SEMINAR SUBJECTS

INTERFERENCE CONTROL
THROUGH USE OF
CAVITY FILTERS AND FERRITE ISOLATORS

**FROM A TALK GIVEN BY DAN KAEGEBEIN
AT EXPO '84, DENVER, COLORADO**

USE OF CAVITY FILTERS AND FERRITE ISOLATORS
FOR INTERFERENCE CONTROL

I. Common Types of Receiver Interference

    1. Transmitter sideband noise
    2. Transmitter spurious outputs
    3. Transmitter carrier overload
    4. Intermodulation

II. Usual Sources of Interference

    1. Your own Transmitter
    2. Nearby Transmitters
    3. TV Stations
    4. FM Broadcast

III. Factors Contributing to Non-I.M. Transmit-Receive Interference

    A. Related to equipment specifications or characteristics

        1. deficient sideband noise filtering in transmit line
        2. deficient carrier suppression filtering in receive line
        3. poor broadband isolation characteristics in Transmit to receive path, allowing excessive sideband energy to "Leak" around narrow isolation notches, especially troublesome at narrow T-R frequency separations.
        4. increased Transmitter sideband spurious as a result of large sideband impedance variations reflected back to the Transmitter or power amplifier by selective filters.

    B. Related to physical conditions of equipment and site environment

        1. poor joints in RF path, principally in common Transmit and receive paths, as antenna lines and antennas.
        2. Loose hardware, guy wires, or old antennas in close proximity to system antenna.
        3. poor joints in Transmit filters.

IV. Origin of Intermodulation Interference

    1. Transmitter final
    2. Receiver front end, RF and mixer stages
    3. Preamps
    4. Ferrite Isolators, under certain conditions
    5. Ordinary joints in RF conductor paths, particularly
       multicoupler intercabling, Transmission lines and antennas.

V. Two methods used to control I.M. Interference

    1. Reduce level of I.M. generated at the source
    2. Increase isolation between receiver and source of I.M.

VI. A Bandpass Filter can be used to locate sources of Interference as:

    1. Insufficient TX Carrier or noise suppression in a duplexed
       or multicoupled system.
    2. I.M. generation in preamps, and receiver front ends
    3. I.M. Generation in TX Finals, when cavity selectivity is
       adequate.

VII. A Ferrite Isolator can be used to locate sources of Interference as:

    1. I.M. generation in TX finals.
    2. Increased TX spurious output on sideband-impedance
       sensitive Transmitters and power amplifiers.

VIII. Sources of Interference against which Cavity Filters are not effective.
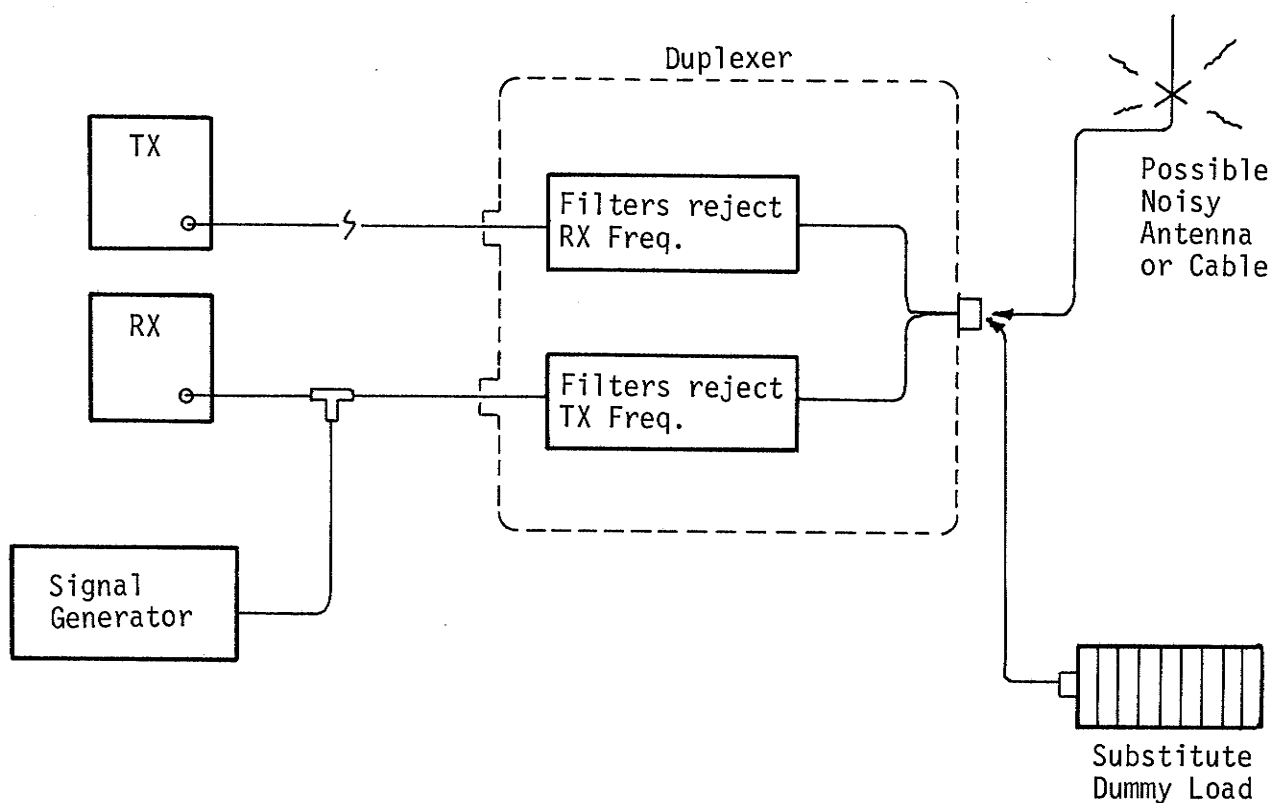
    1. Noise generated in the Transmission line and antenna of a
       duplexed system, or a single antenna multicoupler system.
    2. Transmitter noise or carrier desense, when T-R frequency
       separation is too narrow to allow filter adjustment.
    3. High level I.M. generated in ordinary cable joints in single
       antenna Transmit/Receive Multicoupler Systems.
    4. Inadequate shielding of Transmit and Receive modules.

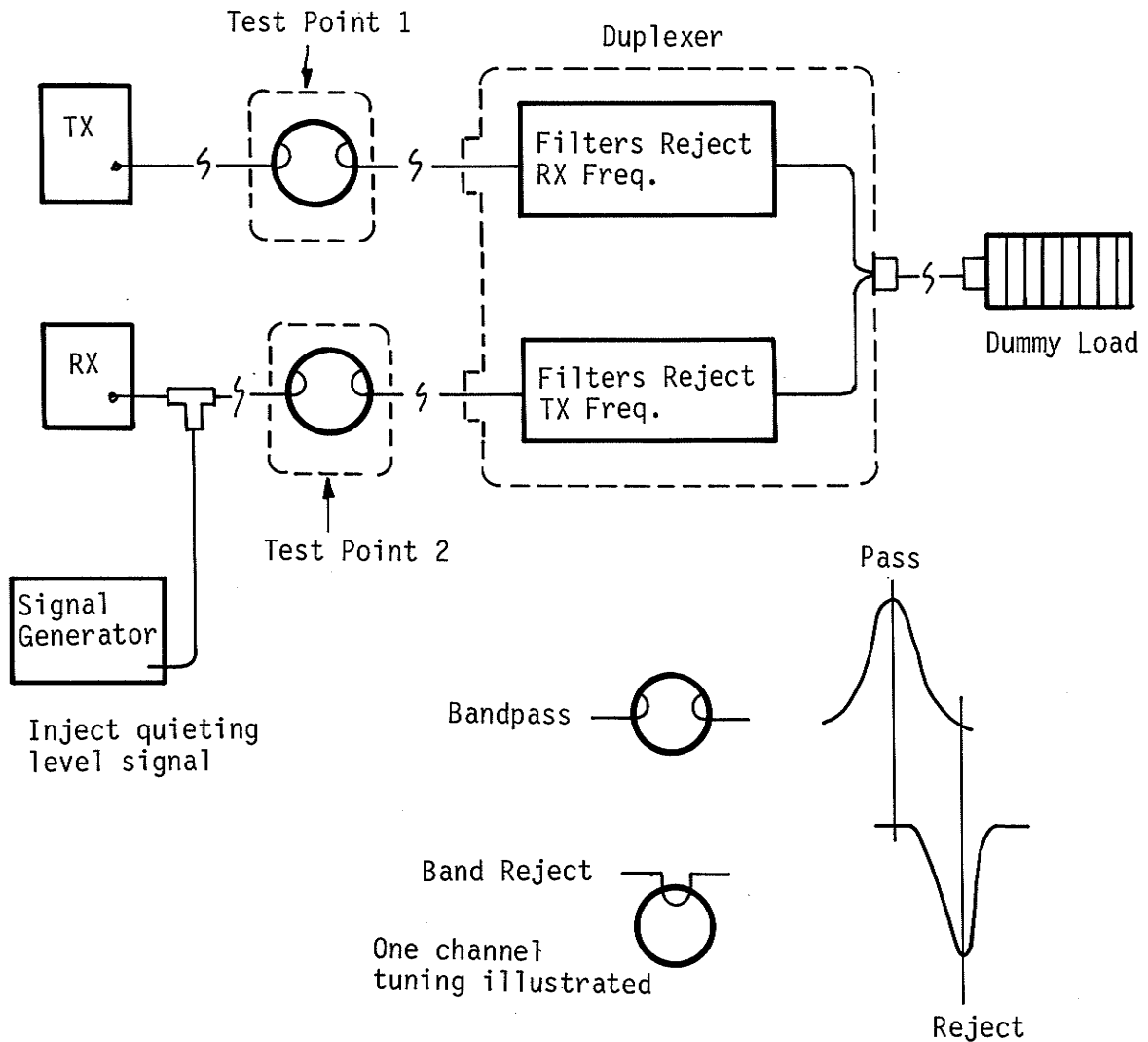IX. Sources of Interference against which Ferrite Isolators are not effective

    1. Transmitter sideband and spurious radiation.
    2. Preceding sources 1, 3 and 4 for cavity filters.

Y(H)503D4

ONE TEST FOR ELIMINATING DUPLEXER
AS A SOURCE OF SYSTEM DEGRADATION

Inject the receive frequency into the line between the duplexer and the receiver using a sampling tee, and adjust signal generator for reference quieting level. Replace the antenna with a 50 ohm dummy load. Make sure all cable connections are sound and tight. If degradation disappears when the transmitter is keyed into the dummy load, check for bad joints in transmission line and/or antenna system. Interaction with another transmitter that is close in frequency and has its antenna a few feet away horizontally, is also a possibility.

Duplexer

TX

RX

Filters reject
RX Freq.

Filters reject
TX Freq.

Possible
Noisy
Antenna
or Cable

Signal
Generator

Substitute
Dummy Load

TEST FOR INADEQUATE DUPLEX ISOLATION
(Using Bandpass or band reject filters)

The bandpass filter test is illustrated, as it is the easiest to perform. Reduction in receiver degradation in position 1 indicates lack of TX noise filtering, and in position 2, TX carrier suppression. In extreme cases, both positions may require extra filtering. Band reject filters may be necessary in this test when T-R frequency separation is very narrow, and bandpass skirt selectivity is inadequate.
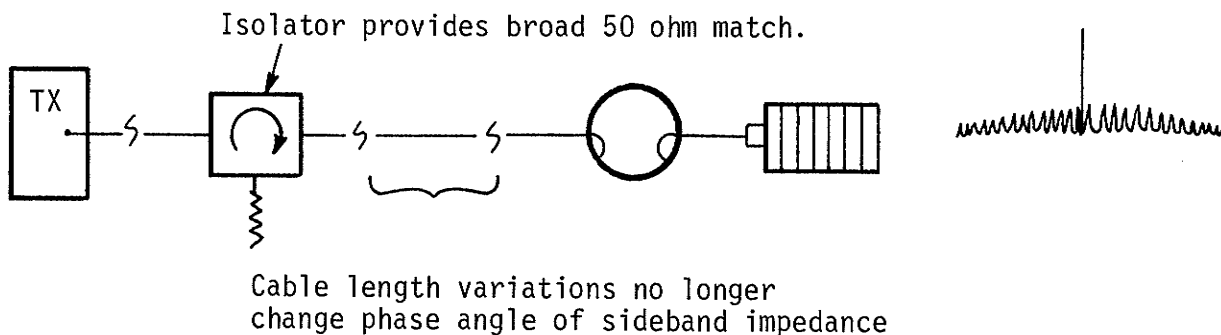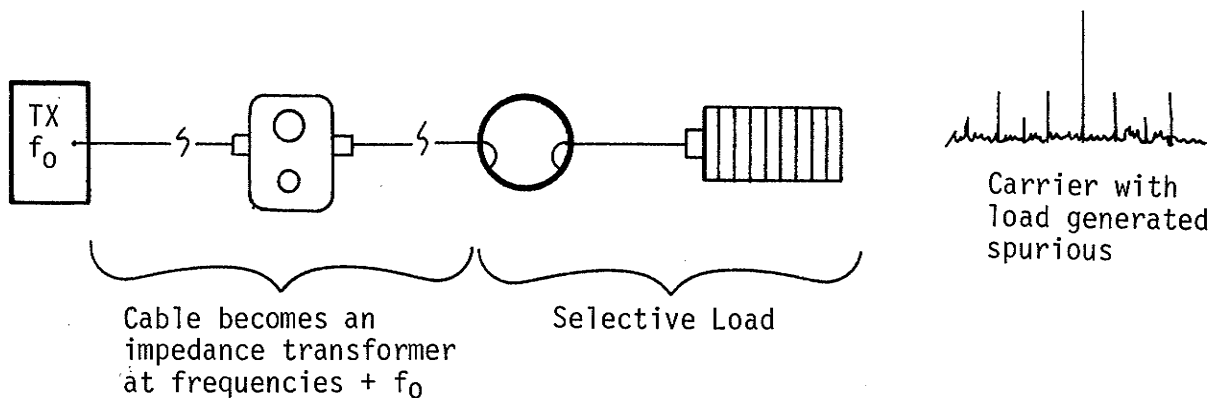
DETECTING TRANSMITTER SENSITIVITY TO SELECTIVE LOAD IMPEDANCE

Symptoms:

1. Poor loading and forward power.
2. Reflected power changes when cable length varied between Transmitter and filter input.
3. Installing isolator reduces reflected power at filter input, restores forward power, and eliminates change in reflected power when varying cable length between isolator and filter input.

Cure:

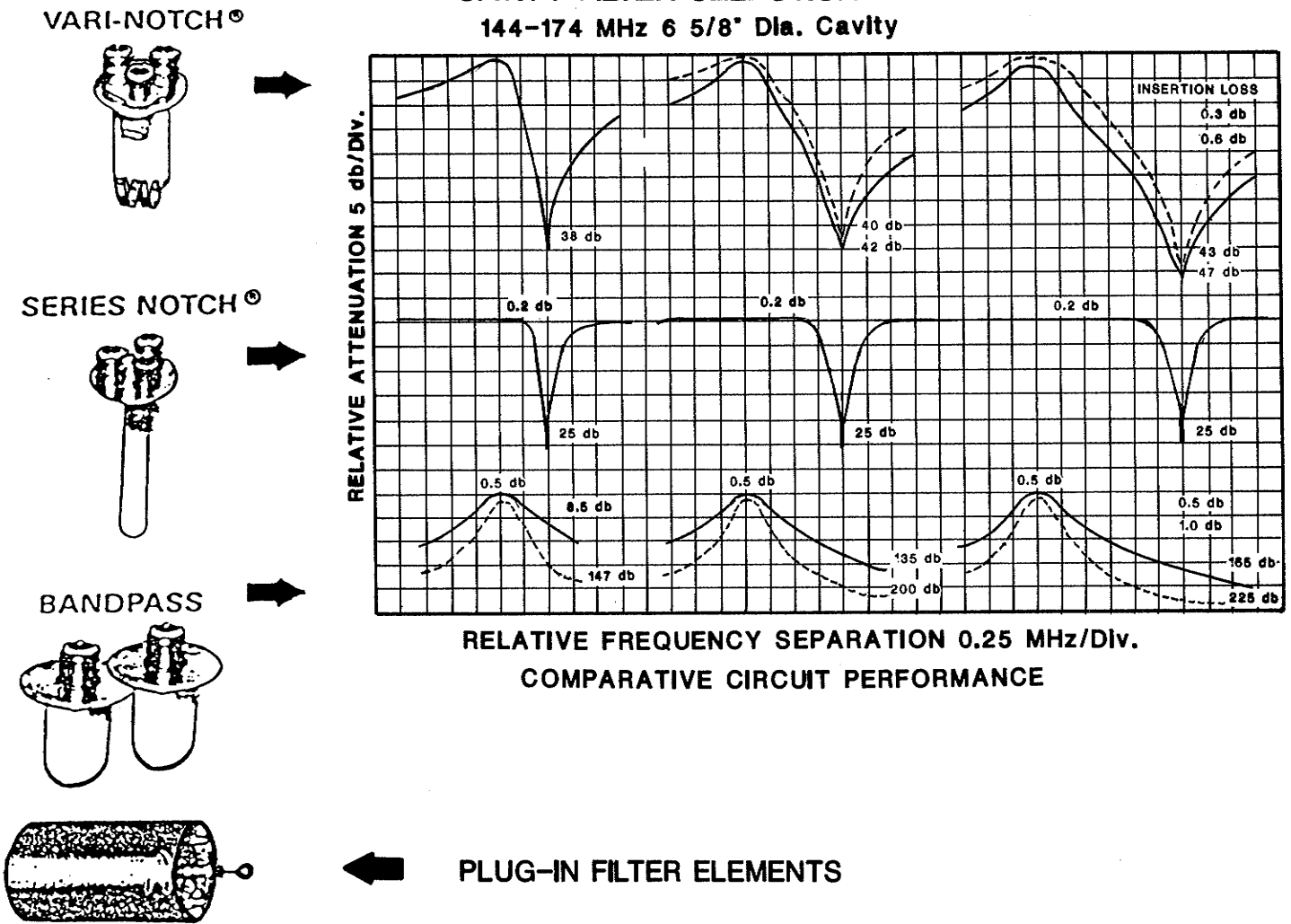Hunt cable length between transmitter and filter which provides acceptable performance. Make changes no larger than one eighth wavelength.
Install isolator, if all else fails.
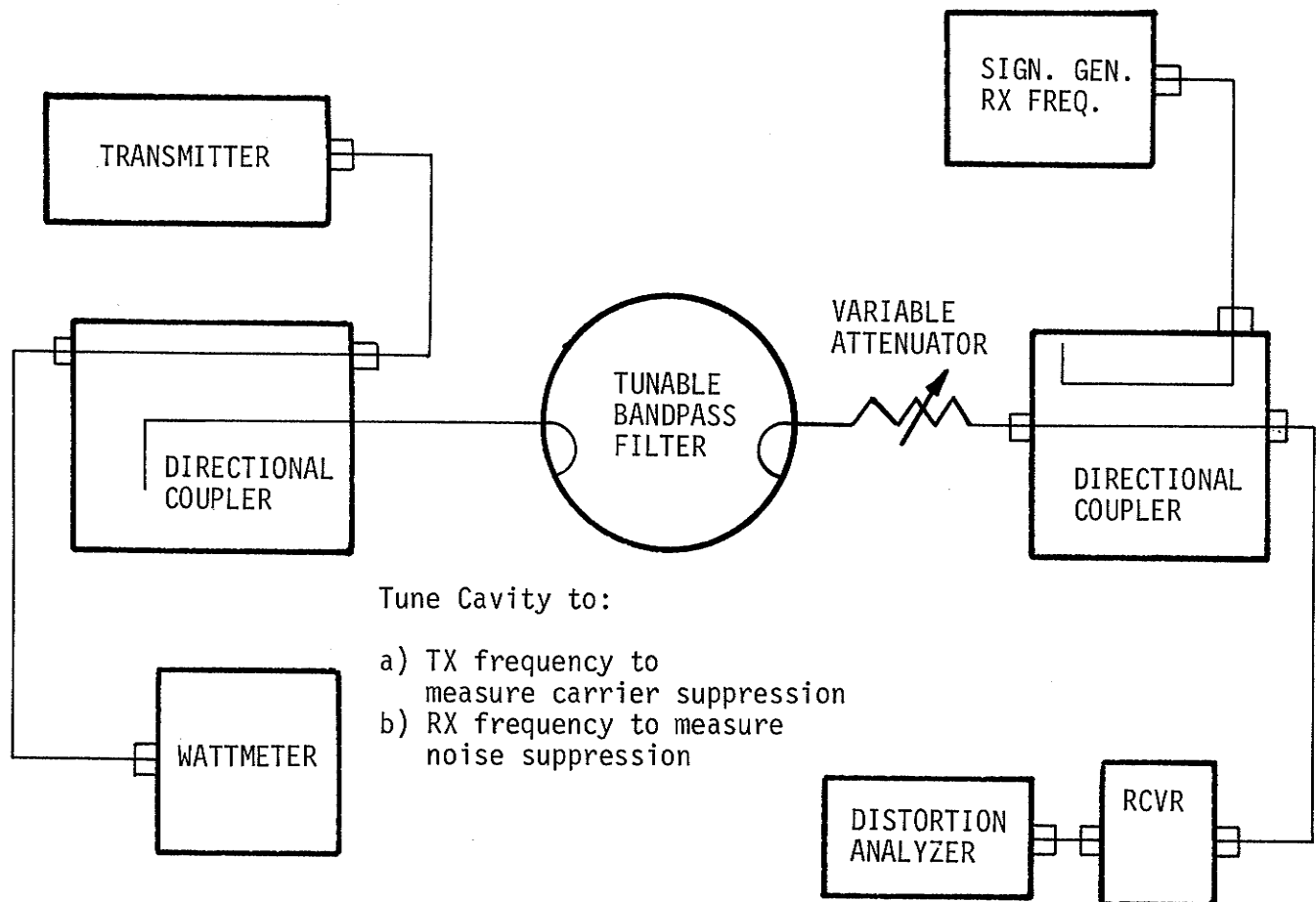
Carrier with
load generated
spurious

Cable becomes an
impedance transformer
at frequencies $\pm f_0$

Selective Load

Isolator provides broad 50 ohm match.

Cable length variations no longer
change phase angle of sideband impedance

CAVITY FILTER SELECTION DATA
144-174 MHz 6 5/8" Dia. Cavity

VARI-NOTCH®

SERIES NOTCH®

BANDPASS

RELATIVE ATTENUATION 5 db/Div.

INSERTION LOSS
0.3 db
0.6 db

38 db
40 db
42 db
43 db
47 db

0.2 db   0.2 db   0.2 db

25 db   25 db   25 db

0.5 db   0.5 db   0.5 db   0.5 db
8.5 db   1.0 db

147 db   135 db   165 db
              200 db   225 db

RELATIVE FREQUENCY SEPARATION 0.25 MHz/Div.
COMPARATIVE CIRCUIT PERFORMANCE

← **PLUG-IN FILTER ELEMENTS**

SPECIFIC FILTER APPLICATIONS AND SELECTION

1. BANDPASS CAVITY FILTER-Passes one narrow band of frequencies and attenuates all others with increasing attenuation above and below the pass frequency. A great filter for general transmitter spurious clean up and sharpening of receiver front end selectivity. TX RX bandpass cavities (4", 6", and 10") have adjustable selectivity characteristics (rotatable loops) to allow a trade-off between insertion loss (0.5-3.0 db) and selectivity. Maximum power handling is determined by insertion loss setting (see available Tech-Aids). This filter is the best choice when interfering frequencies are not known to any degree of accuracy or when very broad band filtering is needed.
2. SERIES NOTCH® (NOTCH)-Passes a relatively wide band of frequencies while rejecting a very narrow band of frequencies. Notch depth is variable from 15-25 db. Both pass and notch frequencies must be known. Best filter for very close separations (70 KHz and greater in low band, 70 KHz to 200 KHz in highband, and 200-400 KHz in the UHF band). The wide passband can be an advantage when filtering multiple channel transmitters and receivers.
3. VARI-NOTCH® -Passes a relatively narrow band of frequencies and rejects (notches out) a relatively wide frequency band. This filter has the greatest notch depth when compared to other types. Notch depth is adjustable but is referenced to a passband insertion loss (0.3 db or 0.6 db typical). Best filter type for moderately close to wide separations (200 KHz and greater in highband, 400 KHz and greater in UHF).

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DUPLEX ISOLATION MEASUREMENT SYSTEM

TRANSMITTER

SIGN. GEN.
RX FREQ.

DIRECTIONAL
COUPLER

VARIABLE
ATTENUATOR

TUNABLE
BANDPASS
FILTER

DIRECTIONAL
COUPLER

WATTMETER

Tune Cavity to:

a) TX frequency to
measure carrier suppression
b) RX frequency to measure
noise suppression

DISTORTION
ANALYZER

RCVR

The isolation required for duplex operation is normally specified at two frequencies, the TX frequency (carrier suppression), and the RX frequency, (transmitter noise suppression). The filters for the former will appear in the receiver section of the duplexer, and for the latter, in the transmitter section.

The circuit used to determine the isolation at the TX and RX frequency is shown above. The tunable bandpass cavity acts as a frequency "window", allowing isolation measurements at essentially discrete frequencies.

A predetermined level of receiver degradation is usually assumed when making these measurements, and this level must be known for the duplex isolation data to be meaningful. A certain db degradation of the 20 db quieting sensitivity or the 12 db SINAD sensitivity is usually referenced.

Due to normal manufacturing variations, reliable isolation values should be determined from a number of measurements on like models under similar conditions.

It should also be noted that the isolation values so determined will only be directly applicable to duplexers having filter response curves similar to the bandpass filter "window". Notch filter duplexers having narrow isolation bands and large "acceptance" bands may require 20-30 db more isolation than the above circuit would indicate, due to the added mixing of broadband noise in the receiver or antenna line components.

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TYPICAL DUPLEX ISOLATION CURVE, 450-470 MHz

Since this data is determined using a laboratory measurement system providing a
50 ohm match at carrier and sideband noise frequencies, and therefore does not
exactly duplicate practical duplexer impedance characteristics, a 10-15 db
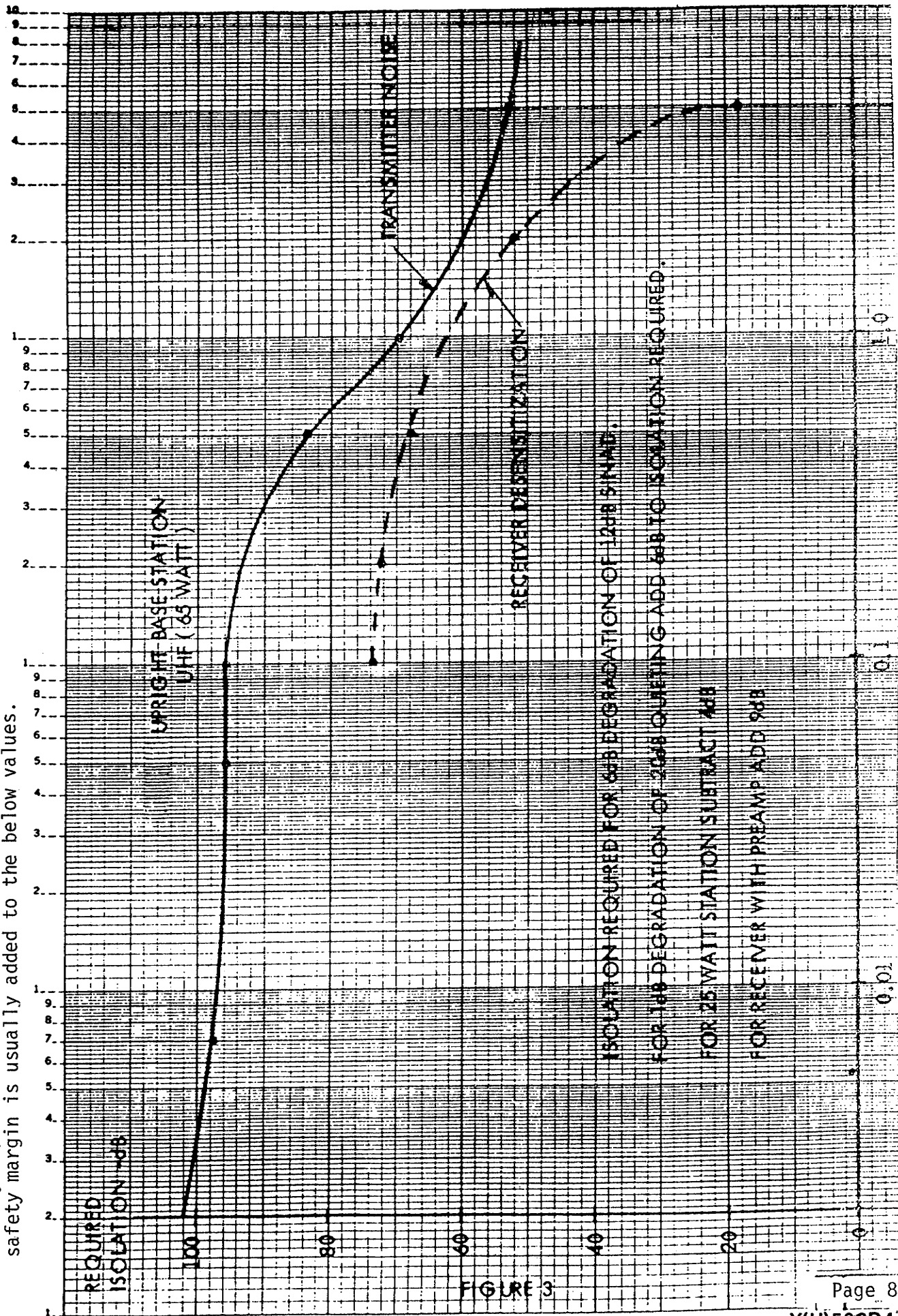safety margin is usually added to the below values.

FIGURE 3

The power of an I.M. product is a function of the power in the fundamental frequencies, the order of the I.M., and a very illusive quantity called the mixing efficiency constant.

Assuming a constant mixing efficiency (which probably is rarely the case) we can determine the effective change in I.M. level for various changes in fundamental levels reaching the mixing point.

For a two frequency third order product:

$$\text{Power of } IM_3 = K \left[P_{f_A}^2 \quad P_{f_B} \right]$$

where K = mixing efficiency constant

P_{f_A} = Power in freq. A in watts

P_{f_B} = Power in freq. B in watts

Logging the above expressions to the base 10 and evaluating a difference relationship, we can obtain an expression easily worked in db levels:

$$\triangle P_{I.M.} = 2\triangle P_{f_A} + \triangle P_{f_B} \quad \text{for a 2A-B product.}$$

This says for a 10 db power change in f_A and also in f_B, the total level change, $P_{I.M.}$ will be:

$$\triangle P_{I.M.} = 2(10 \text{ db}) + (10 \text{ db}) = 30 \text{ db}$$

Similar relationships can be formed for higher order products and three frequency mixes. The value of K usually decreases as the I.M. order increases.

The above illustration shows the importance of maintaining adequate T-R antenna space isolation.

For Txs mixing in a common transmit antenna, the product level radiated to the RX antenna will decrease by an amount equal to the increased space isolation. When mixing is occurring in the RX antenna or in components of the RX system, the I.M. level will drop by (3) three times the increased space isolation.

TODAYS DATE IS: 2/2/83

SITE NAME OR REFERENCE# : SIMULATION RUN

TX 1 = 462.125
TX 2 = 461.475
TX 3 = 464.3
TX 4 = 464.8
TX 5 = 463.3
TX 6 = 461.975

RX 1 = 467.125
RX 2 = 466.475
RX 3 = 469.3
RX 4 = 469.8
RX 5 = 468.3
RX 6 = 466.975

*** THE EQUATIONS SOLVED WILL BE INDICATED BY .THE FOLLOWING ***---*** HITS HAV
    BEEN FOUND   PRINT HEADING

*** NO ENTRIES UNDER THE PRINT HEADING INDICATES THAT NO! HITS WERE FOUND FOR
    THAT EQUATION

****
            THE FOLLOWING *** 2A-B *** HITS HAVE BEEN FOUND---

FREQ A (MHZ)	FREQ B (MHZ)	FREQ IM (MHZ)	FREQ RX (MHZ)	TEST WINDOW (+/-MHZ)
464.3000	461.4750	467.1250	467.1250	0.0150
464.3000	462.1250	466.4750	466.4750	0.0150

****
            THE FOLLOWING *** A+B-C *** HITS HAVE BEEN FOUND---

FREQ A (MHZ)	FREQ B (MHZ)	FREQ C (MHZ)	FREQ IM (MHZ)	FREQ RX (MHZ)	TEST WINDOW (+/-MHZ)
464.3000	464.8000	461.9750	467.1250	467.1250	0.0150
464.3000	464.8000	462.1250	466.9750	466.9750	0.0150

****
            THE FOLLOWING *** 3A-2B *** HITS HAVE BEEN FOUND---

FREQ A (MHZ)	FREQ B (MHZ)	FREQ IM (MHZ)	FREQ RX (MHZ)	TEST WINDOW (+/-MHZ)
463.3000	461.4750	466.9500	466.9750	0.0250

****
            THE FOLLOWING *** 4A-3B *** HITS HAVE BEEN FOUND---

FREQ A (MHZ)	FREQ B (MHZ)	FREQ IM (MHZ)	FREQ RX (MHZ)	TEST WINDOW (+/-MHZ)
464.8000	463.3000	469.3000	469.3000	0.0350

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I.M. levels shown based on the following assumptions:

1. Mixing is occurring only in TX antenna
2. I.M. speicifications on antennas for 2A-B products is 100 db below +47 dbm
    levels of A and B.

I.M. levels at Receiver Antenna
2A-B = -108 dbm
2B-A = -108 dbm

(-108 dbm = .87 uv)

RX
Ant.

55 db
Space
Isolation

2A-B and 2B-A I.M.
levels generated in
RX antenna are usually
undetectable if the
change in I.M. level,
per the power formula
in Figure 1, applies.

Radiated I.M. levels:
2A-B = -53 dbm
2B-A = -53 dbm

TX
Ant.

Tx 'A' power = +47 dbm ──►
Tx 'B' power = +47 dbm ──►
(+47 dbm = 50 watts)

```
┌─────────────────┐
│  TWO CHANNEL    │
│  TRANSMITTER    │
│  MULTICOUPLER   │
└─────────────────┘
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```
┌─────┐   ┌─────┐
│ TX  │   │ TX  │
│ 'A' │   │ 'B' │
└─────┘   └─────┘
```

Tx A and Tx B power
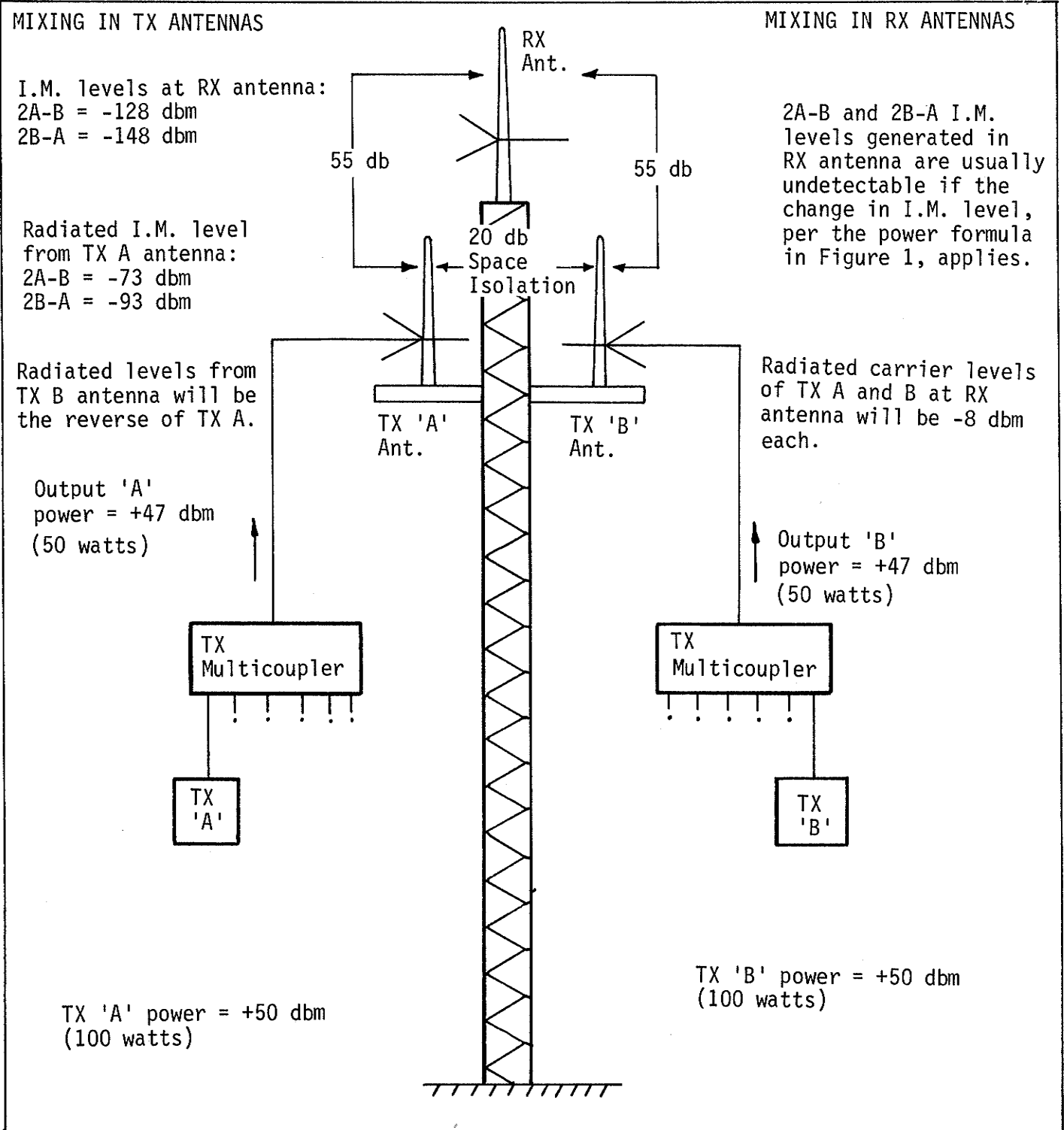equal +50 dbm (100 watts)
each.

Options to eliminate this I.M. interference:

1. Change one of the TX frequencies by more
    than 15 KHz.
2. Use two TX antennas, as shown in Figure 4.
3. Move one TX to a different site.
4. Maybe a long shot, but try to obtain 70 db+
    antenna isolation.

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ANTENNA INTERMOD
Multiple TX Antennas

NOTE: Calculations are based on limited field tests and known I.M.
power relationships. Individual systems may vary considerably
in antenna I.N. mixing efficiency.

Assumption: I.M. specification on an antenna and 500' transmission
line for 2A-B product level generation is 100 db below
+47 dbm levels of A and B.

MIXING IN TX ANTENNAS

I.M. levels at RX antenna:
2A-B = -128 dbm
2B-A = -148 dbm

55 db

Radiated I.M. level
from TX A antenna:
2A-B = -73 dbm
2B-A = -93 dbm

RX
Ant.

55 db

20 db
Space
Isolation

TX 'A'
Ant.

TX 'B'
Ant.

Radiated levels from
TX B antenna will be
the reverse of TX A.

Output 'A'
power = +47 dbm
(50 watts)

MIXING IN RX ANTENNAS

2A-B and 2B-A I.M.
levels generated in
RX antenna are usually
undetectable if the
change in I.M. level,
per the power formula
in Figure 1, applies.

Radiated carrier levels
of TX A and B at RX
antenna will be -8 dbm
each.

Output 'B'
power = +47 dbm
(50 watts)

TX
Multicoupler

TX
Multicoupler

TX
'A'

TX
'B'

TX 'B' power = +50 dbm
(100 watts)

TX 'A' power = +50 dbm
(100 watts)

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TESTING FOR RECEIVER AND PREAMP I.M.

Step 1.

   Reduce gain of preamp and power divider portion of multicoupler
   to unity by pad or variable attenuator. Note level of Receiver
   I.M. (Note: for valid test, pad must be placed after preamp).

Step 2

   Substitute a by-pass cable for unity portion of multicoupler.
   If level of I.M. is unchanged, preamp is not a source. This
   test is valid only if levels of incoming signals to RX are kept
   about equal in steps 1 and 2. If I.M. level drops when by-pass
   cable is substituted, preamp is contributing I.M.

Step 3

   Add a selective bandpass filter ahead of the receiver. If
   the preamp is not a source of I.M., but the selective cavity
   reduces I.M. level, the receiver front end is a source. Add
   selectivity, as practical, to reduce level. Receive - to - trans-
   mit antenna isolations may need to be increased for improved
   overall performance. In Tower Mount receive systems, adding
   selective filters in conjunction with by-pass cable in Step 2
   may reveal RX I.M.

Steps 1 & 2   Step 3

Preselector

Set for unity gain

RX

By-Pass Cable

RX

Bandpass Filter added

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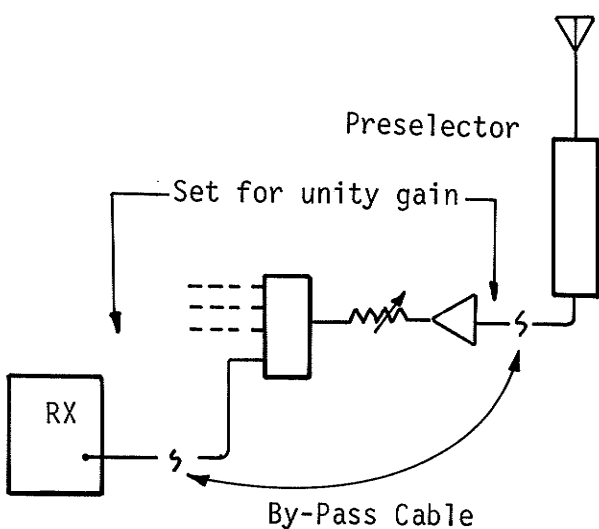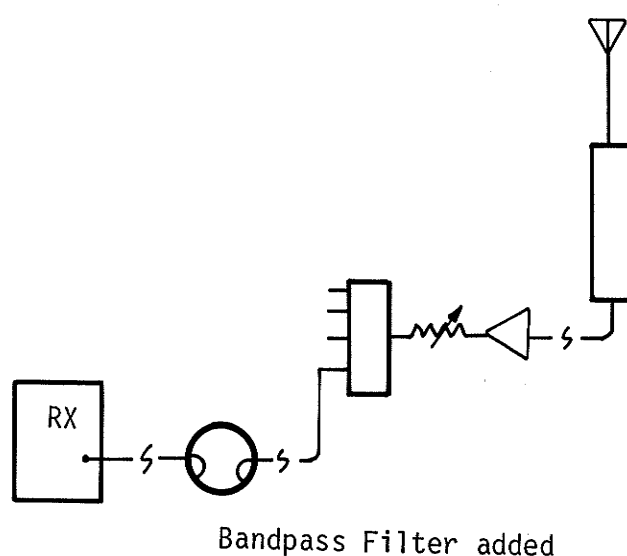
PREAMP INTERCEPT POINT
AND
THIRD ORDER INTERMODULATION

In a multicoupler system, a typical TX carrier input level to a Receive antenna is -8 dbm.

A receiver with an 80 db I.M. rejection specification will begin to suffer I.M. interference at -33 dbm input levels, assumed in the receiver RF passband.

Preselector filters ahead of RX multicouplers, designed to protect a receiver against TX carrier overload (desense) per duplex isolation curves, will generally be inadequate for I.M. protection.

Because of the large difference between multicoupler and receiver I.M. performance, additional selectivity added just ahead of the affected receiver is often sufficient.

To determine level of I.M. below Preamp output, a) read right along the selected output level to the fundamental diagonal, b) then down to the appropriate 2A-B line, c) and left to the vertical scale for the I.M. level.

The following expressions can be used to determine exact levels on the above curve.

2A-B Product Response Curves for Various Output Intercept Points

$$IMD = 2(I_p - P_o)$$

IMD = number of db the 3rd order product is below preamp output.
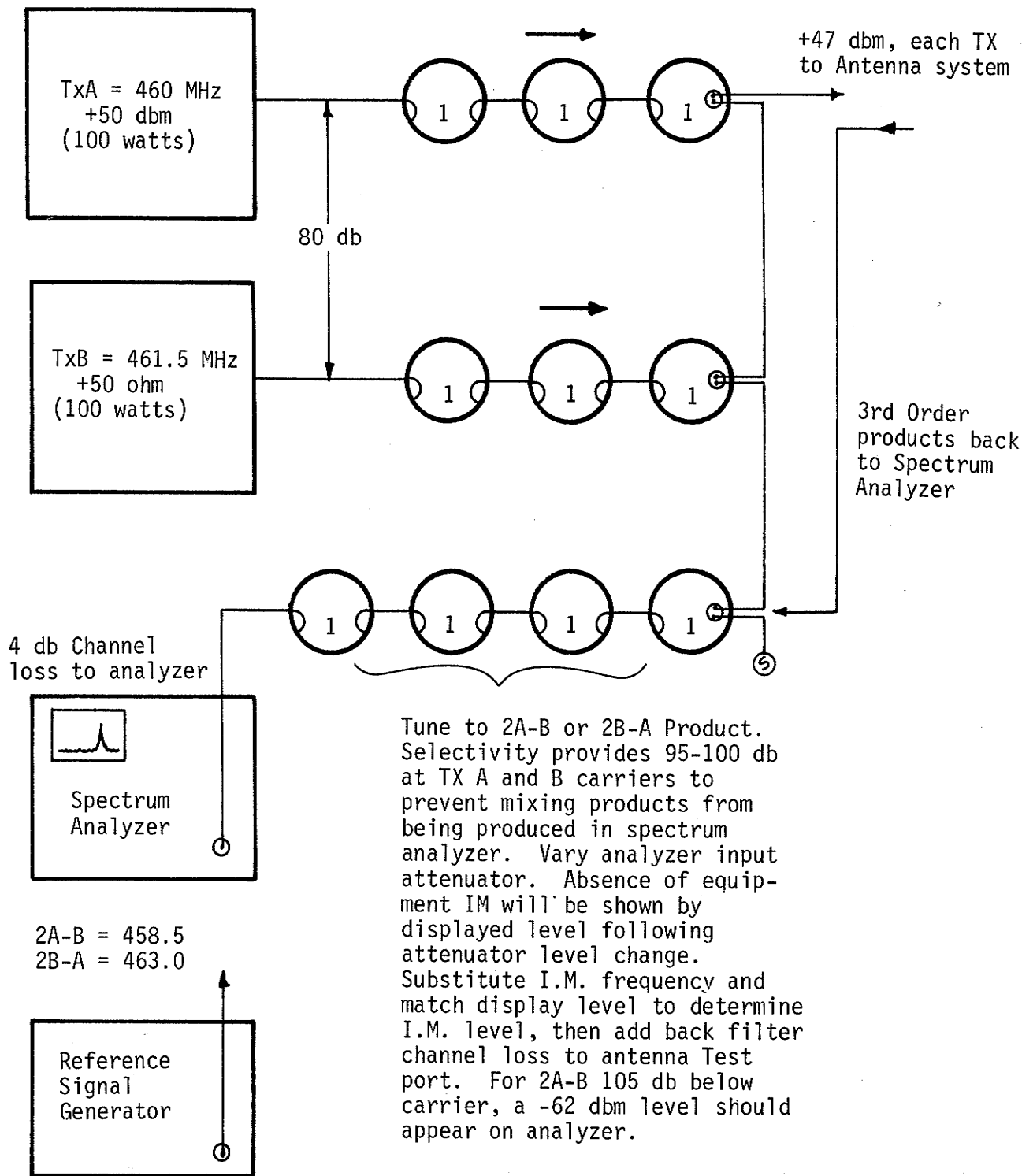
I_p = Preamp 3rd order intercept point in dbm.

P_o = Preamp output power in dbm.

CAVITY FILTER TEST BED
FOR
FIELD MEASUREMENT OF ANTENNA INTERMOD

NOTE: 80 db between TX bandpass channels will produce about
160 db suppression of IM generated in either transmitter.

TxA = 460 MHz
+50 dbm
(100 watts)

80 db

TxB = 461.5 MHz
+50 ohm
(100 watts)

+47 dbm, each TX
to Antenna system

3rd Order
products back
to Spectrum
Analyzer

4 db Channel
loss to analyzer

Spectrum
Analyzer

2A-B = 458.5
2B-A = 463.0

Reference
Signal
Generator

Tune to 2A-B or 2B-A Product.
Selectivity provides 95-100 db
at TX A and B carriers to
prevent mixing products from
being produced in spectrum
analyzer. Vary analyzer input
attenuator. Absence of equip-
ment IM will be shown by
displayed level following
attenuator level change.
Substitute I.M. frequency and
match display level to determine
I.M. level, then add back filter
channel loss to antenna Test
port. For 2A-B 105 db below
carrier, a -62 dbm level should
appear on analyzer.

AN ANTENNA SYSTEM SUBSTITUTION TEST FOR POSSIBLE
SEPARATION OF ANTENNA SYSTEM I.M. FROM MULTICOUPLER I.M.

Elimination of I.M. products when this test is made indicates source is
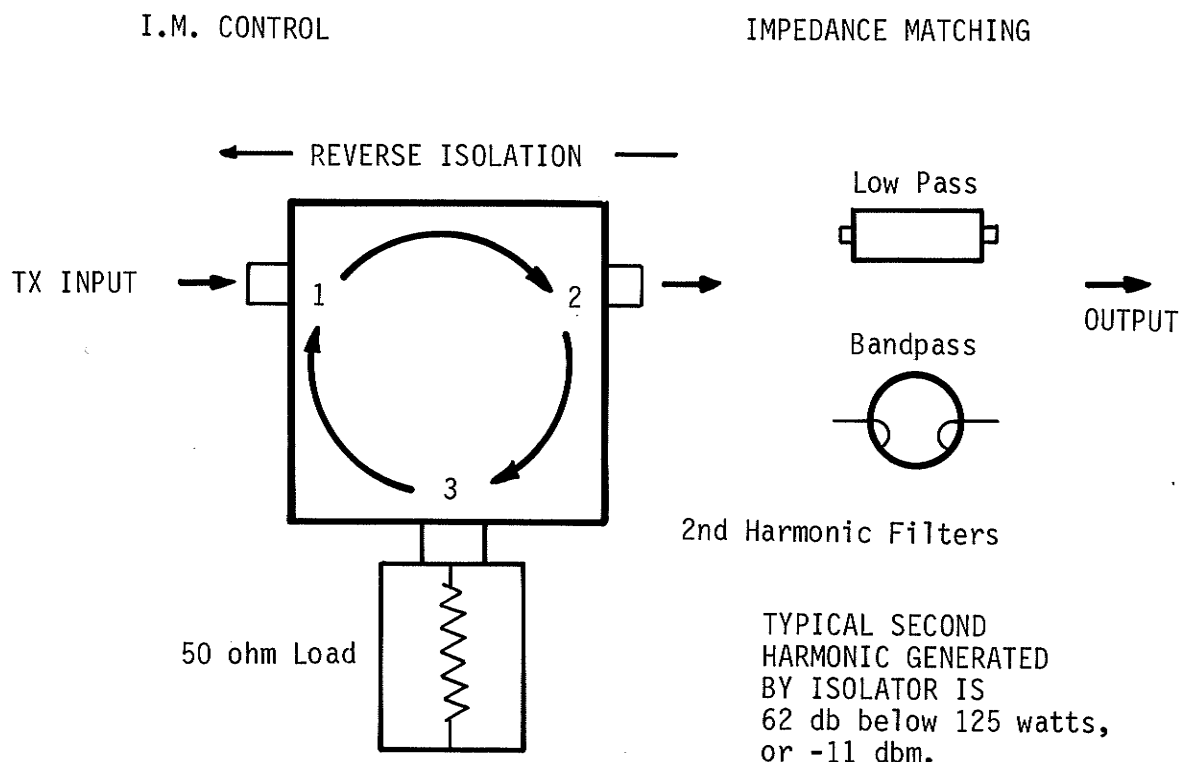exterior to multicoupler system.

Ant. A

Ant. B

RF loads
substitute for
each of the system
antennas A, B, & C.

Space Isolation, Ant. A to B

Decoupling tees simulate
antenna space isolation
between any pair of system
antennas.
A UG-107 B/U and UG-28 A/u
tee connector are mated at
the center. The male pin of
the UG-107 B/u is cut back
for an air gap producing
the desired decoupling.

Ant. C

Space Isolation, Ant. A to C

Space Isolation, Ant. B to C

Transmitter
Receiver
Multicoupler

Receiver
Multicoupler

Transmitter
Receiver
Multicoupler

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FERRITE ISOLATOR

I.M. CONTROL   IMPEDANCE MATCHING

← — REVERSE ISOLATION —

Low Pass

TX INPUT → 1   2 →   OUTPUT

Bandpass

3

50 ohm Load

2nd Harmonic Filters

TYPICAL SECOND
HARMONIC GENERATED
BY ISOLATOR IS
62 db below 125 watts,
or -11 dbm.

PORTS 1 - 2   LOW LOSS, NON-SELECTIVE PASS BAND, WITH INPUT IMPEDANCE
NOT A FUNCTION OF OUTPUT IMPEDANCE

PORTS 2 - 3   REFLECTED POWER, OR OTHER INCOMING SIGNALS TERMINATE
IN PORT 3 LOAD

PORTS 3 - 1   LEAKAGE PATH. ENERGY NOT ABSORBED BY LOAD ON PORT 3,
TRAVELS TO PORT 1.

PORTS 2 - 1   DESIRED REVERSE ISOLATION, NON-SELECTIVE IN CHARACTER.
POOR MATCH OF LOAD TO PORT 3 WILL CAUSE 3 - 1 LEAKAGE
AND REDUCE ISOLATION.

When TX antennas are horizontally spaced and defficient in space
isolation, radiation of Isolator second harmonic into an adjacent
isolator may create a readible 2A - B product.