RADIO ENGINEERING
MOBILE RADIO
CLOSELY COUPLED ANTENNAS

CONTENTS PAGE

1. GENERAL

1.01 This section covers the operation of base station transmitters and receivers into a common antenna or into separate closely coupled antennas. The following are considered:

(1) Closely coupled antennas of:

(a) A transmitter and a receiver in the same frequency band.

(b) Two transmitters in the same frequency band.

(c) Two receivers in the same frequency band.

(2) A common antenna for the same conditions in (a) and (c) above.

1.02 The material in this section covers mobile radio frequency modulation systems in the 35-, 150-, and 450-megacycle bands.

1.03 This section is applicable to new systems and to interference problems which may arise with Bell System mobile telephone services or with some other radio service, along with the remedial measures available. See also Section 940-200-106.

2. OPERATION OF A TRANSMITTER AND A RECEIVER WITH CLOSELY COUPLED ANTENNAS OR INTO A COMMON ANTENNA

2.01 There are three primary conditions to be considered:

(1) The output of the transmitter may overload the rf stages of the receiver.

(2) Transmitter extra band radiations may fall in the same channel as the fundamental response of the receiver.

(3) The transmitter fundamental radiation may occur at the same frequency as a spurious response of the receiver.

2.02 The output of a transmitter may overload the rf stages of a receiver when the transmitter and receiver frequencies are separated by only a few per cent. Such overloading (grid current on positive peaks) has been called desensitization. The value of undesired signal at the rf input that can be tolerated without overloading, depends upon the receiver characteristics and the frequency separation between the desired and undesired signals. The over-all receiver suppression characteristic is not considered, since only the rf stages are involved. The first rf stage is not very selective compared to the performance of the entire receiver. If the frequency separation is small, the loss to the undesired signal provided by the rf input transformer may be less than the gain of the first rf tube. Where this is the case, the voltage applied to the second tube grid becomes controlling. In the 150-megacycle band having 5-megacycle separation between the transmitter and receiver frequencies, and using receivers having only one tuned circuit ahead of the first rf tube, rf overloading will occur with an input signal of about -27 dbw. In the 35-megacycle and 450-megacycle bands having 8-megacycle and 5-megacycle respective separation between the transmitter and receiver frequencies, the level will be somewhat higher, possibly at about -20 dbw.

2.03 Consider an installation in the 35-megacycle band having a transmitter with 250-watt output which is 24 dbw. If the level of the transmitter signal at the receiver rf input is -20 dbw, then 24 - (-20) = 44 db loss that must be provided between the transmitter and the receiver. Considerable margin is desirable, and assuming 16 db margin, the required loss becomes 60 db. This loss can be provided by antenna separation (coupling loss), filters in the transmission line, or a combination of the two.

2.04 Transmitter extra band (spurious) radiations may occur at the same frequency as the fundamental receiver response. These radiations consist of unwanted frequencies outside the desired transmitter bandwidth. They are required (FCC) to be 60 db below carrier level for final stage input power of not over 150 watts, and 70 db down for input power over 150 watts. In present day transmitters they are likely to be 75 to 80 db down. However, for transmitters and receivers having closely coupled antennas these radiations may be at high enough level to be troublesome. They will effectively add to the receiver site noise and may reduce receiver sensitivity, or if of sufficient magnitude may overload the rf stages. These radiations are generally harmonics of the transmitter crystal oscillator frequency. Therefore, in the choice of transmitter and receiver operating frequencies, there is considerable advantage when the harmonics of the transmitter crystal oscillator do not occur at the receiver operating frequency.

2.05 Receiver spurious response may also effect receiver sensitivity when the transmitter fundamental radiation occurs at the same frequency as a spurious response of the receiver. Prediction of the spurious response frequencies is not practical since they are a function of individual receiver characteristics. However, they can be assumed to be at least 70 db below receiver sensitivity level. In present day receivers they are likely to be at least 80 db down. Where spurious response impairs receiver performance, it may usually be shifted out of the troublesome range by moving the oscillator heterodyning frequency a few kc and changing the if. by a like amount.

2.06 The effect of transmitter extra band radiations and receiver spurious response may be considered for an installation in the 35-megacycle or 150-megacycle band, having a frequency separation of 5 to 8 megacycles between transmitter and receiver. By virtue of equipment design, the receiver spurious response should be at least 70 db below signal response, and the maximum transmitter extra band radiations should be at least 70 db below carrier. Therefore, in considering the effect of transmitter extra band radiation falling upon a receiver spurious response, a factor of 70 + 70 or 140 db may be used because of minimum equipment design requirements. Assume a 250-watt transmitter (24 dbw). At a quiet location, the level of a desired signal at the receiver is -140 dbw (1 uv) and this signal should predominate over an interfering signal by 6 db at the first limiter. The total suppression that must be provided between the transmitter and the limiter of the receiver is 24 + 140 + 6 = 170 db. Since 140 db suppression is provided by transmitter and receiver design, a loss of 30 db must be provided by antenna separation or filters. If the transmitter fundamental radiation occurs at receiver spurious response, or if transmitter extra band radiation occurs at fundamental receiver response, the 70 db design suppression is lost and the required loss becomes 170 - 70 = 100 db.

2.07 Where the transmitter and receiver are operated into separate closely coupled antennas, the antenna coupling loss may be estimated or measured as described in Part 6. In the 35-megacycle band with 8-megacycle frequency separation, the receiving antenna will discriminate somewhat (10 to 15 db) against the transmitting frequency since it will be adjusted in length to be more receptive at the receiver frequency. This is not the case in the 150-megacycle or 450-megacycle band where the frequency separation relative to the operating frequency is so small for the two directions of transmission that the same antenna dimensions are used at the receiving frequency as at the transmitting frequency.

2.08 Coaxial line filters (wave traps) tuned to reject the interfering transmitter frequency, may be installed in the receiver lead to provide the desired loss. These filters, however, have poor selectivity and considerable separation between transmitter and receiver frequencies is required to secure large attenuation at the unwanted (transmitter) frequency and small attenuation at the desired (receiver) frequency. For example: With a filter made from 7/8-inch line, the frequency separation must be at least 3 per cent (1.0 megacycle) in the 35-megacycle band or 2.5 per cent (3.7 megacycles) in the 150-megacycle band, to prevent the attenuation at the desired frequency exceeding about 3 db. With a small frequency separation, it will be extremely difficult to build a suitable coaxial line filter. Resonant cavity filters, in comparison, are highly selective with low insertion loss at the desired frequency, and are useful with frequency separations from 60 kc to about 2 megacycles. Resonant cavity filters for the 35-megacycle band, however, because of their large physical size may have accompanying mounting difficulties. Section R40.420 contains descriptive information and instructions for the installation of coaxial line and resonant cavity filters.

2.09 Where both transmitter and receiver are operated into a common antenna, coaxial line or resonant cavity filters will usually be necessary in both the transmitter lead and the receiver lead as shown in Fig. 1. A cavity filter in the transmitter lead tuned to the transmitter frequency provides attenuation to extra band radiations, and to the receiver frequency. A cavity filter in the receiver lead tuned to the receiver frequency provides attenuation to the transmitter frequency and to receiver spurious response. A coaxial line filter in the transmitter lead is tuned so that it provides maximum attenuation at the receiver frequency. A coaxial line filter in the receiver lead is tuned to provide maximum attenuation at the transmitter frequency.

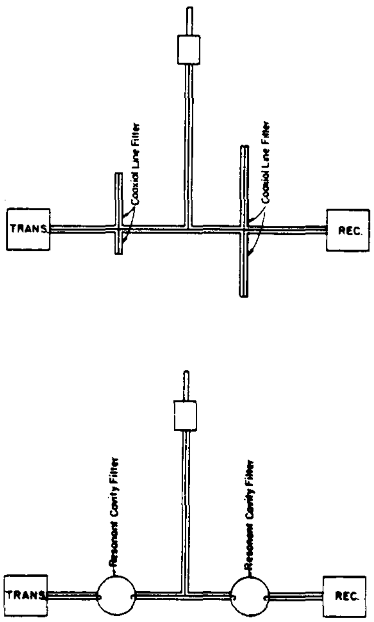

Fig. 1

3. OPERATION OF TWO OR MORE TRANSMITTERS INTO CLOSELY COUPLED ANTENNAS

3.01 The problem here is to keep the radiation of any spurious intermodulation products within tolerable limits. Intermodulation products are generated when the carrier frequency from one or more transmitters reaches the nonlinear impedance presented by the final amplifier of another operating transmitter. Some of these products, on being radiated, may produce interference in neighboring services. Theoretical calculations based upon free space radiation indicate that interference may occur with receivers located within 1/2 mile of two or more transmitters whose intermodulation products are on the same frequency as the fundamental receiver response.

3.02 It has been determined that if A and B represent the assigned channel frequencies of two operating transmitters, the major spurious radiation will be third order intermodulation products having frequencies (2A-B) and (2B-A). That is, the channel frequency of transmitter B combines with the second harmonic of transmitter A channel frequency in the plate circuit of transmitter A, to produce the (2A-B) frequency. The product (2B-A) will also be produced in transmitter A, but its level will be greatly reduced due to attenuation of the transmitter B second harmonic by transmitter output circuits and antenna dimensions. Products (2A-B) and (2B-A) will likewise be produced in transmitter B, but here the (2A-B) product level will be low. Products of this type are important because of their magnitude and position in the frequency spectrum. Other products will be generated, for example, (3A-2B) and (3B-2A) fifth order, but their levels will usually be sufficiently low (after measures are provided to reduce third order products) so that interference with neighboring services is unlikely.

3.03 Consider the 2-channel system shown in Fig. 2. A carrier from channel 12 transmitter reaching the final amplifier of channel 11 transmitter intermodulates with the carrier being transmitted by channel 11 transmitter to:

(1) Produce second order products (A-B, A+B) which differ considerably in frequency from channel 11 and, therefore, are usually sufficiently attenuated by the output circuits, filters, and antenna.

(2) Produce third and higher order products (2A-B, 2B-A, etc) some of which lie close to channels 11 and 12 and, therefore;

(a) Interfere with Telephone Company or other nearby services,

(b) are more difficult to attenuate.

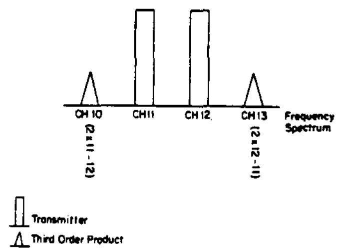

Fig. 2

3.04 A somewhat different situation exists in the 3-channel system shown in Fig. 3, in which all carriers are equally spaced. Here two products fall in-band on frequencies of Telephone Company channels. A third order product (2 x 12 - 13) falling on channel 11 is formed by coupling between channel 12 and channel 13 transmitters, and a channel 13 third order product is formed by coupling between channel 11 and channel 12 transmitters. Third order products will also be formed on channels 9, 10, 14, and 15. The effect of these in-band products with only the undesired channel transmitters active results in a nuisance interference because they appear as an on-frequency signal which will open the receiver squelch, and may also produce a false busy indication on the desired channel. With two transmitters handling calls in a 3-channel system, radiation of the full carrier or even one watt F0 - emission of the third channel will mask to a large extent the interference falling on this channel frequency. Such coordinated operation of transmitters often is used by Telephone Company multisystem installations. However, filters usually will be required to suppress distortion products falling on channels outside the Telephone Company band and to improve service within this band. Note that the channel numbers may be used to determine the intermodulation products only where the transmitter and receiver carriers are equally spaced. When this is not the case, the assigned channel frequencies must be used.

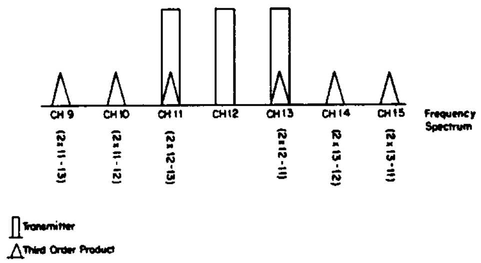

Fig. 3

3.05 All intermodulation products which fall outside the Telephone Company assigned band must be (FCC) at least 60 or 70 db below radiated carrier level for the transmitter in which the products are formed. It would be desirable to allow 2 to 5 db margin. Products which fall in-band should also be reduced to as nearly 70 db below carrier as reasonably feasible if coordinated operation of all transmitters is not used for protection against receiver capture. A filter may be used between each transmitter and its antenna for the suppression of these products. Coaxial line filters may be installed as shown in Fig. 4, providing the frequency separation is great enough and the resulting attenuation at the desired frequency will not be excessive. Resonant cavity filters are suitable for use with transmitters on adjacent channels having 60 kc or greater spacing. In the 3-channel system shown in Fig. 3, resonant cavity filters in the channel 12 transmission line will not only reduce the in-bound channel 11 and 13 carriers, but will also attenuate the intermodulation products progressing to the antenna, with an insertion loss to channel 12 of db or less.

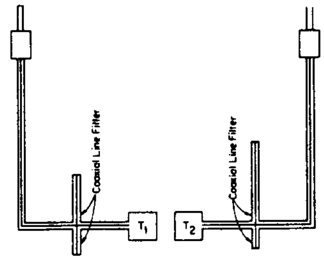

Fig. 4

3.06 The expected level of any specific modulation product generated by a transmitter A and radiated from its antenna may be computed if (1) the level of the signal from the second transmitter B, (2) the conversion loss of the amplifier in transmitter A, and (3) the suppression furnished by coaxial line or resonant cavity filters to the undesired signal and to the modulation product are known. The level of the signal from transmitter B is a function of the antenna coupling loss between the two transmitters, and for the usual case of closely coupled transmitters, may be considered as equal to the antenna coupling loss. The conversion loss of the amplifier in transmitter A may be assumed to be 10 db for third order products and 30 db for fifth order products. The suppression (2-way attenuation) furnished by coaxial line and resonant cavity filters can be determined from Section 402-307-100. The level of the intermodulation product below the carrier radiated by the transmitter in which the product is generated is determined by the three losses noted, provided that the leakage between transmitter cabinets is not governing.

3.07 An example of cavity filter computation for the 3-channel urban system of Fig. 3 may be helpful. Assume that transmitters on channels 12 and 13 are energized, and that it is desired to compute the level of the third order product (2 x 12 - 13) falling on channel 11. Assume the measured antenna coupling loss between channel 12 and channel 13 antennas is 51 db. Assuming a conversion loss of 10 db for third order products, the channel 11 product generated by the channel 13 carrier in the channel 12 transmitter will be 10 db lower than the level of the channel 13 carrier arriving at the channel 12 transmitter. Assume two Motorola cavities in cascade, the first with 1/2 db loops and the second with 1 db loops, are placed in the transmission line of channel 12 transmitter, and tuned to resonance at channel 12 frequency. The 2-way suppression of these two cavities (with total insertion loss of 1.5 db) from Fig. 5 is 9.5 db

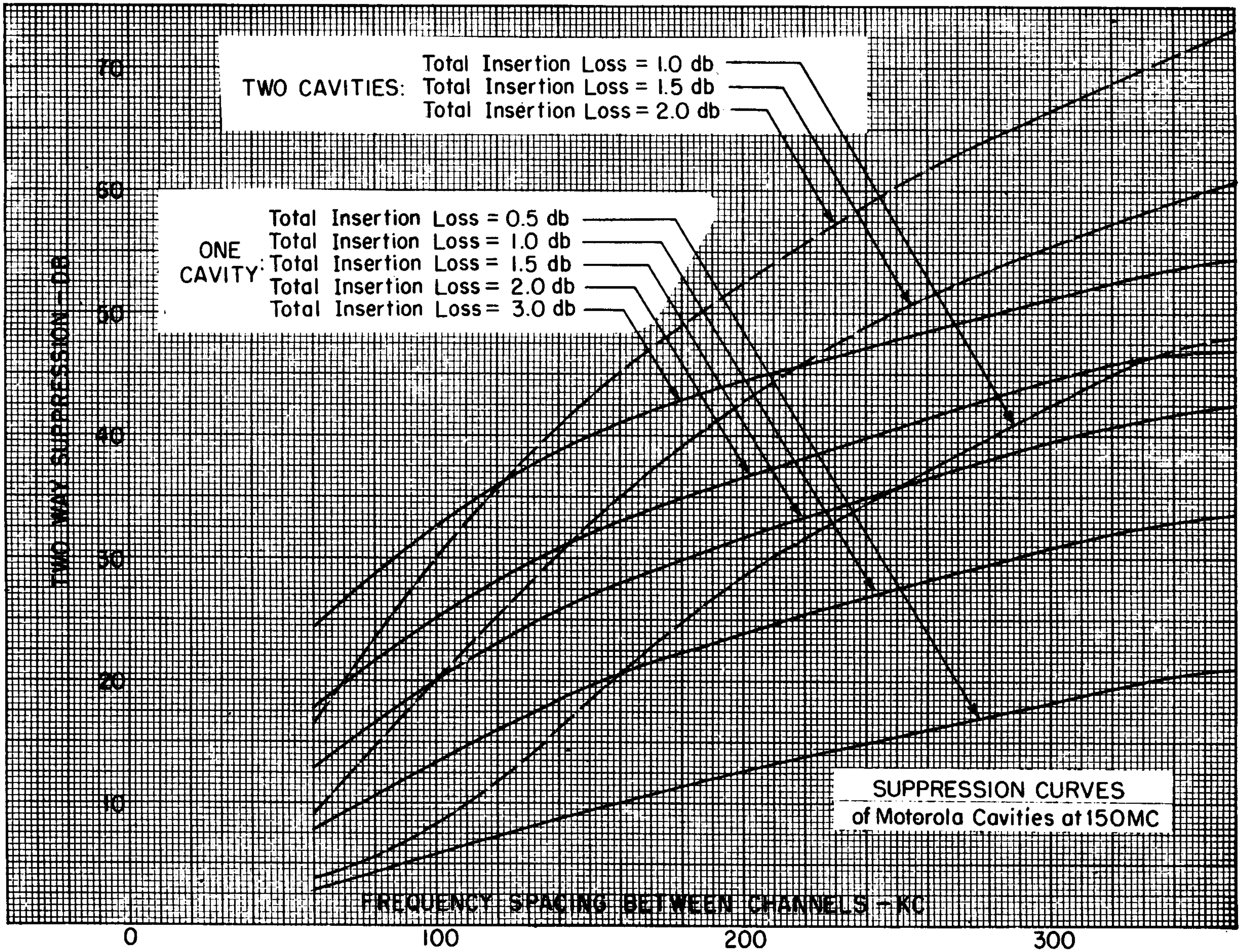
TWO CAVITIES: Total Insertion Loss = 1.0 db
Total Insertion Loss = 1.5 db
Total Insertion Loss = 2.0 db
ONE CAVITY: Total Insertion Loss = 0.5 db
Total Insertion Loss = 1.0 db
Total Insertion Loss = 1.5 db
Total Insertion Loss = 2.0 db
Total Insertion Loss = 3.0 db
TWO WAY SUPPRESSION - DB
70
60
50
40
30
20
10
FREQUENCY SPACING BETWEEN CHANNELS - KC
0
100
200
300
SUPPRESSION CURVES
of Motorola Cavities at 150MC

Fig. 5

for 60 kc separation. This suppression is made up of 4.75 db loss to the in-bound energy from channel 13 transmitter (60 kc above channel 12 to which the cavities are tuned) and 4.75 db loss to the product generated in channel 12 transmitter on channel 11 (60 kc below channel 12).

Measured Antenna Loss	51 db
Assumed Conversion Loss	10 db
2-Way Cascade Cavity Suppression	9.5 db
Level of Product on Channel 11	70.5 db

The product formed in the channel 12 transmitter and radiated at the channel 11 frequency should be 70.5 db below the level of the channel 12 carrier. A channel 11 product is also produced in the channel 13 transmitter, but it is many db below that generated in the channel 12 transmitter and can be neglected.

3.08 In the example, consideration has been given to the important third order symmetrical case. The fifth order products which are not symmetrical may be considered as follows. Assume that transmitters on channels 12 and 13 are energized. The fifth order product (3 x 12 - 2 x 13) falls on channel 10. Assume the measured antenna coupling loss channel 12 to channel 13 antennas is 51 db. Assuming a conversion loss of 30 db for fifth order products, the channel 10 product generated in channel 12 transmitter will be 30 db lower than the channel 13 carrier arriving at the channel 12 transmitter. Again assume two cavities in cascade, the first with 1/2 db loops and the second with 1 db loops, are placed in the transmission line of channel 12 transmitter. The 2-way suppression is found from Fig. 5 by reading the two-cavity 1.5 db curve for 60 kc (spacing between channels 12 and 13) as 9.5 db, and for 120 kc (spacing between channels 12 and 10) as 26 db. Taking one half of these figures (since each of them represents 2-way suppression) results in losses of 4.75 db and 13 db.

Measured Antenna Loss	51 db
Assumed Conversion Loss	30 db
One-Way Cavity Suppression at 60 kc	4.75 db
One-Way Cavity Suppression at 120 kc	13 db
Level of Product on Channel 10	98.75 db

The product formed in the channel 12 transmitter and radiated at the channel 10 frequency should be 98.75 db below the radiated channel 12 carrier. It is difficult to measure the level of products that far down, but fifth order products have been repeatedly shown to be in the order of 100 db down.

3.09 While a single Motorola cavity with 1.5 db coupling loops may provide somewhat greater attenuation at 60 kc off resonance than the cascade cavities, it is undesirable to dissipate 80 watts (1.5 db loss to 250-watt transmitter) in a single cavity. The cascade cavities also produce considerably more attenuation than the single cavity as the frequency spacing is increased which is helpful where antenna loss figures are less favorable for transmitters 120 kc or more apart. A single cavity should be used where it will give sufficient suppression, but coupling loops over one db are not recommended with 250-watt transmitters.

3.10 Experience indicates that it should not be necessary to measure the level of intermodulation products. However, there may be little margin in the level of some products after suppression is provided. All potential sources of stray coupling between transmitter cabinets should, therefore, be removed and the installation of cavity filters and transmitters should follow closely the instructions in Section 402-307-100 and the appropriate system line-up practices.

3.11 Reducing the mutual coupling between the several transmitters provides a db-for-db reduction in the product. The bi-stack colinear antenna array for the 152-162 megacycle band provides considerably smaller mutual couplings between antennas than can be achieved in a reasonable space using random multiple masts. It may be desirable to erect such a mast where less than six channels are planned initially to provide for subsequent system growth.

4. OPERATION OF TWO RECEIVERS FROM CLOSELY COUPLED ANTENNAS

4.01 With the superheterodyne type receiver, harmonics of the local oscillator in one receiver may reach a nearby receiver through the antenna coupling. This type of spurious output has been measured on sample receivers as between -60 dbw and -84 dbw. The level of a desired signal in a quiet location may be -140 dbw. If the spurious output of the disturbing receiver falls within the pass band of the disturbed receiver, the required loss between receivers should be 140 - 84 = 56 db or more. However, the spurious response of the disturbed receiver should be 70 db or more below signal response. The coupling loss between the antennas will provide additional attenuation, so that interference is unlikely unless the spurious receiver output falls within the pass band of the disturbed receiver and the 70 db design suppression is lost. Interference of this type should be infrequent, but if present may usually be controlled with coaxial line filters.

FREE SPACE LOSS BETWEEN COAXIAL ANTENNAS TERMINATED IN SELF IMPEDANCE

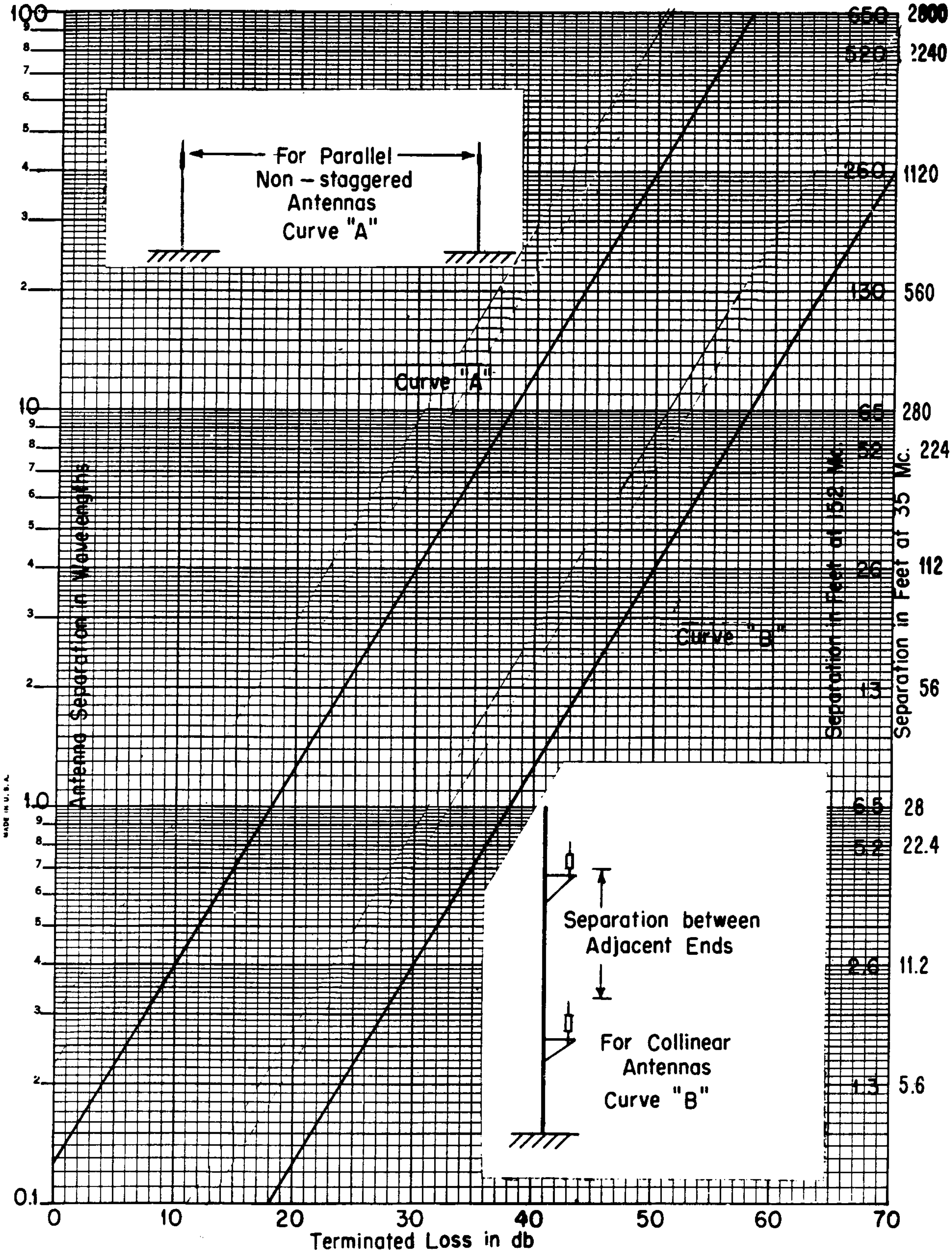

Fig. 6

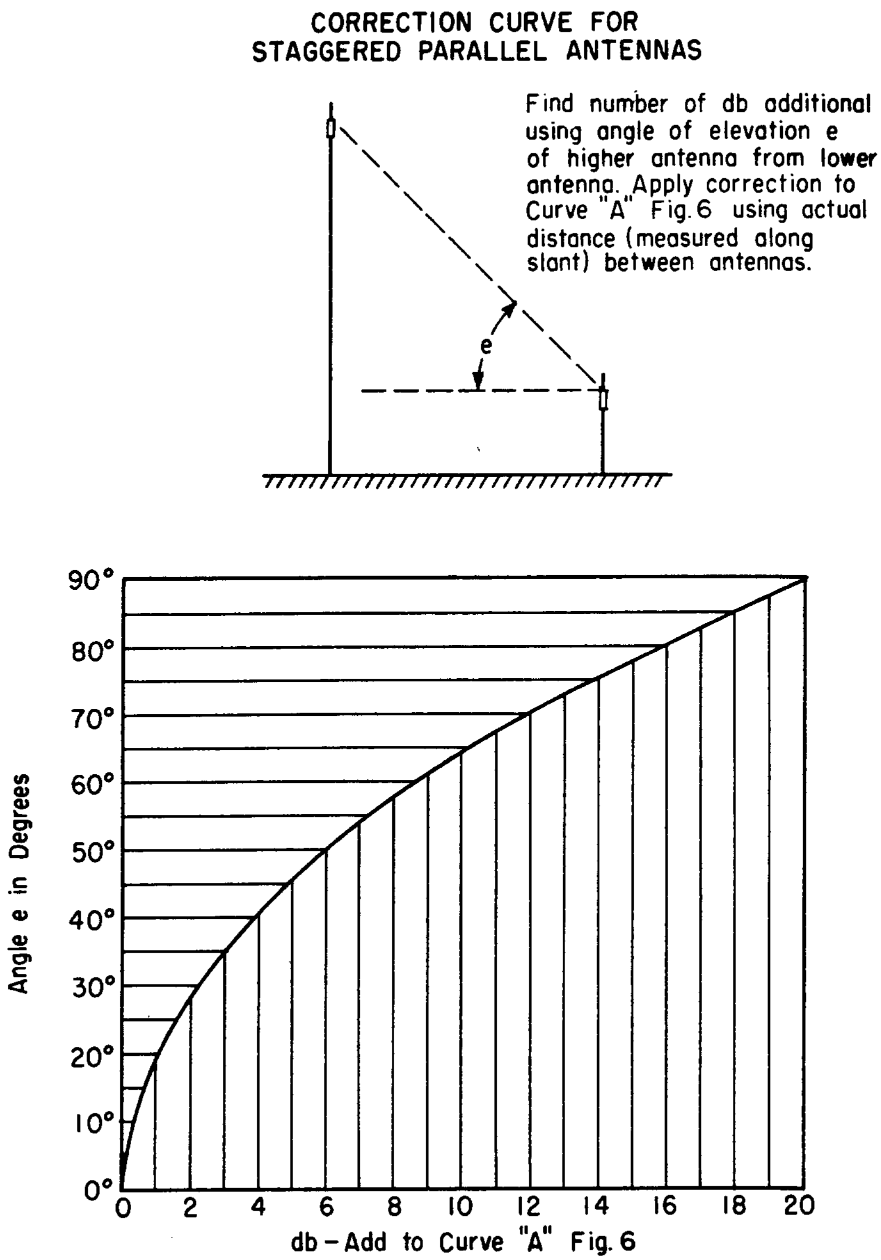
CORRECTION CURVE FOR
STAGGERED PARALLEL ANTENNAS
Find number of db additional using angle of elevation e of higher antenna from lower antenna. Apply correction to Curve "A" Fig. 6 using actual distance (measured along slant) between antennas.
e
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
Angle e in Degrees
0
2
4
6
8
10
12
14
16
18
20
db - Add to Curve "A" Fig. 6

Fig. 7

5. OPERATION OF TWO OR MORE RECEIVERS FROM A COMMON ANTENNA

5.01 For systems operating in the 152-162-megacycle band, bridging networks have been developed for connecting two to ten 40-type receivers to a common antenna. This arrangement will not reduce receiver coverage if the rf site noise delivered to the receiver input from the antenna minus the set noise generated in the early receiver stages is greater than the total bridging loss of all receivers connected to the antenna. Where set noise is controlling, the receiver coverage is reduced by the bridging loss of the bridging network. Where site noise is controlling, the receiver coverage is not reduced provided that the site noise delivered to the receiver input, with the bridging network connected, is greater than the set noise.

5.02 Present information indicates that at least 10 db bridging loss can be tolerated at a large proportion of receiver sites. At a few locations where the site noise is very low, bridging loss may be partly offset by the use of gain type antennas. The construction of these bridging networks is covered in Section R90.910.

5.03 Antenna matching units (bridging amplifiers) GE models 4KY8A2, 30-40 mc, 4KY8A3, 4-50 mc, 4KY8C1, 152-174 mc, are available for connecting two or three receivers to a common antenna. The 4KY8A2 and 4KY8A3 units will not affect receiver sensitivity when the operating frequencies of the receivers fall within a 120 kc band. When the receivers are used on frequencies within a 400 kc band the sensitivity will be reduced 3 db at the edges of the band. With a frequency separation of 1.0 megacycle this loss will be about 10 db. The 4KY8C1 unit will not affect receiver sensitivity when the operating frequencies of the receivers fall within a 400 kc band. When the receivers are used on frequencies within a 1.5-megacycle band the sensitivity will be reduced 3 db at the edges of the band.

6. ANTENNA COUPLING LOSS

6.01 The free space loss between antennas at various separations is shown in Fig. 6. The loss shown is for antennas terminated as in a normal system. The loss for parallel antennas at the same height is curve A and for colinear antennas is curve B. The loss for parallel antennas not at the same height is found by adding the additional loss of Fig. 7 to Fig. 6. These losses assume the separation is the shortest measured distance between antennas and are based upon free space conditions neglecting all stray coupling and reflection. The actual loss may vary by as much as 10 to 20 db due to roof tops or other objects or the supporting mast itself. Measurement of the antenna coupling loss is, therefore, preferable in most cases.

6.02 The coupling loss between antennas may be measured using the test setup shown in Fig. 8. For Test A, adjust signal generator for first limiter current from 50 to 100 ua at receiver frequency. For Test B, adjust signal generator to produce the same first limiter current as in Test A. Note the attenuator settings of the signal generator in both tests. The difference between the attenuator settings (microvolts) converted into db is essentially the coupling loss between the two antennas at the test frequency.

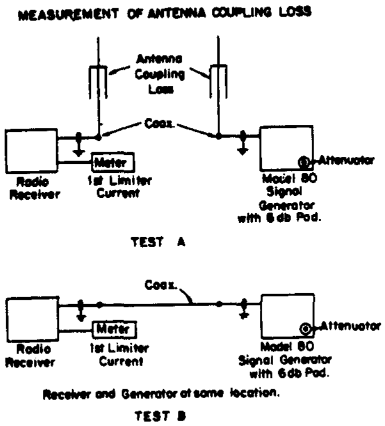

Fig. 8