f_c, display. Measure the value of f_c below 0 dB. This value is the amount of carrier suppression. Typical carrier suppression is 60 dB.

d. Compare the reading obtained with the manufacturer's specifications or previous measurements.

e. Reinject the single tone from the signal generator. Recheck the transmitter for full rated output. Reset, if necessary, the spectrum analyzer display for 0 dB on the waveform peak.

f. Examine the display for the indication of the suppressed sideband. The suppressed sideband will typically be 60 to 70 dB below the wanted sideband (figure 76).

g. Compare the results with the manufacturer's specifications or previous readings.

5.9.2.4 **Frequency stability.** Connect the equipment as shown in figure 77.

a. After a full warmup period and complete stabilization, tune the receiver to one of the WWV frequencies (2.5, 5, 10, 15, and 20 MHz).

b. Tune the exciter to the same frequency.

c. Starting with maximum attenuation and minimum exciter output, adjust the attenuator and the output of the exciter until the signal level, at the receiver, is approximately the same as that of the WWV signal.

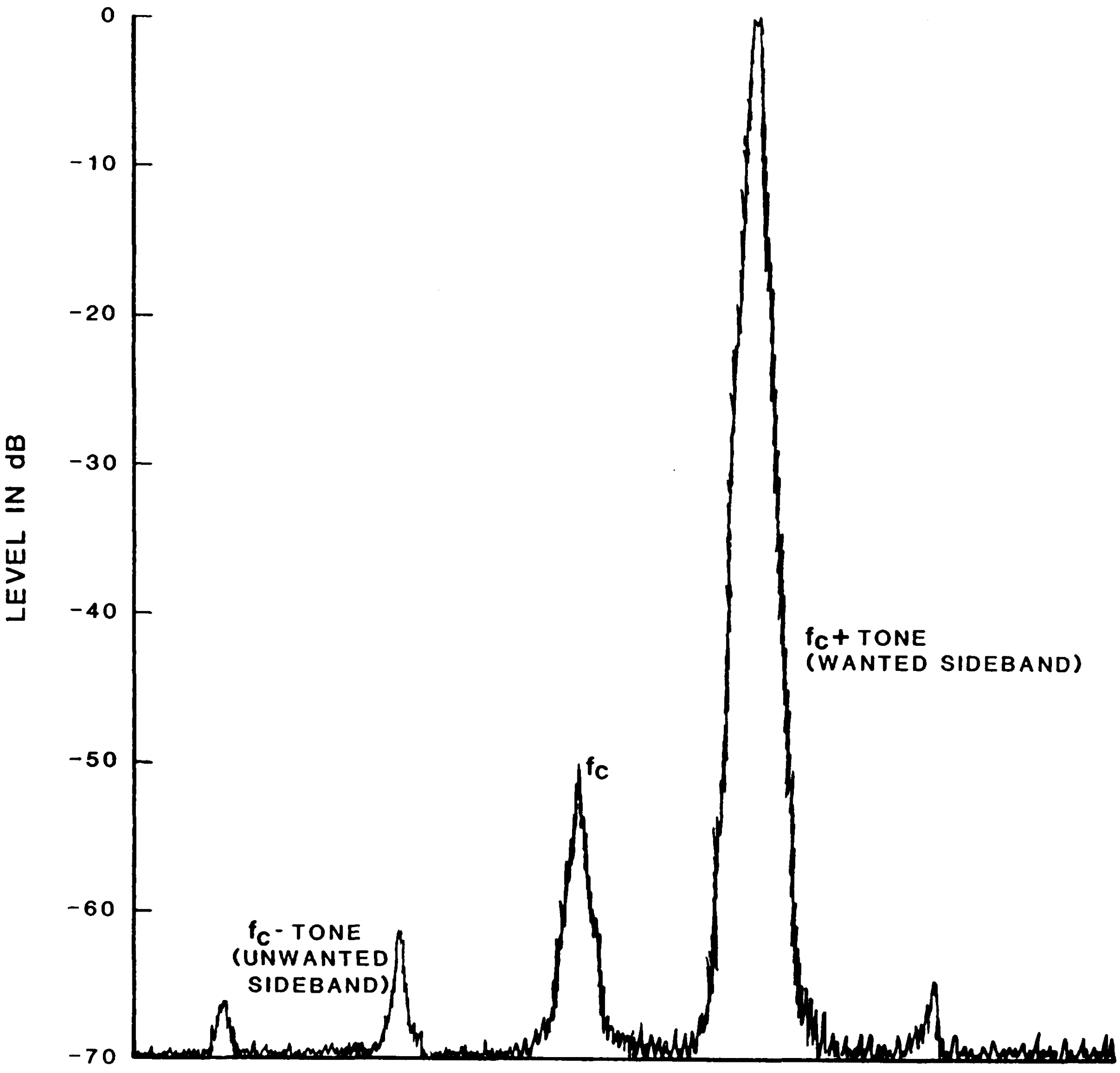


FIGURE 76. Transmitter carrier and sideband suppression display.

d. Carefully adjust the exciter frequency to an exact zero beat with the WWV signal. Although several techniques can be used here, the preferred method is to offset tune the receiver thus producing a comfortable audio tone with WWV. Both the "S" meter and the tone will then signal the zero beat of the exciter with WWV.

e. Maintain the testing condition for several hours as required to either demonstrate stability or to show drift.

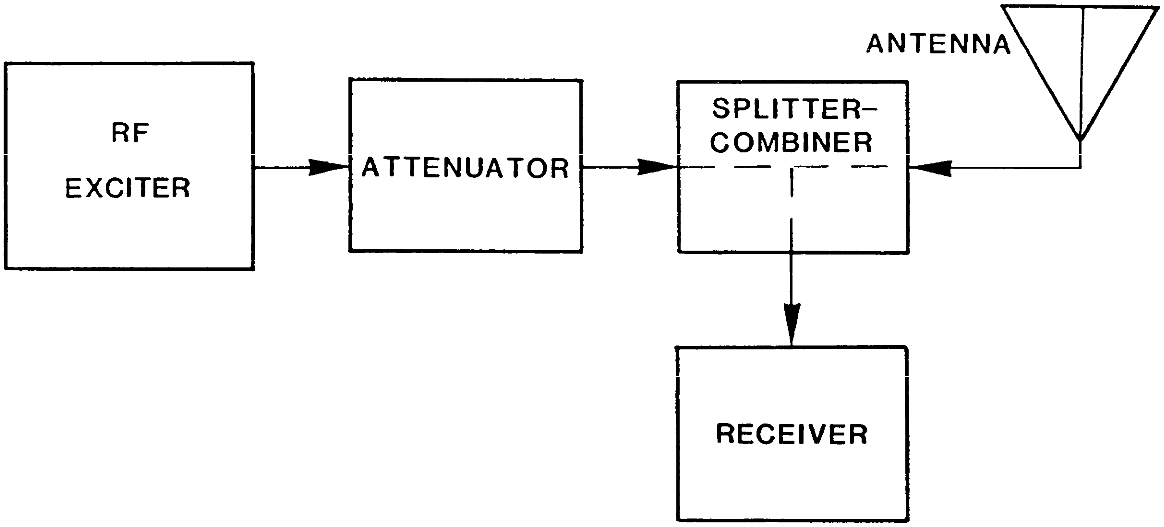


FIGURE 77. Transmitter frequency stability test setup.

5.9.3 **Antenna and transmission line tests.** At the time an antenna or transmission line is constructed or installed, extensive measurements must be made over its frequency range. The results of periodic tests compared to the original test figures will do much to indicate the condition of the antenna or transmission line.

5.9.3.1 **Voltage standing wave ratio (VSWR) test.** Connect the equipment as shown in figure 78.

a. The signal generator (or low power rf exciter) can be used in this test in several ways, depending on the employment of the antenna under test. If the antenna is designed for and employed at one frequency only, the signal source is tuned only to that frequency. If the antenna is designed for and employed at several specific frequencies, the signal source is to be tuned to each of these frequencies in turn. If the antenna is designed to operate over a frequency band, select a number of frequencies evenly spaced across the frequency band for testing. Whichever method is required, all subsequent routine tests on that antenna system have to follow the original testing method so as to provide a valid comparision with the initial test data.

b. Calibrate the VSWR meter by adjusting the signal source output and the VSWR sensitivity control. Switch the VSWR meter to the reading position and record the VSWR.

c. Compare the results obtained with the original and subsequent tests. Higher VSWR measurements may indicate an antenna problem, lower measurements may indicate an increase in transmission line loss.

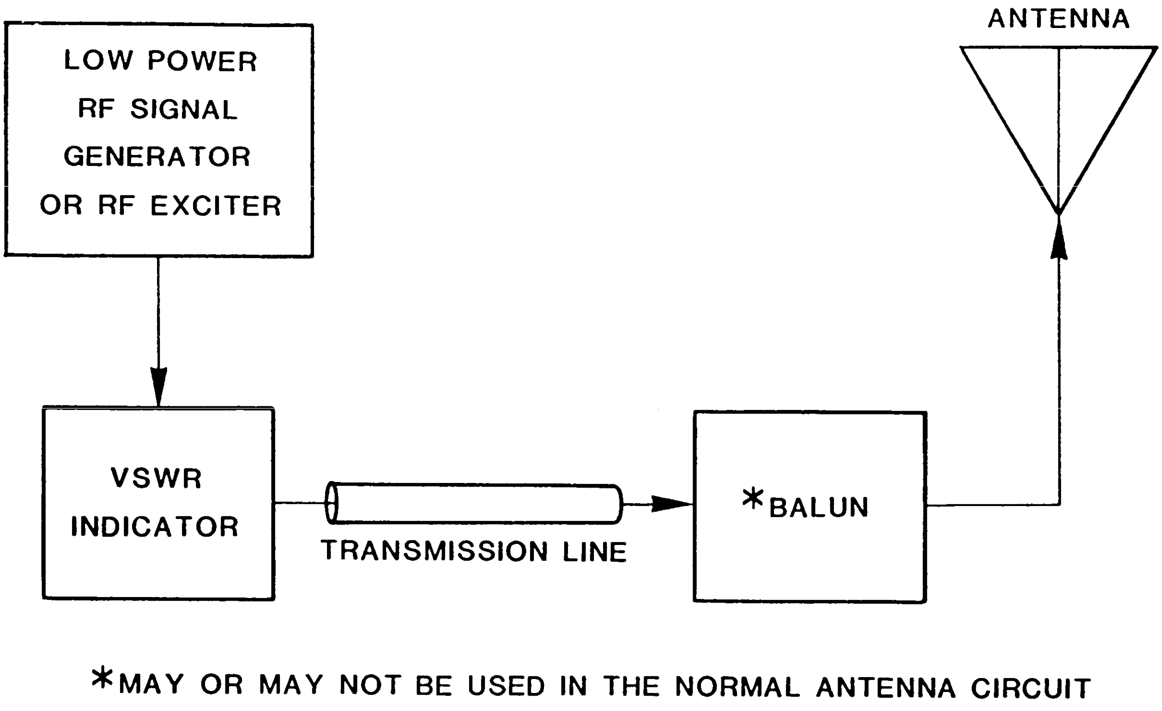


FIGURE 78. Transmission line, balun, and antenna VSWR test setup.

5.9.3.2 **Transmission line loss.** Two procedures are given here. The first uses close tracking (< 2%) identical rf wattmeters. The second procedure uses a single rf wattmeter of at least 10% accuracy.

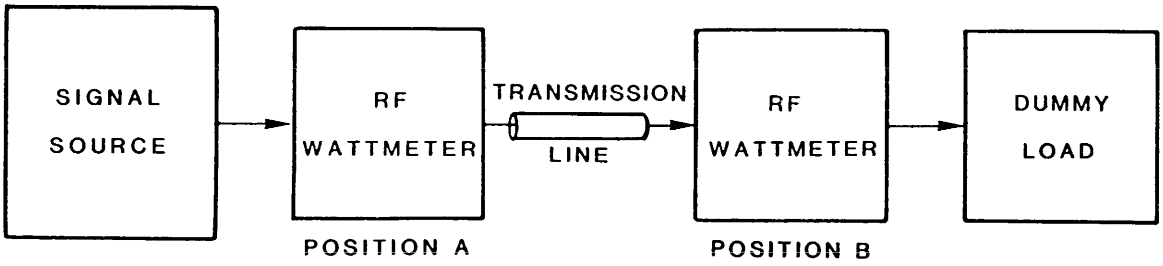


FIGURE 79. Transmission line loss test setup.

a. Connect the equipment as shown in figure 79. The signal source should be the normal rf exciter. If the single wattmeter procedure is being used, connect the transmission line to the dummy load.

b. Communications between the two ends of the test are required. Either field telephones or low power portable radios can be used.

c. Adjust the output level of the signal source for a wattmeter power of 0 dBm or other convenient low power reading at position A.

d. Using the two wattmeter procedure, read the power at position B. Determine the transmission line loss from:

$$\text{Loss (dB)} = 10 \log \frac{\text{Power output (B)}}{\text{Power input (A)}} \qquad (5\text{-}17)$$

e. Using the one wattmeter procedure, turn off the signal source, disconnect the wattmeter from position A, and connect the signal source directly to the transmission line. Transport the wattmeter to the other end of the transmission line (position B) and install it between the line and the dummy load as shown in figure 79.

f. Turn the signal source back on and read the power at position B. Determine the transmission line loss as in d above.

g. Compare this loss (step d or step f) with the loss recorded from the initial installation test and with the subsequent periodic tests.

h. Testing open wire transmission line requires two identical baluns installed at each end of the transmission line under test. These two baluns must be bench tested for identical operation prior to their use.

5.9.3.3 **Antenna impedance measurements.** These measurements can be made with a noise bridge, figure 80A, or with an impedance bridge, figure 80B. Ideally, measurements should be made at the antenna terminals. In practice, the test instrument can be physically located at any point along a transmission line connected to the antenna. In this case, the exact electrical length of the transmission line between the antenna and the instrument must be known. A Smith Chart is then used in conjunction with the measured impedance to obtain that of the antenna.

a. Connect the equipment as shown in figure 80A or B according to the historical record for that antenna. Either method may be selected for initial testing based on equipment availability.

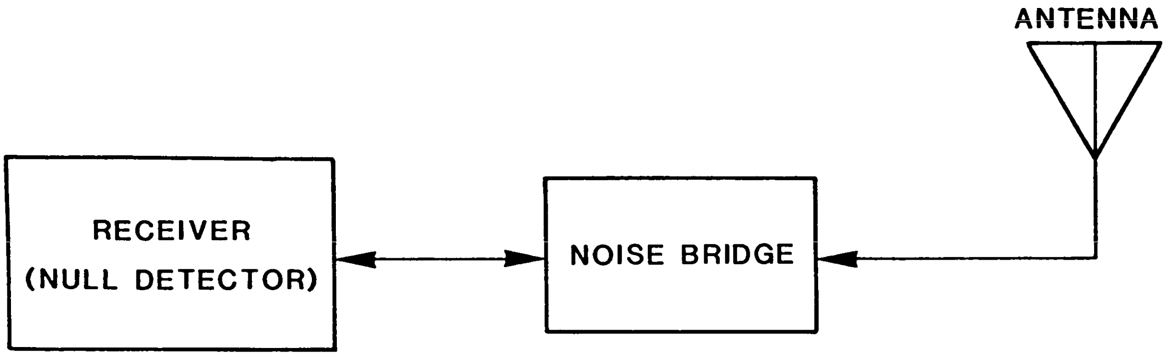
b. Tune the receiver to the frequency under test.

c. For the noise bridge test, adjust the noise bridge to null out the receiver noise. Read the resistance and reactance directly.

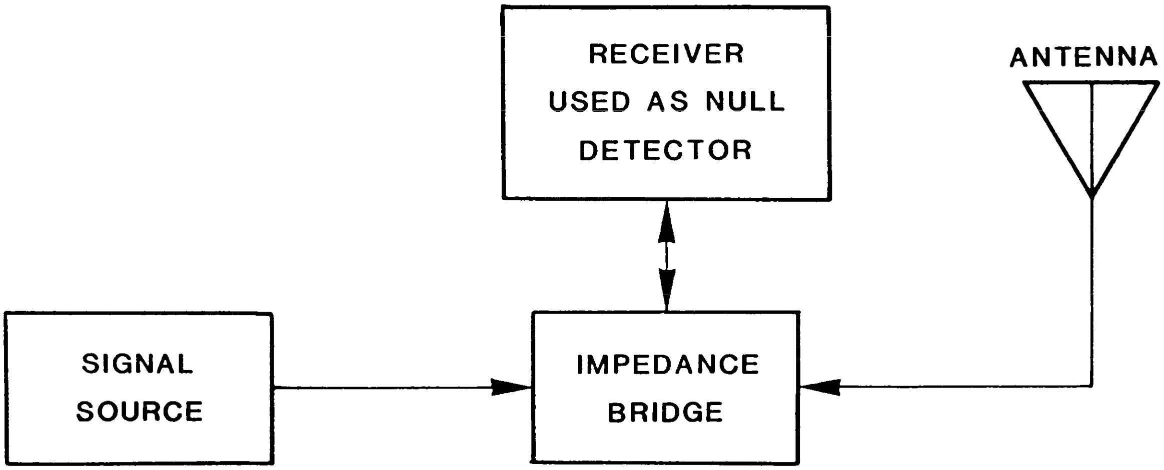
d. For the impedance bridge test, tune the signal generator (or rf exciter) to the test frequency. Tune the impedance bridge to null the signal generator as monitored on the receiver. Some bridges have a null indicator meter.

e. Compare the readings obtained with the initial installation test and subsequent readings.

f. The antenna can be adjusted (lengthened or shortened) based on this test. An approximation of the amount that the antenna needs to be adjusted can be obtained by finding the frequency at which the antenna resonates with zero reactance. The percentage difference between this frequency and the test frequency represents the amount of adjustment needed.



A. NOISE BRIDGE



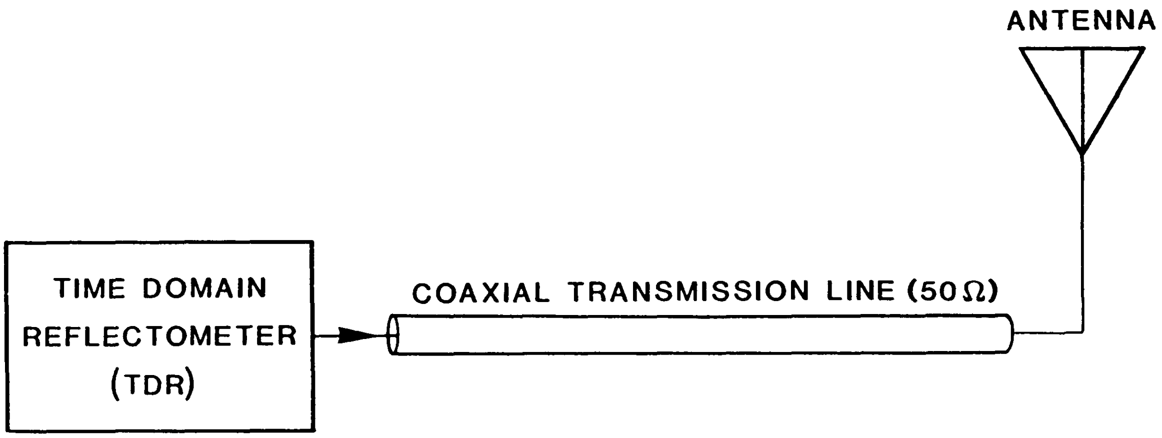
B. IMPEDANCE BRIDGE

FIGURE 80. Antenna impedance measurement test setup.

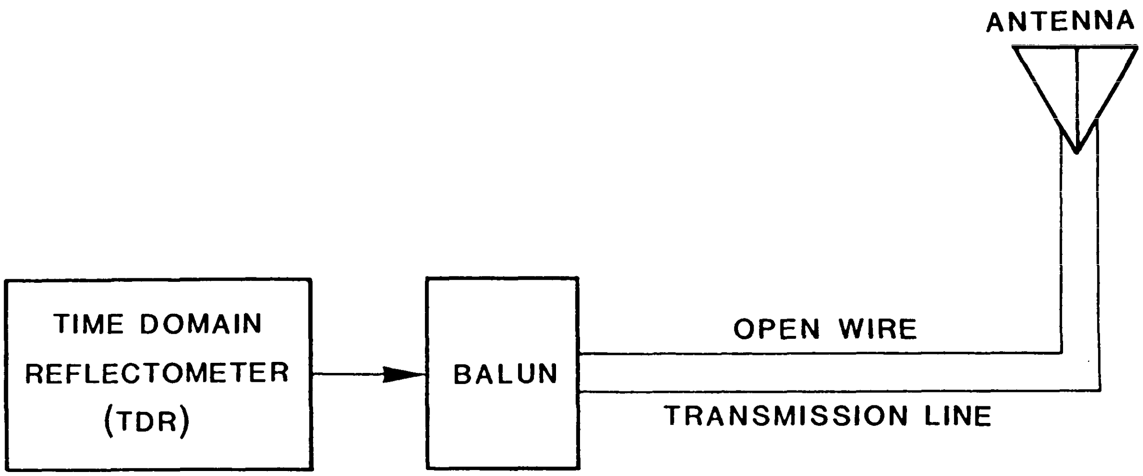
5.9.3.4 **Transmission line discontinuity test.** Connect the equipment as shown in figure 81.

a. If a transmission line of an impedance of other than 50 ohms is to be tested, an impedance matching device must be used (figure 81B).

b. Magnitudes of mismatch and the distance to the mismatch or discontinuity can be read from the time domain relectometer (TDR) scope presentation.



A. COAXIAL TRANSMISSION LINE



B. OPEN WIRE TRANSMISSION LINE

FIGURE 81. Transmission line discontinuity test setup.

Custodians:

Army — SC
Navy — EC
Air Force — 90

Review Activities:

Army — CR,AC
Navy — YD, MC, OM, TD, NC
Air Force — 2, 11, 13, 17, 26
DCA — DC
NSA — NS
JTC^{3}A — JT
DoD/ECAC

User Activities:

Army
Navy - MC, YD
Air Force

Preparing Activity:

Army — SC
(Project SLHC — 4130)

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APPENDIX A. HF POWER BUDGET WORKSHEET

Link or net identification ______________________________

Site A ____________________ Site B ____________________

Latitude ____________ Latitude ____________

Longitude ____________ Longitude ____________

Traffic type (voice, teletypewriter, digital data)

Number of channels ________ Message channel bandwidth ______ kHz

Modulation ____________

Diversity ____________ Combiner ____________

If teletypewriter:
Maximum character error rate, P_C (5.2.4.2b) ________ %
Code (7-unit start-stop, 5-unit synchronous)
Corresponding BER (Fig. 62) ________

If digital data:
Maximum BER (5.2.4.2c) ________

If voice:
Required SNR (5.2.4.1b) ________

If teletypewriter or digital data:
SNR required for BER (Fig. 65) ________ dB

Required time availability for specified performance ________ %

CALCULATION OF REQUIRED RECEIVED POWER LEVEL

SNR (from above)	________	dB	I_d (5.4.2.1b)	________	dB
M_f (5.4.2.1)	________	dB	I_c (5.4.2.1c)	________	dB
F_m (5.4.4)	________	dB	G_p (5.4.5)	________	dB
M_d (5.4.6)	________	dB			
F_a (5.4.3)	________	dB			
TOTAL A	________	dB	TOTAL B	________	dB

$P_r = 10 \log kT + 10 \log b + A - B$
$= -204 + 10 \log b + A - B$
$= -204 +$ ________ $+$ ________ $-$ ________ $=$ ________ dBW

CALCULATION OF REQUIRED TRANSMITTER POWER OUTPUT LEVEL

L_p (5.4.7.1)	________	dB	G_t (5.4.7.2)	________	dB
L_l (5.4.7.3)	________	dB	G_r (5.4.7.2)	________	dB
P_r (from above)	________	dB			
TOTAL C	________	dB	TOTAL D	________	dB

$P_t = C - D =$ ________ $-$ ________ $=$ ________ dBW

Antilog (P_t /10) $=$ ________ W $=$ ________ kW

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APPENDIX B. SAMPLE FILLED-IN HF POWER BUDGET WORKSHEETS

10. Example 1

Link or net identification EAST - WEST LINK 1

Site A EAST
Latitude 38° 40' N
Longitude 77° 05' W

Site B WEST
Latitude 31° 26' N
Longitude 110° 30' W

Traffic type ([✓ voice], teletypewriter, digital data)

Number of channels 4

Message channel bandwidth 3 kHz

Modulation ISB

Diversity DUAL SPACE

Combiner SELECTION

If teletypewriter:
Maximum character error rate, P_C (5.2.4.2b) ______ %
Code (7-unit start-stop, 5-unit synchronous)
Corresponding BER (Fig. 62) ______

If digital data:
Maximum BER (5.2.4.2c) ______

If voice:
Required SNR (5.2.4.1b) 29

If teletypewriter or digital data:
SNR required for BER (Fig. 65) ______ dB

Required time availability for specified performance 95 %

CALCULATION OF REQUIRED RECEIVED POWER LEVEL

SNR (from above) 29 dB
M_f (5.4.2.1) 12 dB
F_m (5.4.4) 3 dB
M_d (5.4.6) 8 dB
F_a (5.4.3) 50 dB
TOTAL A 102 dB

I_d (5.4.2.1b) 7 dB
I_c (5.4.2.1c) 0 dB
G_p (5.4.5) 0 dB
TOTAL B 7 dB

P_r = 10 log kT + 10 log b + A − B
= − 204 + 10 log b + A − B
= − 204 + 35 + 102 − 7 = −74 dBW

CALCULATION OF REQUIRED TRANSMITTER POWER OUTPUT LEVEL

L_p (5.4.7.1) 152 dB
L_l (5.4.7.3) 2 dB
P_r (from above) −74 dB
TOTAL C 80 dB

G_t (5.4.7.2) 20 dB
G_r (5.4.7.2) 20 dB
TOTAL D 40 dB

P_t = C − D = 80 − 40 = 40 dBW

Antilog (P_t /10) = 10,000 W = 10 kW

20. Example 2

HF POWER BUDGET WORKSHEET

Link or net identification EAST - WEST LINK 2

Site A EAST

Latitude 38° 40′ N

Longitude 77° 05′ W

Site B WEST

Latitude 31° 26′ N

Longitude 110° 30′ W

Traffic type (voice, [✓ teletypewriter], digital data)

Number of channels 16

Message channel bandwidth 3 kHz

Modulation FSK (VFCT)

Diversity DUAL SPACE

Combiner SELECTION

If teletypewriter:

Maximum character error rate, P_C (5.2.4.2b) 0.1 %

Code ([✓ 7-unit start-stop], 5-unit synchronous)

Corresponding BER (Fig. 62) 1.5×10^{-4}

If digital data:

Maximum BER (5.2.4.2c) ________

If voice:

Required SNR (5.2.4.1b) ________

If teletypewriter or digital data:

SNR required for BER (Fig. 65) 23 dB

Required time availability for specified performance ________ %

CALCULATION OF REQUIRED RECEIVED POWER LEVEL

SNR (from above) 23 dB

M_f (5.4.2.1) - dB

F_m (5.4.4) 19 dB

M_d (5.4.6) 7 dB

F_a (5.4.3) 50 dB

TOTAL A 99 dB

I_d (5.4.2.1b) - dB

I_c (5.4.2.1c) - dB

G_p (5.4.5) 0 dB

TOTAL B 0 dB

P_r = 10 log kT + 10 log b + A − B

= − 204 + 10 log b + A − B

= − 204 + 35 + 99 − 0 = −70 dBW

CALCULATION OF REQUIRED TRANSMITTER POWER OUTPUT LEVEL

L_p (5.4.7.1) 152 dB

L_l (5.4.7.3) 2 dB

P_r (from above) −70 dB

TOTAL C 84 dB

G_t (5.4.7.2) 22 dB

G_r (5.4.7.2) 22 dB

TOTAL D 44 dB

P_t = C − D = 84 − 44 = 40 dBW

Antilog (P_t /10) = 10,000 W = 10 kW

30. Example 3

HF POWER BUDGET WORKSHEET

Link or net identification EAST - WEST LINK 3

Site A	EAST	Site B	WEST
Latitude	38° 40′ N	Latitude	31° 26′ N
Longitude	77° 05′ W	Longitude	110° 30′ W

Traffic type (voice, teletypewriter, [✓ digital data])

Number of channels 1 (1200 bps)   Message channel bandwidth 3 kHz

Modulation DPSK

Diversity DUAL SPACE   Combiner SELECTION

If teletypewriter:

Maximum character error rate, P_C (5.2.4.2b) ______ %

Code (7-unit start-stop, 5-unit synchronous)

Corresponding BER (Fig. 62) ______

If digital data:

Maximum BER (5.2.4.2c) 10^{-5}

If voice:

Required SNR (5.2.4.1b) ______

If teletypewriter or [✓ digital data]:

SNR required for BER (Fig. 65) 30 dB

Required time availability for specified performance ______ %

CALCULATION OF REQUIRED RECEIVED POWER LEVEL

SNR (from above)	30	dB	I_d (5.4.2.1b)	–	dB
M_f (5.4.2.1)	–	dB	I_c (5.4.2.1c)	–	dB
F_m (5.4.4)	0	dB	G_p (5.4.5)	0	dB
M_d (5.4.6)	7	dB			
F_a (5.4.3)	50	dB			
TOTAL A	87	dB	TOTAL B	0	dB

$P_r = 10 \log kT + 10 \log b + A - B$

$= -204 + 10 \log b + A - B$

$= -204 + \underline{35} + \underline{87} - \underline{0} = \underline{-92}$ dBW

CALCULATION OF REQUIRED TRANSMITTER POWER OUTPUT LEVEL

L_p (5.4.7.1)	152	dB	G_t (5.4.7.2)	17	dB
L_l (5.4.7.3)	2	dB	G_r (5.4.7.2)	17	dB
P_r (from above)	-92	dB			
TOTAL C	72	dB	TOTAL D	34	dB

$P_t = C - D = \underline{72} - \underline{34} = \underline{38}$ dBW

Antilog $(P_t/10)$ = 6310 W = 6.3 kW

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APPENDIX C. SITE SURVEY REPORT

10. GENERAL

10.1 **Scope.** This appendix provides guidance to the site survey team to aid in the gathering of required information.

10.2 **Identification material.** The site survey report should include the following identification data in addition to the information contained in the report itself.

a. Site Identification Number or Serial Number.

b. Date.

c. Engineer.

20. FORMAT

20.1 **Site survey report format.** The site survey format shown in annex A is suggested for use by the site survey team. As with any preset format, it may require modification to meet the requirements of a specific project. The suggested format in annex A is paragraphed to reflect the paragraph numbering and organization of the site survey report.

20.2 **Distribution.** Copies of the final site survey should be distributed in accordance with command policies of the communications engineering activity.

ANNEX A. SITE SURVEY REPORT FORMAT

SECTION I — INTRODUCTION

1. WHAT WAS SURVEYED:

When survey was conducted.

Authority under which conducted.

2. THE PURPOSE OF THE SURVEY AND OBJECTIVES:

3. TEAM COMPOSITION THAT MADE SURVEY:

4. ASSISTANCE FROM LOCAL AND/OR COMMAND REPRESENTATIVE ACKNOWLEDGED:

5. LIMITATIONS, IF ANY:

6. SHORT SYNOPSIS OF SITE FINDINGS:

Provide a brief summary of the results of the survey. Include the overall rating of each site such as Excellent, Good, Poor, or Unsatisfactory with primary reason for such rating.

SECTION II — SITE REPORT

7. COORDINATES:

Latitude

Longitude

8. ELEVATION:

Meters

Feet

9. DESCRIPTION OF SITE LOCALE:

Recommend use of real estate description worksheet, figure C-1.

10. DESCRIPTION OF TOPOGRAPHY AT SITE:

Recommend use of topography and terrain worksheet, figure C-2.

11. PHYSICAL SECURITY CONSIDERATIONS OF THE SITE:

12. SOIL CONDITIONS:

Describe soil conditions, particularly those that may affect the buildings or other site features. Include any reliable local soil load bearing data available or indicate if soil samples have been taken. Take soil resistivity measurements. If soils samples have been taken, indicate where analysis is being performed and when the analysis is to be completed.

13. SITE PREPARATION REQUIRED:

Cover in detail, with estimate of cost, all site preparation needed.

14. SITE OWNERSHIP:

The name of the site owner and authorized representative with mailing addresses and telephone numbers should be recorded here or in figure C-1.

15. INDEX OF SITE PHOTOGRAPHS:

List all site photographs that will be attached to this report by number or other identification and give a concise statement of what pertinent information each photograph contains. If video recordings have been made of the site, correlate the footage reading of the VCR with the scenes.

16. AVAILABILITY OF COMMUNICATIONS CIRCUITS:

If circuits are required, list by identification number all available circuits and systems that could be used or expanded. Describe type, quality, and controlling organization.

17. CABLE ROUTING:

Determine route and ground conditions for proposed land lines or cables if no present circuits are available. Attach sketch showing sufficient detail for support-planning groups to evaluate and plan facilities to meet requirements.

18. PROXIMITY AND DIRECTION TO AIRFIELDS:

SECTION III — TRANSMISSION PATH REPORT

19. MODE OF TRANSMISSION:

20. GROUND CONDUCTIVITY:

21. PATH AZIMUTH:

22. DISTANCE TO RADIO HORIZON:

23. TAKE-OFF ANGLES TO RADIO HORIZON AT SELECTED AZIMUTHS:

Azimuth	Take-off Angle		
0 —	__________	(zero degrees is equal to the great circle bearing to the distant station; R = right, L = left)	
R 5°	__________	L 5°	__________
R 10°	__________	L 10°	__________
R 15°	__________	L 15°	__________

Thereafter, every 5° around the horizon.

Note and map all metal structures within three wavelengths of the proposed antenna.

24. LOCATION OF CRITICAL POINTS:

Locations	Kilometers (Miles) from Site — Horizon
a.	
b.	
c.	
etc.	

25. GROUND ELEVATIONS: OBSTRUCTION HEIGHT:

Site:

Radio Horizon:

Critical Points:

a.

b.

c.

etc.

26. DESCRIPTION OF TERRAIN:

Radio Horizon:

Critical Points:

a.

b.

c.

etc.

27. DESCRIPTION OF TERRAIN BETWEEN SITE AND RADIO HORIZON:

28. CLEARANCE REQUIRED AT CRITICAL POINTS:

Critical Points	Clearance
a.	
b.	
c.	
etc.	

SECTION IV — LOGISTIC SUPPORT DATA

29. TRANSPORTATION:

Indicate equipment and individual transportation, military and commercial, available to the military and contractor personnel.

a. Military transportation information should include:

(1) Type of vehicles.

(2) Method of dispatch (trip ticket, 24-hour dispatch, driver).

(3) Operator-licensing requirements for contractor personnel.

b. Commercial transportation information should include:

(1) Availability and rates for various types of vehicles.

(2) Regulations governing use of personal automobile.

(3) Driver license requirements.

(4) Availability and rates of local bus and taxi service.

30. PERSONNEL SUPPORT:

Recommend use of personnel support worksheet, figure C-3.

31. SITE ACCESSIBILITY:

Recommend use of site access requirements worksheet, figure C-4.

32. LOCAL SUPPLIERS:

a. Record information on the availability of local subcontractors and their rates for services listed below. Indicate source and estimate reliability of this information. Facilities Engineer offices usually have such information for services listed below:

(1) Concrete Workers.

(2) Sheet Metal Mechanics.

(3) Pipefitters.

(4) Carpenters.

(5) Riggers.

(6) Ironworkers.

(7) Electricians.

(8) Painters.

(9) Laborers.

b. Request names from local military units of contractors who have been used before, with comment on the quality of their work.

33. LOCAL MILITARY PERSONNEL:

Record name, rank, position, and organization of key military personnel in the area.

34. COMMUNICATIONS FACILITIES:

Recommend use of communications facilities worksheet, figure C-5.

35. WAREHOUSE AND STORAGE FACILITIES:

Record information of the following nature concerning warehouse facilities, both Government and commercial.

a. Ownership.

b. Location.

c. Availability and amount of open and inside storage area available.

d. Shipping address.

e. Security.

f. Availability of material handling equipment (fork lifts, pallets, dollies, and cranes).

g. Procedures for use.

36. PROJECT ADMINISTRATION FACILITIES:

Record the availability of Government-furnished office space, if any, for the station project engineer. A minimum of 3 m (10 ft) by 6 m (20 ft) is desirable. Ascertain if office space will be equipped with furnished desk, drawing table, and filing cabinet.

37. ADDITIONAL REMARKS:

Check availability of diesel fuel, water supply, sanitation facilities, and security requirements, if applicable.

SECTION V — COMMERCIAL POWER SURVEY

38. ELECTRICAL POWER:

Recommend use of electrical power worksheet, figure C-6.

SECTION VI — AREA ENVIRONMENTAL CONDITIONS

Obtain data for previous ten years, if available, and note source.

39. TEMPERATURE:

a. Mean maximum, by month:

b. Mean minimum, by month:

c. Annual mean:

d. Absolute maximum:

e. Absolute minimum:

40. AVERAGE RELATIVE HUMIDITY:

Summer ________ %

Winter ________ %

Annual mean ________ %

41. PRECIPITATION:

a. Annual average rainfall:

b. Duration of rainy season:

c. Annual average snowfall:

d. Duration of snow season:

42. PREVAILING WIND DIRECTION:

43. SPECIAL ENVIRONMENTAL CONSIDERATIONS:

Effect of fungus and humidity on equipment, buildings, antenna towers, and power equipment. Humidity and salt content of the environment which may require special corrosion control measures.

REAL ESTATE DESCRIPTION

Legal description of property: ____________________

____

Describe the boundaries of the area where the site is located. Include a sketch or an area map if available. ____________________

Present ownership of land:

Name(s) of owner(s)	**Address(es)**	**Telephone Number(s)**

Agent(s) handling property	**Address(es)**

Type of acquisition/lease: ____________________

Cost of acquisition/lease: ____________________

Acquisition of property for access roads:

Name(s) of owner(s)	**Address(es)**

Procedure for acquiring property: ____________________

____

Easement requirements

Government: ____________________

Landlord: ____________________

Source of real estate information:

FIGURE C-1. Real estate description worksheet.

TOPOGRAPHY AND TERRAIN

SITE ELEVATION (above mean sea level)

High: ________________ m (ft) Low: ________________ m (ft)

GENERAL DESCRIPTION

Vegetation: Heavy __________ Light __________ None __________

Trees: Heavily wooded ________ Lightly wooded ________ None ________

Slopes: Steep ________ Gentle ________ Rolling ________ Flat ________

Surface characteristics: Rock ________ Gravel ________ Sand ________

Clay ________ Silt ________ Other ________

Remarks:

SOURCE OF WORKSHEET INFORMATION

Existing documentation: Yes ______ No ______

If yes, identify documentation: ____

____

Direct observation: Yes ______ No ______

FIGURE C-2. Topography and terrain worksheet.

PERSONNEL SUPPORT

Housing available (officer, enlisted, civilian, contractor)

On-base housing, bachelor and family

Type and quality: ______________________________

Method of assignment: ______________________________

Waiting time: ______________________________

Availability of furnishings: ______________________________

Off-base housing

Location: ______________________________

Distance from site: ______________________________

Hotels: Plentiful ________ Scarce ________ None ________

Quality: Excellent ______ Adequate ______ Poor ______

Lodging, average price per day: dollars ______

Food, average price per day: dollars ______

Private homes: Plentiful ______ Scarce ______ None ______

Accommodations: Excellent ______ Adequate ______ Poor ______

Average price per month: dollars ______ furnished/unfurnished

Utilities

Type available and approximate cost

Heating (oil, gas, electric): ______________________________

Water: ______________________________

Electricity: ______________________________

Electricity: Voltage ______ Frequency ______ Reliability ______

Telephone service, availability and cost: ______________________________

____

FIGURE C-3. Personnel support worksheet (sheet 1 of 4).

PERSONNEL SUPPORT — Continued

Messing facilities (officer, enlisted, civilian, contractor)

Onsite: ____________________

Offsite: ____________________

List military clubs available indicating policies governing privileges for officers, NCOs, DoD civilians and contractor personnel: ____________________

____

Local restaurants: Yes ______ No ______

Prices compared to U.S.: ______ percent higher ______ percent lower

______ same

Local merchants: Plentiful ______ Scarce ______ None ______

Prices compared to U.S.: ______ percent higher ______ percent lower

______ same

Import supplies: Yes ______ No ______

From where? ____________________

Medical and dental facilities

Military (distance): ____________________

Commercial (distance): ____________________

Name and address: ____________________

____

Dispensary facilities or doctors: Yes ______ No ______

Distance: ____________________

FIGURE C-3. Personnel support worksheet (sheet 2 of 4).

PERSONNEL SUPPORT — Continued

Military exchange

Distance: ______________________________

Size: ______________________________

Type of stock: ______________________________

____

Commissary

Distance: ______________________________

Size: ______________________________

Schools (distance and grades taught)

On-base ______________________________

Off-base: ______________________________

Existing: Grade school ________ High school ________ College ________

Private tutors: Yes ______ No ______

Distance: ______________________________

Standards: Excellent ________ Adequate ________ Inadequate ________

Sponsor: Government ________ Private ________ Municipal ________

Name of sponsor: ______________________________

Availability of school transportation facilities: ______________________________

____

Recreation (TV, radio, sports, hobbies, movies, etc.)

On-base: ______________________________

Off-base: ______________________________

FIGURE C-3. Personnel support worksheet (sheet 3 of 4).

PERSONNEL SUPPORT — Continued

Churches

On-base: ______

Off-base: ______

Clothing supplies

Local merchants: Plentiful ______ Scarce ______ None ______

Prices compared to U.S.: ______ percent higher ______ percent lower

______ same

Import: Yes ______ No ______

From where? ______

Banking

Local banks: Plentiful ______ Scarce ______ None ______

Distance to nearest large bank: ______

Name and address: ______

SOURCE OF WORKSHEET INFORMATION

Existing documentation: Yes ______ No ______

If yes, identify documentation: ______

Direct observation: Yes ______ No ______

FIGURE C-3. Personnel support worksheet (sheet 4 of 4).

SITE ACCESS REQUIREMENTS

HIGHWAYS

Distance from site access road and highway intersection to support base or town:

____ km (mi)

Classification: State ________ County ________ Municipal ________

Other (specify) ________________________________

Type of surface: Concrete ________ Asphalt ________ Gravel ________

Stone ________ Dirt ________ Other (specify) ________

Minimum width: __________ m (ft)

Paved shoulders: Yes ______ No ______

Maximum grades: Paved roads _________ % Dirt roads _________ %

Months of year usable: __________

Bridge, tunnel, culvert limits

Total load: ________ kg (tons), or ________ kg (tons)/axle

Overhead clearance: ________ m (ft)

Total width: ________ m (ft)

Number of lanes: ________

Improvements required:

FIGURE C-4. Site access requirements worksheet (sheet 1 of 3).

SITE ACCESS REQUIREMENTS — Continued

EXISTING ACCESS ROAD (FROM SITE TO HIGHWAYS)

Length of access road: ______________________________ km (mi)

Classification: State ________ County ________ Municipal ________

Other (specify) ______________________________

Type of surface: Concrete ________ Asphalt ________ Gravel ________

Stone ________ Dirt ________ Other (specify) ________

Minimum width: __________ m (ft)

Paved shoulders: Yes ______ No ______

Maximum grades: Paved roads _________ % Dirt roads _________ %

Months of year usable: __________

Bridge, tunnel, culvert limits

Total load: ________ kg (tons), or ________ kg (tons)/axle

Overhead clearance: ________ m (ft)

Total width: ________ m (ft)

Number of lanes: ________

Improvements required:

FIGURE C-4. Site access requirements worksheet (sheet 2 of 3).

SITE ACCESS REQUIREMENTS — Continued

NEW ACCESS ROAD

Length required: ______________________________ km (mi)

Culverts required (number, size, and approximate amount of fill per culvert): ________

____

____

____

____

Bridges required (number and approximate span of each): ______________

____

____

____

____

Location of required new work and necessary field data are shown on drawing or sketch number: __________

Existing tramways: Yes ______ No ______

Capacity: __________ m^3 (ft^3), __________ kg (tons-lb)

Car dimensions: __________

SOURCE OF WORKSHEET INFORMATION

Existing documentation: Yes ______ No ______

If yes, identify documentation: ______________________________

Direct observation: Yes ______ No ______

FIGURE C-4. Site access requirements worksheet (sheet 3 of 3).

COMMUNICATIONS FACILITIES

COMMUNICATIONS

a. Telephone service

Type of service: Military ________ Commerical ________

Distance to nearest telephone service connection: __________ km (mi)

Type of line construction: Open wire ________ Aerial cable ________

Buried cable ________

Number of pairs available: __________

Wire gauge of pairs: __________

Estimated cost of line extension:

Open wire-dollars __________

Aerial cable-dollars __________

Buried cable-dollars __________

If on an existing base:

Type of base exchange switchboard: ____

Number of lines: ____

Number of line drops unassigned: ____

Number of trunks to each connecting base: ____

Remarks and source of information:

FIGURE C-5. Communications facilities worksheet (sheet 1 of 3).

COMMUNICATIONS FACILITIES — Continued

b. Radio service

Type of radio service (military or commercial) now available from the site to:

Nearest military base: ____________________

Area command headquarters: ____________________

Access to Defense Communications System: ____________________

Type of radio system for this service: ____________________

____

Remarks and source of information:

c. Communications services available to construction contractor

Will the contractor be permitted to use Government-owned or -operated communications facilities for communication from the base during the construction and installation phase?

Yes ______ No ______

If such use is permitted, what is the approximate charge? ____________________

____

Will mobile and manpack equipment be available during the installation? __________

____

FIGURE C-5. Communications facilities worksheet (sheet 2 of 3).

COMMUNICATIONS FACILITIES — Continued

d. Secure communications

Will secure communications facilities for off-base circuits be required:

During construction and installation: Yes ______ No ______

After installation: Yes ______ No ______

e. Postal Service (APO, FPO)

Name of nearest military installation: ______________________________

____

Distance: ______________________________

Policy governing mail use: ______________________________

____

FIGURE C-5. Communications facilities worksheet (sheet 3 of 3).

ELECTRIC POWER

Commercial or base supply; name, address, and telephone number of supplying company or base engineer: ____________________

____

Primary (to nearest available point of connection):

Voltage ________ Frequency ________ Phase ________

Wires ________

kW available for new facility: ________

Will available power be sufficient for new facility? Yes ______ No ______

Regulation: ________ Voltage: ________ Frequency: ________

Power outages: No. per year ________ Duration ________

Distance to nearest point of connection (line transformer or substation where takeoff of usable power can be effected): ____________________

Cost: dollars ________ per kWh

Does this include high-volume discount? Yes ______ No ______

Are power cables underground or overhead? ____________________

Secondary (to nearest available point of connection; obtain distribution and switching diagram if possible and attach to this form):

Voltage ________ Frequency ________ Phase ________

Wires ________

kW available for new facility: ________

Cost: dollars ________ per kWh

Alternate primary power:

Is an alternate power supply available? Yes ______ No ______

Where is it located? ____________________

FIGURE C-6. Electrical power worksheet (sheet 1 of 2).

ELECTRIC POWER — Continued

Is feeder continuously energized? Yes ______ No ______

Voltage __________ Frequency __________ Phase __________

Wires __________

Is switching manual or automatic? ______________________________

Is there a standby charge? ______________________________

Stability of power source(s)

Primary

a. Frequency of power outage ______________________________

b. Average length of power outage ______________________________

c. Range of voltage fluctuation ______________________________

d. Range of frequency fluctuation ______________________________

Alternate

a. Frequency of power outage ______________________________

b. Average length of power outage ______________________________

c. Range of voltage fluctuation ______________________________

d. Range of frequency fluctuation ______________________________

FIGURE C-6. Electrical power worksheet (sheet 2 of 2).

APPENDIX D. MODULO 2 ARITHMETIC

The rules of modulo 2 arithmetic are as follows:

$0 + 0 = 0$
$1 + 0 = 1$
$0 + 1 = 1$
$1 + 1 = 0$

$0 \times 0 = 0$
$0 \times 1 = 0$
$1 \times 0 = 0$
$1 \times 1 = 1$

The sign $\oplus$ is sometimes used to denote modulo 2 addition.

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2. DOCUMENT TITLE
DESIGN HANDBOOK FOR HIGH FREQUENCY RADIO COMMUNICATIONS SYSTEMS

3a. NAME OF SUBMITTING ORGANIZATION

b. ADDRESS *(Street, City, State, ZIP Code)*

4. TYPE OF ORGANIZATION *(Mark one)*
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