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DUPLEX OPERATION CURVES

144-174 MC PROGRESS LINE

ABSTRACT

The curves included in this Bulletin present data for planning duplex systems using hi-band Progress Line equipment. They are also useful in solving interference problems where Progress Line base stations operating on nearby channels share an antenna site. When a receiver and a transmitter operate simultaneously, close to each other, it is necessary to provide adequate attenuation between the output of the transmitter and the input of the receiver to prevent loss in reception of desired signals. The curves show:

- the amount of attenuation (isolation) required between the transmitter and receiver to maintain intelligibility at an acceptable level.
- the amount of antenna spacing (using unity-gain antennas) and/or the number of cavity filters required to provide this attenuation.

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ILLUSTRATIONS

DUPLEX OPERATION CURVES

for

144-174 MC PROGRESS LINE TRANSMITTERS AND RECEIVERS

Transmitter ET-9-C (ET-21-A + EF-1-A)	Receiver ER-25-A
Transmitter ET-21-A	Receiver ER-25-B
Transmitter ET-26-A (ET-21-A + EF-5-A)	Receiver ER-25-C
Transmitter ET-48-A	Receiver ER-25-D

The curves included in this Bulletin may require some explanation for those who are unfamiliar with duplex operation of transmitters and receivers, although an attempt has been made to make the curves self-explanatory. The information supplied in these instructions may not be sufficient to solve all problems that result from the simultaneous transmission and reception of multiple signals. In these cases, further investigation and consultation with Engineering will be necessary.

INTERFERENCE CAUSED BY DUPLEX OPERATION

The signal from a transmitter operating on a different frequency than a receiver can cause interference in that receiver. That is, the intelligibility of desired signals -- particularly the weak signals -- may be reduced. This interference has two causes. First, the portion of the transmitter's noise spectrum which falls within the passband of the receiver increases the noise level, relative to the desired signal. Second, off-frequency RF and IF voltages generated by a strong off-frequency signal are rectified in the grid circuits of the receiver, producing bias voltages that reduce the gain of these stages and, therefore, the sensitivity of the receiver. Transmitter noise and receiver desensitization are discussed in more detail in DATAFILE Bulletin 10002-2, RF Interference in Two-Way FM Radio Systems.

The closer the frequencies of the transmitter and receiver are together, the more severe the effects of transmitter noise and receiver desensitization. With very little separation, the effect of transmitter noise is predominant. At greater frequency separations, the effect of receiver desensitization becomes greater.

Simultaneous operation of a receiver and a transmitter at the same location requires adequate attenuation between the output of the transmitter and the input of the receiver to prevent interference with desired signals. This attenuation (isolation) is usually obtained by antenna spacing and/or the use of cavity filters. For transmitters and receivers operating in the same cabinet, additional shielding may also be necessary to prevent RF coupling between the output stages of the transmitter and the input of the receiver.

MEASUREMENT PROCEDURES

Determining the amount of attenuation required between the receiver and the transmitter requires the use of a practical, realistic method for measuring desensitization. Since the most realistic measurement of FM or PM receiver sensitivity is the 12-db sinad ratio* method (EIA Standard RS204, Section 3), measurement of desensitization is also based on this method. When the desired signal alone produces a 12-db sinad ratio at the receiver output, the addition of an interfering signal at the receiver input can reduce this output sinad ratio, producing an effective loss in the receiver's sensitivity to the desired signal.

Desensitization measurements are most easily made by producing a 12-db sinad ratio at the receiver output with the desired signal alone, and then reducing this output to a 6-db sinad ratio by adding interference such as noise or an off-frequency signal. The resulting 6-db degradation in receiver sensitivity is normally considered the maximum acceptable amount of desensitization for practical operation. The corresponding loss of intelligibility is comparable to a 3-db loss in signal strength of the desired, on-frequency signal. To restore the original 12-db sinad ratio of the desired signal, with interference, the power of the desired signal must be doubled.

A 6-db degradation in a 12-db sinad ratio (or a 3-db power loss) is used in making measurements for these duplex operation curves, because it is the smallest loss for which the receiver desensitization characteristics are approximately linear. As shown by the typical curves in Figure 1, variations between receivers make it difficult to predict what the effective loss of power will be if the desensitizing signal does not produce at least a 6-db reduction in the 12-db sinad ratio.

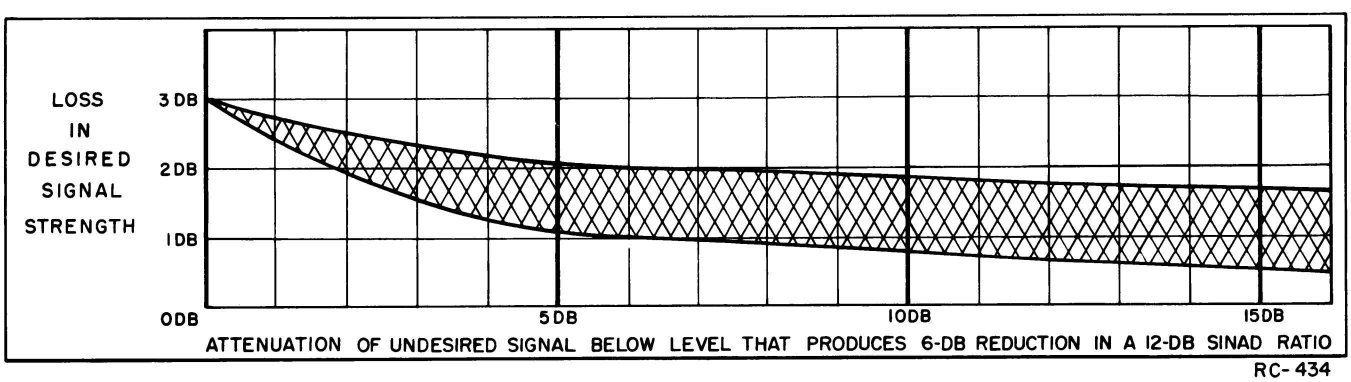


Figure 1 - Level of Undesired Signal vs Effective Loss of Desired Signal

The two curves in Figure 1 show the maximum and minimum effective loss of power below 3 db. The shaded area between the curves indicates the variation that can be expected between receivers. For losses in signal strength greater than 3 db, the receiver characteristics are approximately linear.

*** Sinad ratio is the ratio:** $\dfrac{\text{signal + noise + distortion}}{\text{noise + distortion}}$

Since the effective loss in the desired signal normally results from two factors, transmitter noise and receiver desensitization, it is possible that both types of loss in signal occur at the same level. When this happens -- with both independently producing a 3-db loss in desired signal -- the combined loss will be between 4 and 5 db.

METHODS OF REDUCING LOSS IN DESIRED SIGNAL

Three methods are commonly used for reducing loss in desired signal due to interference caused by receiver desensitization or transmitter noise:

1. Increasing the attenuation between the transmitter and the receiver by using separate antennas, spaced the required amount vertically or horizontally.

2. Increasing the selectivity of the transmitter and receiver by adding cavity filters.

3. Using both antenna spacing and cavity filters.

For a detailed discussion of receiver desensitization and transmitter noise, refer to DATAFILE Bulletin 10002-2.

EXPLANATION OF CURVES

The curves provided in this Bulletin may be considered as typical and only slight variations will be noted when the transmitter and receiver types indicated are operated under the same conditions. The curves are based on the use of dipole antennas. Corrections will have to be made if other types of antennas are used. The figures for vertical antenna spacing are accurate only if one antenna is mounted directly above the other. Horizontal displacement of the centerline of the antennas will decrease the attenuation indicated by the curves for vertical separation.

FIGURE A

Curve 1: Transmitter Noise

This curve gives the attenuation required, due to transmitter noise, between transmitter ET-21-A or power amplifier EF-1-A (adjusted for an output of 50 watts or 250 watts, respectively) and receiver ER-25-B (which has a 0.5-microvolt sinad ratio sensitivity) so as not to reduce the 12-db sinad ratio more than 6 db. When the transmitter power output is not adjusted for 50 watts, Curve 11 must be used to apply the proper power correction. The required ATTENUATION is found by reading the value from Curve 1 which corresponds to the FREQUENCY SEPARATION between the transmitter and the receiver.

Curve 2: Receiver Desensitization

This curve gives the attenuation required between a 50-watt transmitter, assuming no transmitter noise interference, and receiver ER-25-A or B, which has a 0.5-microvolt sinad ratio sensitivity -- so as not to reduce the 12-db sinad ratio more than 6 db. If the receiver is not operated at a 0.5-microvolt sensitivity, Curve 10 should be used to make the proper correction. The proper correction must also be made, using Curve 11, if the transmitter power output is not 50 watts. The required ATTENUATION can be read from Curve 2 which corresponds to the FREQUENCY SEPARATION between the transmitter and the receiver. Interference caused by transmitter and receiver spurious radiation is not considered in this Bulletin.

Some variation in the required attenuation may be experienced if the receiver is operated under conditions different from those used in making the measurements. This variation can be attributed to the fact that, because the RF transformer is tuned to the desired signal, a large VSWR will result when undesired signals are introduced into the receiver. Because of the large VSWR, it is important to use the proper length of transmission line between the receiver and any cavity filter used. With the receiver connected directly to the antenna, only slight variations from Curve 2 will be found, since the antenna is a relatively high impedance source, compared to a cavity filter, at any undesired frequency. To obtain maximum attenuation from a cavity, the length of the line to the receiver must be adjusted to produce a low-impedance point at the cavity. If the line length were to produce a high-impedance point at the cavity, the attenuation obtained would be 3 to 6 db less.

Curves 3 and 4: 12-db and 20-db Loss

Curves 3 and 4 give the attenuation required between 50-watt transmitter ER-21-A (or equivalent) and receiver ER-25-A or -B (which has a 0.5-microvolt sinad ratio sensitivity) to prevent greater than 12-db (Curve 3) or 20-db (Curve 4) loss in desired signal performance. These curves represent the combined effect of transmitter noise and receiver desensitization. To determine which is greater, refer to Curves 1 and 2. For different transmitter power outputs of receiver sensitivities, use the appropriate correction curves.

Curves 5 and 6: Antenna Spacing

Curves 5 and 6 can be used to find the attenuation provided by vertical or horizontal spacing of half-wave dipoles (using vertical polarization). The attenuation is given at the receiver terminals and the receiver is assumed to have the same impedance as the antenna. As explained above for Curve 2, a slight variation in attenuation will be experienced as the length of the transmission line between the antenna and the receiver is adjusted. This variation becomes smaller as the transmission line becomes longer. Curve 6 is based on free-space propagation, while Curve 5 is based on measured data.

Curves 7, 8 and 9: Cavity Filter

These three curves show the attenuation which can be obtained by using the loops normally supplied with Cavity Model 4KY5A1. Other attenuation curves can be obtained if special loops are used. All values of attenuation are measured with the cavity input and output terminated with 50-ohm impedances. As explained above, it is possible to obtain more attenuation by terminating the cavity with less than 50 ohms, or less attenuation by terminating the cavity with more than 50 ohms. When two cavities are operated in series and the connecting transmission lines are adjusted according to instructions, the attenuation is greater than the sum of the attenuation of each individual cavity.

Curve 10: Correction for Receiver Sensitivity

This curve is used to find the correction in db that is required when the receiver's sensitivity is not 0.5 microvolt. For example, a receiver located in an area of high noise level might have a sensitivity of 1.0 microvolt. Curve 10 indicates that the correction for a sensitivity of 1.0 microvolt is -6 db. This means that 6 db can be subtracted from the required attenuation determined from Curves 1, 2, 3 or 4.

Curve 11: Correction for Transmitter Power Output

Curve 11 is provided for making corrections for transmitter power outputs other than 50 watts. Since the attenuation curves are based on a 50-watt output, the correction is zero for that value of power. Correction should also be made for transmission line losses, when significant.

FIGURE B

Curves 1 and 2: Transmitter Noise

Curves 1 and 2 give the attenuation required, due to transmitter noise, between Transmitter ET-26-A* or ET-48-A and Receiver ER-25-C or D -- so as not to reduce the 12-db sinad more than 6 db. The curves are drawn for an 80-watt transmitter and a receiver having a 0.5 microvolt sinad sensitivity. Use correction curve 9 if the transmitter power output is not 80 watts and use correction curve 10 if the receiver's operating sensitivity is not 0.5 microvolt. The required ATTENUATION is found by reading the value from curve 1 or 2 which corresponds to the FREQUENCY SEPARATION between the transmitter and the receiver.

Curve 3: Receiver Desensitization

This curve gives the attenuation required between an 80-watt transmitter (assuming no transmitter noise interference) and receiver ER-25-C or -D, which has a 0.5-microvolt sinad sensitivity -- so as not to reduce the 12-db sinad ratio more than 6 db. Correction Curves 9 and 10 should be used for other transmitter power outputs and receiver sensitivities. The required ATTENUATION can be found by reading the value from Curve 3 which corresponds to the FREQUENCY SEPARATION between the transmitter and the receiver.

* Transmitter ET-26-A uses driver ET-21-A and 330-watt power amplifier EF-5-A.

Curves 4 and 5: Antenna Spacing

Curves 4 and 5 can be used to find the attenuation provided by vertical or horizontal spacing of half-wave dipoles (using vertical polarization). The attenuation is given at the receiver terminals and the receiver is assumed to have the same impedance as the antenna. As explained for Figure A (Curve 2), the attenuation will vary slightly with the length of the transmission line between the antenna and the receiver. This variation becomes smaller as the transmission line becomes longer. Curve 5 is based on free-space propagation, while Curve 4 is based on measured data.

Curves 6, 7 and 8: Cavity Filter

These three curves show the attenuation which can be obtained by using the loops normally supplied with Cavity Filter Model 4KY5A1. All values of attenuation are measured with the cavity input and output terminated with 50-ohm impedances. As explained above, it is possible to obtain more attenuation by terminating the cavity with less than 50 ohms, or less attenuation by terminating the cavity with more than 50 ohms. When two cavities are operated in series and the connecting transmission lines are adjusted according to instructions, the attenuation is greater than the sum of the attenuation of each individual cavity.

Curve 9: Correction for Transmitter Power Output

Curve 9 is provided for making corrections for transmitter power outputs other than 80 watts. Since the attenuation curves are based on an 80-watt output, the correction is zero for that value of power. Correction should also be made for transmission line losses, when significant.

Curve 10: Correction for Receiver Sensitivity

This curve is used in calculating the correction in db that is required when the receiver's sensitivity is not 0.5 microvolt. For example, a receiver located in an area of high noise level might have a sensitivity of 1.0 microvolt. Curve 10 indicates that the correction for a sensitivity of 1.0 microvolt is -6 db. This means that 6 db can be subtracted from the required attenuation determined from Curves 1, 2 or 3.

FIGURE C

Curve 1: Signal Strength vs First Limiter Voltage

Curve 1 shows how the first limiter voltage reading varies with the strength of the received signal for receiver ER-25-C (narrow band). The readings are typical measurements, taken with a VTVM. Since the LIM-1 jack on the receiver is shunted within the receiver by an 18K-ohm resistor, a correction factor will have to be used for measurements on meters having an internal resistance of less than about 180K ohms.

Curve 2: Effective Sensitivity vs First Limiter Voltage

Curve 2 can be used to estimate the effective sensitivity of Receiver ER-25-C from the first limiter voltage reading (due to random noise). Corrections can thereby be made for local noise conditions. The effective sensitivity (12-db sinad sensitivity) of the receiver can be read on the INPUT SIGNAL scale for the 1ST LIMITER voltage read with the antenna connected and no signal being received. A high-band receiver operating with a 3-db noise figure will provide a sensitivity of 0.16 microvolt on narrow band or 0.23 microvolt on wide band to produce a 12-db sinad ratio under standard test conditions. Such sensitivities can seldom, if ever, be realized when the receiver is connected to an antenna in an actual installation, due to noise being received or due to the receiver's operating frequency. This noise condition produces the increase in first limiter voltage noticed when the antenna is connected.

ILLUSTRATIVE EXAMPLE

As mentioned earlier, the attenuation needed to reduce receiver desensitization and transmitter noise can be obtained (1) by spacing the transmitter and receiver antennas far enough apart, (2) by using cavity filters in both transmission lines, or (3) by using both techniques. The following example is provided to illustrate the use of the duplex operation curves in determining the amount of attenuation which is required and how it can be obtained.

EXAMPLE (Using Fig. A)

Find the parameters required for duplex operation of the following transmitter and receiver so that the desired signal will not be degraded more than 4 db:

TRANSMITTER		FREQUENCY	
Frequency:	154.2 megacycles	Frequency:	155.0 megacycles
Power Output:	20 watts	Sinad Sensitivity:	1.0 microvolt

FINDING THE REQUIRED ATTENUATION

First, the frequency separation between the transmitter and the receiver is found. This separation is then used to determine the attenuation required at the transmitter frequency to reduce receiver desensitization (Curve 2) and at the receiver frequency to reduce transmitter noise (Curve 1). Corrections must be made for receiver sensitivity, transmitter power output and (if significant) transmission line losses. The curves presume the use of dipole antennas. If gain antennas are used, curves showing attenuation vs antenna spacing will have to be obtained from the antenna manufacturer.

Receiver Frequency	155.0 MC
Transmitter Frequency.	-154.2 MC
Frequency Separation	0.8 MC

Attenuation Required to Reduce Rcvr Desensitization (Curve 2)	50 db
Correction for Receiver Sensitivity (Curve 10)	-6 db
Correction for Transmitter Power Output (Curve 11)	-4 db
Total Attenuation Required at Xmtr Freq to Reduce Rcvr Desensitization	40 db

Attenuation Required to Reduce Transmitter Noise (Curve 1)	45 db
Correction for Receiver Sensitivity (Curve 10)	-6 db
Correction for Transmitter Power Output (Curve 11)	-4 db
Total Attenuation Required at Rcvr Freq to Reduce Xmtr Noise	35 db

METHOD 1 - ATTENUATION OBTAINED BY ANTENNA SPACING

The attenuation obtained by increasing the spacing between the antennas will be almost identical at either 154.2 MC or 155.0 MC. That is, the attenuation at the receiver frequency will be about the same as the attenuation at the transmitter frequency. In this example, more attenuation is required to reduce receiver desensitization than to reduce transmitter noise. Therefore, if there is enough attenuation for receiver desensitization, there will be more than enough attenuation for transmitter noise. The required 40 db can be obtained with 12 feet of vertical spacing (Curve 5) or 38 feet of horizontal spacing (Curve 6) -- whichever is more convenient. This spacing will provide more than enough attenuation for transmitter noise.

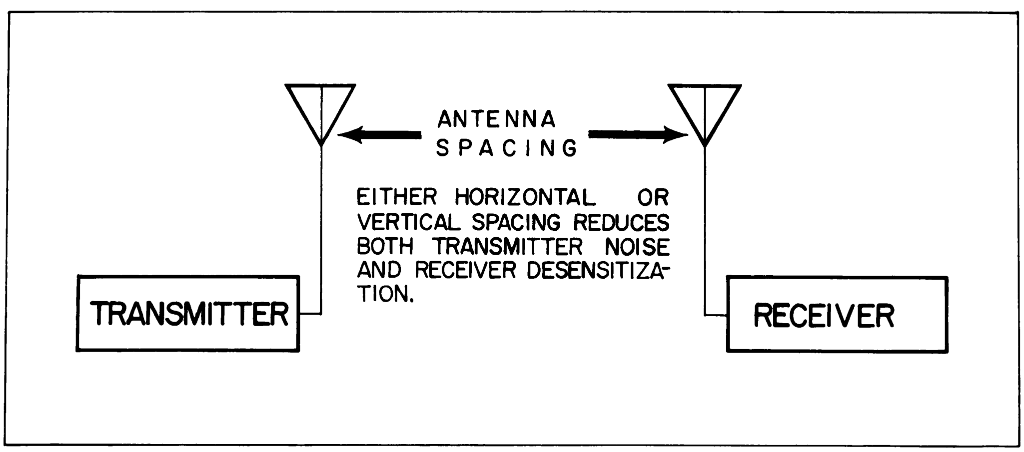


Figure 2 - Isolation Obtained by Antenna Spacing

METHOD 2 - ATTENUATION OBTAINED BY ANTENNA SPACING AND CAVITY FILTERS

It may not always be feasible to obtain all the necessary attenuation by antenna spacing. Cavity filters will then prove useful. To obtain the 40-db attenuation required in this example to prevent receiver desensitization, a 0.5-db cavity in the receiver input and a vertical antenna spacing of six feet could be used.

Cavity Attenuation with 0.5-db Loops (Curve 9)	**17 db**
Attenuation for Antennas with 6 feet of Vertical Spacing (Curve 5)	**26 db**
Total Attenuation.	**43 db**

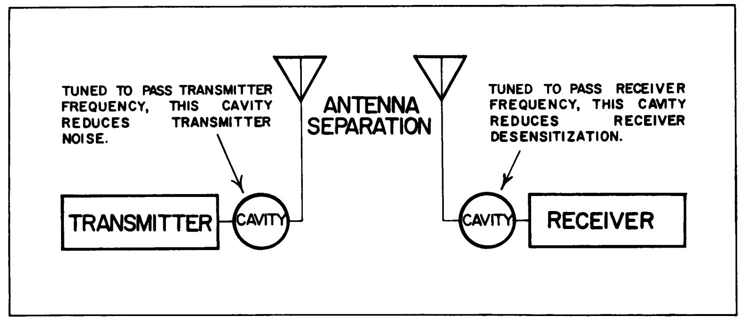


Figure 3 - Isolation Obtained by Antenna Spacing and Cavity Filters

The receiver cavity will reduce receiver desensitization, but will be ineffective against transmitter noise. A 0.5-db cavity in the transmitter output (with the 26-db attenuation provided by the six-foot antenna spacing) will be more than adequate to attenuate the transmitter noise.

METHOD 3 - ATTENUATION OBTAINED BY CAVITY FILTERS

It is sometimes desirable to use a common antenna for several transmitters and receivers. To do this, cavity filters must be used to obtain isolation between the units. To obtain the 40 db required in this example to prevent receiver desensitization, a 1.0-db cavity and a 0.5-db cavity could be used in the receiver input.

Cavity Attenuation with 1.0-db Loops (Curve 8)	24 db
Cavity Attenuation with 0.5-db Loops (Curve 9)	17 db
Total Attenuation	41 db

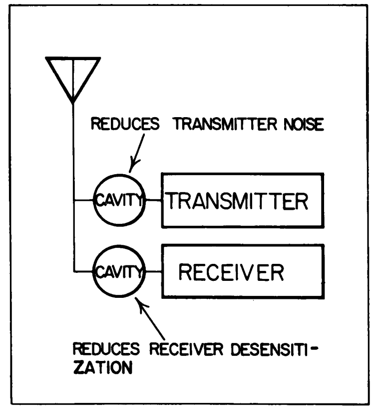
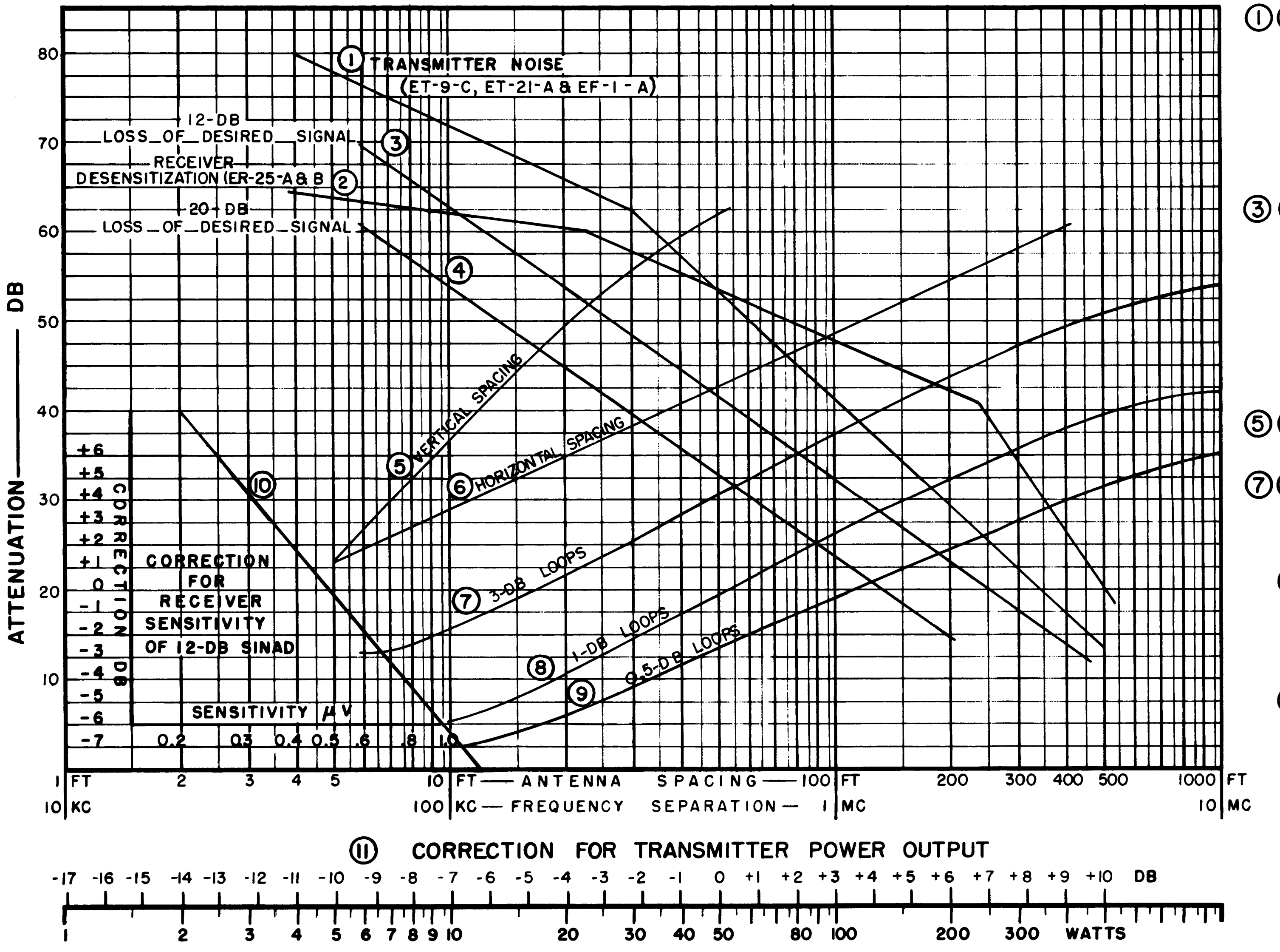


Figure 4 - Isolation Obtained by Using Cavities (Common Antenna)

For transmitter noise, two 0.5-db cavities in the transmitter output could be used, providing an attenuation of 34 db.

DUPLEX OPERATION (160 MC)



①② REQUIRED ATTENUATION TO PREVENT GREATER THAN 6-DB REDUCTION IN A 12-DB SINAD RATIO (EQUIVALENT TO 3-DB LOSS OF DESIRED SIGNAL).

③④ REQUIRED ATTENUATION TO PREVENT GREATER THAN 12-DB ③ OR 20-DB ④ LOSS OF DESIRED SIGNAL FOR COMBINATION OF DESENSITIZATION AND TRANSMITTER NOISE.

⑤⑥ ANTENNA ATTENUATION.

⑦⑧⑨ CAVITY ATTENUATION (4KY5A1).

⑩ CORRECTION FOR RECEIVER SENSITIVITY OF 12-DB SINAD RATIO.

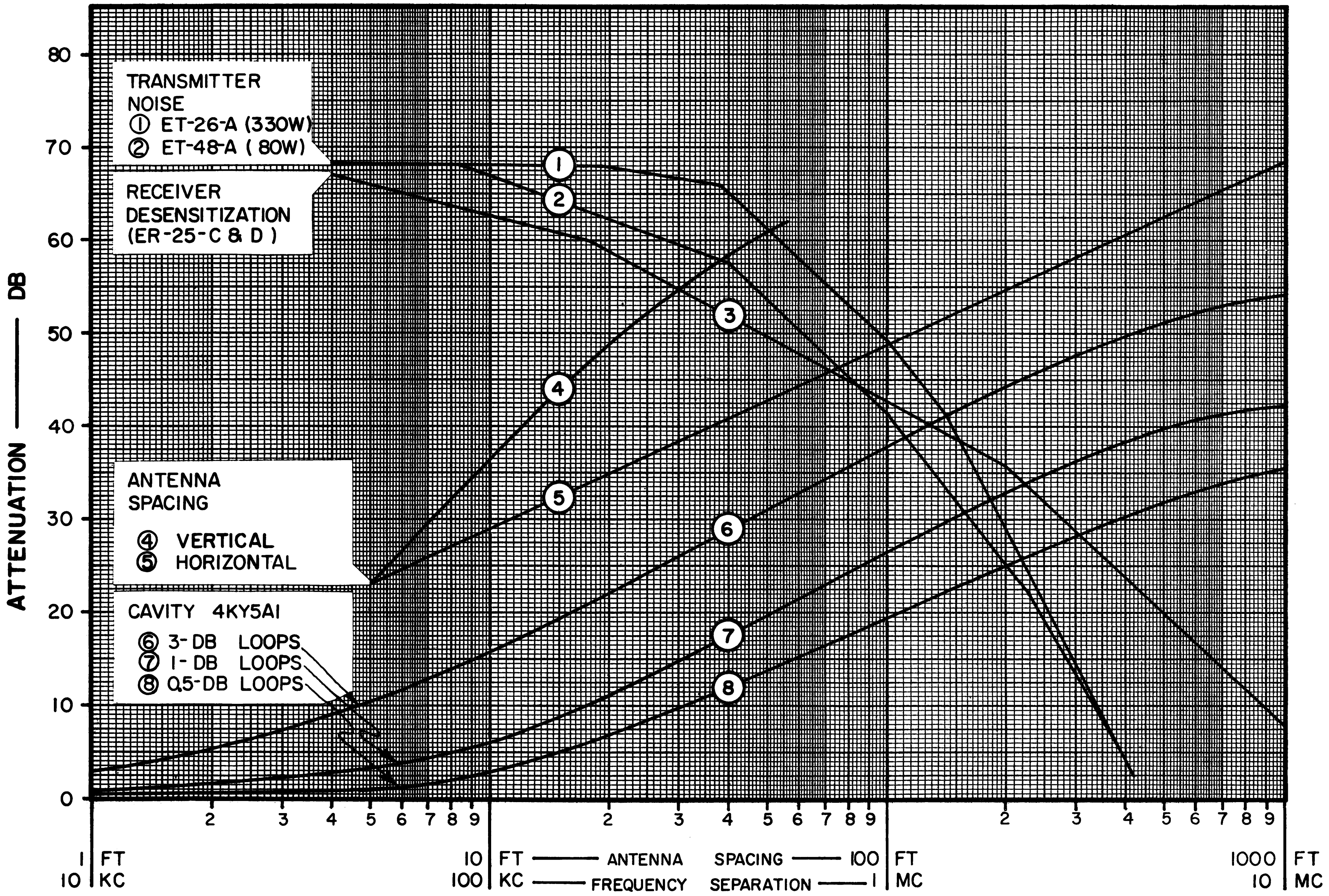
⑪ CORRECTION FOR TRANSMITTER POWER OUTPUT. (IF SEPARATE ANTENNAS ARE USED, ALLOWANCE SHOULD BE MADE FOR TRANSMISSION LINE LOSS).

RC-435B

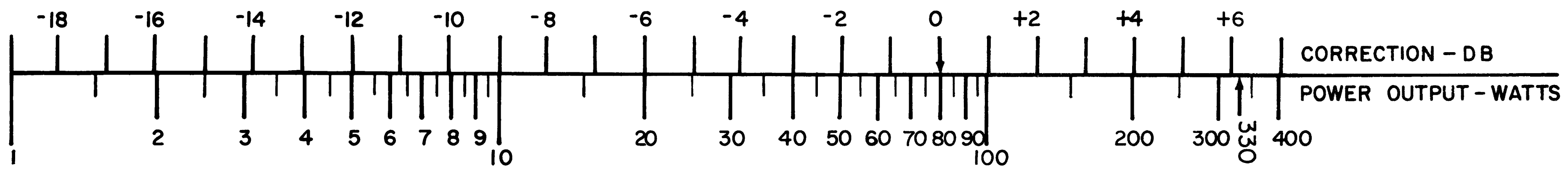
Figure A

DUPLEX OPERATION CURVES FOR ET-9-C (ET-21-A + EF-1-A), ET-21-A, ER-25-A and ER-25-B

DUPLEX OPERATION (160 MC)



⑨ **CORRECTION FOR TRANSMITTER POWER OUTPUT. IF SEPARATE ANTENNAS ARE USED, ALLOWANCE SHOULD BE MADE FOR TRANSMISSION LINE LOSS.**



①②③ ATTENUATION REQUIRED TO PREVENT GREATER THAN 6-DB REDUCTION IN A 12-DB SINAD RATIO (EQUIVALENT TO 3-DB LOSS OF DESIRED SIGNAL).

④⑤ ANTENNA ATTENUATION.

⑥⑦⑧ ATTENUATION PROVIDED BY CAVITY FILTER 4KY5AI.

⑩ CORRECTION FOR RECEIVER SENSITIVITY (12-DB SINAD RATIO)

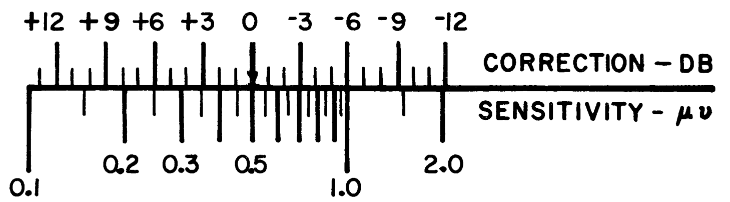
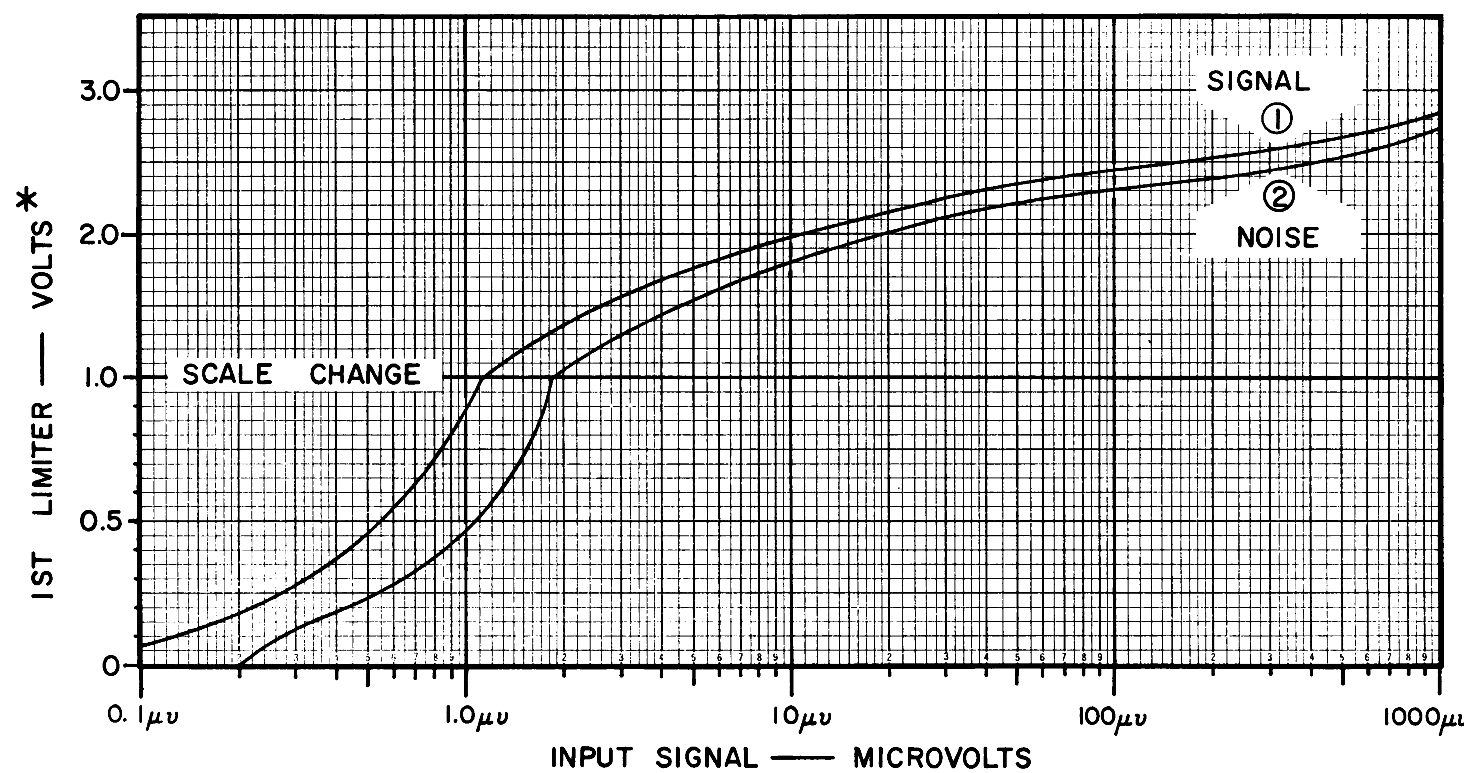


Figure B

DUPLEX OPERATION CURVES FOR ET-26-A (ET-21-A + EF-5-A), ET-48-A, ER-25-C and ER-25-D

TYPICAL 1ST LIMITER CURVES FOR ER-25-C (NARROW BAND)



① INPUT SIGNAL STRENGTH VS FIRST LIMITER VOLTAGE (VTVM).

② 1ST LIMITER VOLTAGE (DUE TO RANDOM NOISE) VS SIGNAL LEVEL REQUIRED TO PRODUCE 12-DB SINAD RATIO.

* MULTIPLY BY 0.78 TO CALCULATE READING ON 20,000 OHM-PER-VOLT METER.

Figure C

TYPICAL 1ST LIMITER CURVES FOR RECEIVER ER-25-C