H. Arnold

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MUTUAL ELECTROMAGNETIC INTERFERENCE

1 SEPTEMBER 1960

DEPARTMENT OF THE AIR FORCE

AIR FORCE MANUAL
NO. 100-35

DEPARTMENT OF THE AIR FORCE
WASHINGTON, *1 September 1960*

FOREWORD

1. **Purpose and Scope.**—This manual provides procedural and general technical guidance peculiar to, and required for, identifying and analyzing electromagnetic interference, locating and suppressing or eliminating sources of interference, and predicting the future extent of mutual interference among communications, radar, and navigation systems within the present state of the art.

2. **Policy.**—This manual is an integral part of the USAF Communications-Electronics Doctrine, as described in AFR 100-13. It is informative only.

3. **Citation of References.**—The procedures outlined herein will be referred to by citing "CED" followed by the paragraph number; for example, "CED 3502.4a."

4. **Changes.**—Recommendations for Changes in the manual will be submitted directly to: Communications-Electronics Doctrinal Project Office (AU Project 4736), Research Studies Institute, Air University, Maxwell Air Force Base, Alabama.

BY ORDER OF THE SECRETARY OF THE AIR FORCE:

OFFICIAL:

THOMAS D. WHITE
Chief of Staff

J. L. TARR
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CED 3500
MUTUAL ELECTROMAGNETIC INTERFERENCE

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SECTION I—INTRODUCTION

3501. MUTUAL ELECTROMAGNETIC INTERFERENCE

.1 Objective.—This manual is written to aid in optimum utilization of electronic systems through proper application of radio interference reduction techniques, consistent with a given environmental situation and the current state of the electronic art. This objective can only be achieved by careful consideration of the interference factors that influence the operation of a particular system. This manual discusses areas of equipment compatibility at the design level, factors to be considered during equipment installation, and operational and maintenance techniques tending to reduce interference. A basic plan for the reduction of radio interference is also included.

.2 Purpose of the Manual.—This manual has been prepared as a general radio-interference reference for the C-E officer and his staff. Its purpose is to provide him with an understanding of the causes and effects of radio interference as applied to modern radar and communications systems and to acquaint him with the techniques employed to effect its reduction. For the C-E officer to fulfill his obligations in the area of interference reduction and control in the most efficient manner, he must have a generalized technical background dealing with prediction, prevention, recognition, identification, and suppression of interference, and he must be acquainted with the related administrative requirements of his assignment. This doctrinal manual has been prepared to provide him with this basic information, and to direct him to other military references where further details may be obtained. By the very nature of the technical field involved, the publication is instructive in approach, rather than directive. It is intended to serve as a guide in the handling of all problems relating to electromagnetic interference.

.3 Scope.—This manual includes a qualitative discussion of the natural laws which govern the generation, transmission, and reception of radio interference. However, emphasis is not upon the fundamental natural behavior, but upon the application of these basic laws to the interference picture. Particular stress is given to the identification of interference sources, and to the various specialized methods of reducing their effect. Emphasis is also placed upon the techniques employed to predict equipment electromagnetic environment and compatibility before installation.

a. Supplementary Education.—One of the most effective methods available to the Air Force for combating electromagnetic interference is the education of individuals who work with potential interference sources and receivers. The C-E officer is one of the key individuals in any educational program stressing the importance of minimizing interference, and the problems and techniques that arise in the suppression of interference. This manual aids the C-E officer in providing for the interference training requirements of his subordinates, and helps him organize personnel training programs which result in a high level of equipment effectiveness consistent with the state-of-the-art of interference reduction and control.

b. Recognizing and Categorizing Radio Interference.—The C-E officer encounters problems in the field of electromagnetic interference encompassing a wide range of equipment types and characteristics. For example, he may be confronted simultaneously with the presence of undesired LF signals in an intercom amplifier, local oscillator radiation effects from an HF communication receiver, and interference spirals on the PPI screen of a radar system. This manual provides him with some of the specialized technical background required to recognize and categorize these to electromagnetic interference problems.

c. Planning Installations.—When he is involved in the establishment of an Air Force facility, installation, or base, the C-E officer may be required to predict all or part of the interference problems that may arise due to specific equipment and system deployment. He also may be called on to assist in laying out sites that will minimize equipment interaction without degrading the capabilities of the sites with regard to their primary missions. This manual discusses the considerations which must be given both to the spatial distribution of sources and receivers of interference, and to the electrical distribution as it pertains to the problems of equipment frequency compatibility.

d. Operational Installation.—The responsibilities of the C-E officer at operational Air Force installations include the recognition, identification, and elimination of all interference phenomena that cause a reduction of system effectiveness. This manual provides the C-E officer with a method of determining when degradations in equipment and system performance occur, and a plan to aid the reduction of the interference to a tolerable level.

.4 Manual Contents.—CEDs 3502. through 3504. cover the background and fundamental theory of electromagnetic interference. They give accounts of the phenomena by which interference is generated, as well as detailed information on its transmission and reception to the extent that such considerations are peculiar to the treatment of radio-interference phenomena. Interference-reduction techniques applicable to the generation, transmission, and reception of electromagnetic interference are given in CEDs 3505. and 3506. To obtain a quantitative description of radio interference, measurements are normally performed by specialized instrumentation. The basic characteristics of such instruments are presented in CED 3507. Since it is often desirable to anticipate the interference situation before it occurs, much recent attention has been given to interference prediction. Some of this work has been adopted in a simplified step-by-step approach to prediction in CED 3508. A systematic plan for reducing interference is presented in CED 3509; practical examples of the application of this plan to radar and communications systems are given in CEDs 3510. and 3511. Test procedures are presented in CED 3512. Radio-interference considerations in advanced communication systems are presented in CED 3513. CED 3514. is the bibliography. For general references on electromagnetic interference, refer to CEDs 3514. 15, .16, .18, .23, and .24. Specific references in CED 3514. are cited within parenthesis throughout the text.

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SECTION II—PRINCIPLES OF ELECTROMAGNETIC INTERFERENCE

3502. PRINCIPLES OF ELECTRONIC INTERFERENCE —GENERATION.

.1 Introduction.—Electromagnetic interference to Communications-Electronics equipment can be subdivided into three steps. These include the interference generation aspect; the process involving transmission of interference signals to the receiver; and the process of reception by a susceptible device. The first step is concerned with the generation of undesired signals—often an operational by-product of a normally radiating or nonradiating device. The second step is concerned with the transfer of the interference energy from the source to the receiver. This transfer may take place by free-space radiation (propagation), conduction, inductive or capacitive coupling, or a combination of these. The third step involves the paths of signal entry into a receiver, as well as the internal susceptibility of the receiver. All three processes are governed by the same natural laws which control desired signals. Therefore, this CED discusses the generation of interference and its special relationship to these basic physical laws.

.2 Fundamentals of Interference Generation.—The generation of interference is always associated with a varying electric and magnetic field. The question may be asked, "Is this the fundamental reason for the generation of interference?" To answer this question, we must consider the orgin of such fields. A field is always associated with charges. If the charges are stationary, no magnetic field exists; and as the electric field remains constant, interference signals will not be generated. If the charges move in a manner uniform with time, they generate static magnetic and electric fields. Again interference will not be generated. However, if the charges have nonuniform motion, varying electric and magnetic fields result and interference may be generated. This nonuniform charge motion is caused by the nonuniform acceleration of the charges and is commonly known as a varying current. Stated in another way, interference is generated if the rate of change of current (i) with respect to time (t) is not zero, or mathematically:

$$\frac{di}{dt} \neq 0 \qquad (1)$$

This equation is not only the fundamental equation of interference generation, but it is also a required condition for the existence of an alternating current. If a varying current is essential for the operation of an equipment, equation (1) can be reduced to zero provided only that the rate of change of current refers to that portion of the total current which remains after subtracting the desired current.

a. Methods of Generation.—"What can cause a varying current?" To answer this question, we must go back to one of the basic equations of circuit theory—Ohm's Law for a-c circuits:

$$I = \frac{E}{Z} \qquad (2)$$

where I is the current into a two terminal network, E is the voltage across the terminals, and Z is the impedance between the terminals. From equation (2) it will be noted that variations in currents must be associated with variations in voltage (E), variations in impedance (Z), or both. The causes of such variations will be discussed briefly in the following paragraphs.

(1) Varying Voltages.—There are three major methods by which a varying voltage is generated: generation by feedback or negative resistance in vacuum tube or transistor circuits; generation by mechanical means in rotating machines; and generation by electrical variations in the characteristics of an impedance. Generation of a varying voltage can also take place by chemical means or by a change in the energy (quantum) level of an electron. However, the total energy generated by chemical or quantum variations is usually minute and will not be considered in this section.

(a) Active-Element Circuits.—If a vacuum tube or transistor circuit contains regenerative feedback loops, or operates in a region of negative-impedance characteristic, it may generate an alternating voltage. In some equipments, this type of circuit is required for normal system operation, e. g., the local oscillator of a superheterodyne receiver. However, such circuits can cause interference to other equipments, even if the oscillator is an ideal one and generates a perfect sine wave. If the signal is not ideal, it may contain many harmonics and is potentially capable of causing additional interference.

(b) Rotating Machinery.—When the proper relative motion occurs between a conductor and a magnetic field, a voltage is induced in the conductor. The value of the voltage (E) may be determined from the following mathematical relationship:

$$E=BLV, \qquad (3)$$

where:

B is the magnetic flux density,

L is the effective length of the conductor perpendicular to the field,

V is the component of relative velocity perpendicular to both L and B.

All a-c and d-c generators are designed on this principle, and motors function on a converse principle. In an ideal a-c generator, the variation in the induced voltage (E) is that the generated voltage is a sine wave. In a d-c machine, the generated voltage is a constant. Irregular variations of the voltage (E) occur because the velocity of the conductors may not be exactly constant, or the effective length of the many conductors involved may not all be the same. However, the major difficulty arises because the voltage across the output conductors must jump abruptly from one constant value to another and back again, each time the brushes pass from one commutator segment to another. Thus, the current in the armature will show rapid variations, and be rich in harmonics. Additional information on the generation of interference in rotating machines can be obtained from CED 3502.4c.

(2) Variations in Impedance.—A variation in the impedance characteristic of an element can cause a varying current, and thus represents an interference potential. Such variation can be subdivided into two types, linear and nonlinear. Impedances whose magnitude do not depend upon the currents flowing through them or the voltage impressed across them are called linear impedances. All others are called nonlinear impedances.

(a) Nonlinear Impedances.—It can be shown both experimentally and theoretically that a nonlinear impedance acts like a generator in that it creates harmonics of the impressed signal. Mathematically, it is possible to replace any nonlinear resistance by a linear resistance in series with a number of harmonically related generators, as illustrated

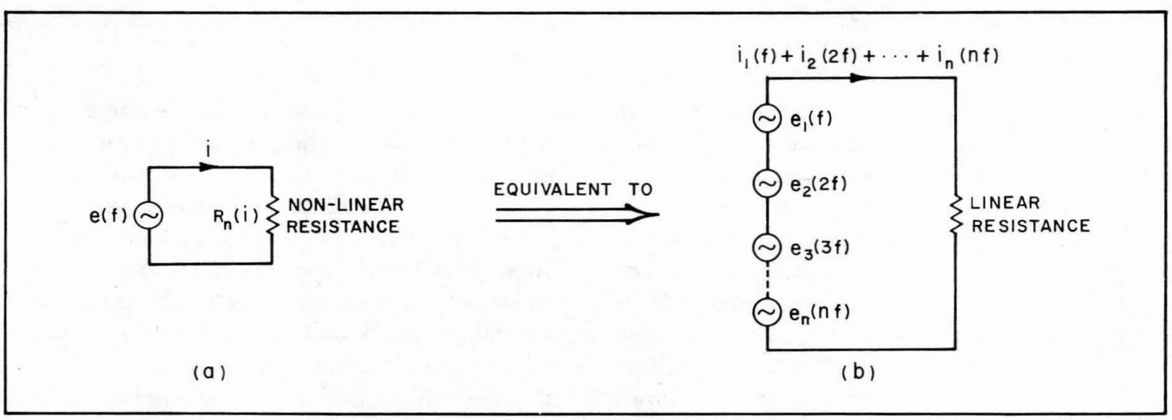


Figure 35-1.—*Linear Equivalent of Non-Linear Circuit.*

in Figure 35-1. The situation becomes slightly more complex when nonlinear inductors and capacitors are considered; however, the net results are essentially the same. Any nonlinear impedance must be considered as a possible cource of interference. Both intermodulation, described in CED 3504.2c(4)(a), and cross-modulation, described in CEDs 3502.4i (6)(a) and CED 3504.2c(4)(b), are direct results of nonlinear action. Figure 35-1 shows the linear equivalent of a nonlinear circuit.

(b) Linear Impedances.—The variation of impedance is one of the most important causes of undesired current variation in man-made interference of nonelectronic origin. Even though the magnitude of linear impedances are independent of the currents flowing through them, they may have their magnitudes varied in time by some external process. As an example of this class of interference generation, let us examine a simple switch. When the switch is closed, the impedance across its terminals changes from an infinite to a finite, extremely low value in a very short period of time. This causes a rapid change in current flow. Less extreme cases occur where the impedance changes from one finite value to another in a very short period of time. It can be shown the rate at which the impedance varies is important; very slow or gradual changes in impedances do not result in appreciable interference. However, very sudden changes may cause the generation of a very large amount of undesired spurious energy. Sources of this type of interference include motor brushes, mechanical and automatic switches, arc-welding equipment, gaseous discharges, etc.

.3 Classification of Sources.—Depending upon origin, the sources of interference generation can be divided into three groups: natural, man-made nonelectronic, and man-made electronic.

a. Natural Sources. — Certain natural sources can generate sufficient electromagnetic energy to become the limiting factor determining the useful operating range of radio equipment. These sources can be classed according to their location in the sense that they are of a terrestrial or extraterrestrial nature. For the purpose of this discussion, noise from terrestrial sources will be limited to atmospheric noise and that from extraterrestrial sources will be limited to galactic and solar noise.

(1) Atmospheric Noise. — Atmospheric radio noise is used to denote electromagnetic disturbances at radio frequencies arising from natural phenomena within the earth's atmosphere. This noise is produced mostly by lightning flashes associated with thunderstorms. These flashes are high-amplitude, short-duration bursts of energy which radiate over a wide spectrum of frequencies. The resultant noise level at any point on earth is caused by the sum of many flashes, and is dependent on frequency, time of day, weather, season of the year, and geographical location. Information regarding the geographical distribution of atmospheric noise is extensive and can be obtained from such sources as those listed in CED 3514.

(2) Extraterrestrial Noise.—Galact ic and solar noise, which have the characteristics of random fluctuation noise, are caused by disturbances which originate outside of the earth's atmosphere. The major source of galactic noise is usually considered to be near the center of the galaxy, while solar noise originates within our sun. Both types of noise are dependent upon ionic absorption characteristics and, therefore, vary as a function of time of day, time of year and latitude. Solar noise is also cyclic in nature, varying in accordance with the sunspot cycle. This type of noise is predominant in a frequency range from approximately 10 mc to 200 mc in current vacuum-tube and transistor circuitry, but will be significant over a wider bandwidth when lower-noise circuitry such as parametric amplifiers and masers become operational.

b. Man-Made, Nonelectronic Origin.— An unlimited number of sources, including many devices associated with the operation of Air Force facilities, may act as nonintelligible sources of electromagnetic interference. The majority of such base-located devices may not come under the immediate cogizance of the C-E officer. However, the performance characteristics of these equipments can have an appreciable effect upon the overall operation of the base electronics complex. The interference emanations from nonelectronic sources are usually caused by an abrupt change in waveform, e.g., due to a sudden variation in impedance, and result in a broad band signal; that is, a signal whose energy is distributed over a relatively wide frequency range. Some devices may have certain resonant characteristics resulting in a particularly predominant narrow band of frequencies. The effect of this type of interference generally decreases with increasing frequency, but has produced significant deleterious results at 300 mc and higher.

c. Man-Made, Electronic Origin.—It is the principal purpose of Air Force radar, communication, and navigation equipment to emit energy at particular frequencies, commensurate with the performance of assigned tasks. Such equipment may also emit energy at harmonic and spurious frequencies. In addition, other types of electrical equipments which employ sinusoidal energy as a part of the basis of their operation are potentially capable of generating harmonic and spurious information. The latter category includes r-f stabilized arc-welding equipment, induction and dielectric-heating units, and some electro-medical devices.

.4 Specific Sources.—The specific sources of man-made electromagnetic interference, including the mechanism of noise generation and possible reduction techniques are discussed in CEDs 3502.4a through 3502.4j.

a. Power-Line Interference.—The sources of electromagnetic power-line interference can be considered as: interference associated with the power source and load, interference induced into the power line via electromagnetic coupling, and interference attributed to an impedance variation of a transmission line component. Since power sources, load effects, and coupling aspects are covered in CEDs 3502.4c and 3503.3, only impedance variation will be treated here. The interference generated by transmission lines usually results from a sudden current or potential change caused by an arc, corona or other breakdown. Generally these effects are caused by depreciation of the system, or improper installation or maintenance of the components of the transmission line. Component parts of the system include the conductors, insulators, other line hardware, and switchgear equipment.

(1) Conductor-Generated Interference.—A higher-than-normal electric field, resulting from insufficient wire insulaton, corroded insulation, a reduction in line-to-line or line-to-ground spacing, or nicks, sharp points, or small radius bends, is the principle source of interference generated by the conductors of a line.The interference starts with ionization of the air in the high-field-strength region, followed by a corona discharge. As the current through the discontinuity increases, a spark or arc discharge may take place. The rapid changes in current waveform result in the generation of broad band interference. In addition, the spark or arc can cause permanent injury to the insulation and allow frequent sparking or arcing. Another possible source of conductor-generated interference can arise if the conductor starts to corrode. The corrosion region is actually a nonlinear impedance which can act as an r-f rectifier in detecting radiated signals, and/or in mixing two or more signals, thereby generating spurious responses. The energy at the undesired frequencies can either be conducted along the power line or re-radiated to susceptible equipment near-by.

(2) Insulator-Generated Interference.—Electric-field leakage paths can be produced on a power-line insulator by fog, rain, salt spray, lightning surges or cracked insulator glaze. The electric-field breakdown causes a spark or arc discharge and interference is generated. The spark or arc results from the large field strengths, plus the uneven distribution of the fields across the insulator. Special insulators are available under such names as *radio-proofed* and *silent type* which attempt to keep insulator interference to a minimum level. These insulators have a semiconductor applied under the glaze which tends to maintain an even distribution of the potential gradient. When a new power line is constructed, or even when a single insulator is replaced, the special radio-interference type should be considered. Periodic insulator cleaning is recommended. This is accomplished by the use of special, high-pressure washing equipment which utilizes an atomized spray to avoid a new breakdown path.

(3) Hardware-Generated Interference.—Power-line hardware, including such items as cross-arm brackets, bolts, clamps, and guy wire, is situated in the vicinity of the high electric and magnetic fields generated by the line. Distortions of the fields by hardware may result in large potential gradients in

certain regions surrounding the lines. If the field intensities reach sufficiently high values, sparking or arcing may occur between pieces of hardware. One solution is to maintain a secure bond between all hardware. Another solution is to assure that sufficient separation of all affected hardware is maintained.

(4) *Switchgear-Generated Interference.*—The mechanism of interference production for switchgear components is similar to that in the previous examples. A corona discharge caused by a potential gradient and/or insulation breakdown results in an arc. Radio-interference generation can be a sign of potential failure of such items as transformers and oil switches. Periodic system maintenance will help to reduce appreciably this type of interference.

b. Lighting Interference. — The steep waveforms associated with the operation of certain types of lamps can cause broad band radio interference. The major source of this interference is the voltage discharge phenomena inherent in the operation of fluorescent, mercury, and sodium lamps. The interference exists in both radiated and conducted forms. Most of the conducted interference can be eliminated by low-pass line filters. Radiated effects in the 100-mc range have been noted, although the radiation levels decrease rapidly with distance from the source. The use of a type of lamp which generates appreciable interference should be avoided in locations near communication receivers.

(1) *Fluorescent Lamps.*—The fluorescent lamp generates HF components during the gas breakdown interval that occurs 120 times a second. Thus, in installations near sensitive electronic equipment, such as HF communication centers, utilization of fluorescent lights might be open to question. Their interference characteristics must be weighed against such factors as the increased power and air conditioning that might be required with incandescent lamps. Fluorescent fixtures using cold-cathode type lamps, or having louvers or conductive glass over the lamps, have resulted in somewhat radiated-interference levels.

(2) *Mercury and Sodium, Arc and Vapor Lamps.*—These types of lamps are characterized by the typical interference associated with an arc discharge. The high voltage and current levels utilized for operation allow generation of copious amounts of interference energy. Thus, the interference will not only be of higher level at low frequencies, but higher frequency energy components will also appear. These types of lamps should only be used if communication or other sensitive equipment is remotely located or adequately shielded, and then only if suitable transmission line filters have been installed.

c. Motors and Generators as Sources of Interference.—Electrical motors and generators constitute one of the largest sources of electromagnetic interference. Rotating electrical machinery interference is generated by transients due to commutator sparking, slip-ring noise, and static discharges. The transients, which are rapid changes in voltage and/or current, produce noise over an extremely broad band. Use of special types of brushes and application of appropriate filtering may be employed to reduce the interference levels. Small, low-cost, universal motors sometimes create particularly severe interference, since they use a minimum number of commutator segments per volt. Secondary sources of interference in rotating equipment can be attributed to bearing, belt, shaft, and clutch static. These types of interference, which are significant primarily in high-speed or large-capacity machines, consist of periodic discharges of static electricity from charged machine surfaces. In the case of bearing static, the arcs occur as a result of dielectric breakdown of the lubricant film or intermittent metal-to-metal contact at the bearings. The discharge current passes from the shaft of the motor or generator, through the bearings, to the housing or bedplates. This source can be eliminated by either a low-impedance path for the current using a conducting grease, or by insulation of the bearing assembly from the bedplate. In the cases of belt, shaft, and clutch static, the voltage is generated by friction. When the voltage assumes a sufficiently large value, a breakdown takes place, producing interference. The sources can be removed by use of radio-active static eliminators which ionize the air and provide a low-impedance path to ground, by application of special conducting material to belts to reduce the possibility of static buildup, and by installing grounding brush assemblies on shafts for the same reason. Increased mechanical or electrical load on the motor or generator will increase interference levels. This result is primarily due to the increased currents associated with larger loads. Good maintenance practices are a vital factor in motor and generator interference reduction. A rotating machine with rough commutator contacts, little or no lubrication, or one which has been overlubricated, will be far noisier than a properly maintained unit. The C-E officer should stress this area of the preventative maintenance program; he should see that items such as worn brushes, weak springs, and warped shafts are replaced.

(1) D-c Machinery.—Of the two general categories of rotating equipments, the d-c type consistently produces the higher levels of interference. The most important source of this interference is the switching of input or output power from one set of windings to another (commonly called the commutation process). This switching process results in generation of the signal by means of a step-by-step buildup process. Noise outputs have been measured up to 1000 mc; however, the high-level noises are usually confined below 100 mc. It is also possible for high-amplitude impulse noise to shock-excite a resonant circuit within the unit, causing oscillations at discrete frequencies. These oscillations will be considerably larger in magnitude than the broad band interference (at the resonant frequency), and thus may produce a "high-powered" source of interference to communications equipment.

(2) A-c Equipment.—With a-c generators, particular attention must be given to the production of as pure a sine wave as possible. As has been noted previously, a nonsinusoidal waveform could contain harmonics of strength sufficient to cause interference. Any impedance variations in the process of feeding power through the slip-rings can introduce such distortion effects. A secondary consideration is the prevention of resonant conditions within the unit, for these could increase the output of the harmonic components. Another important factor is the source of the d-c field excitation current. If this current has a pulsating waveform, it can introduce interference into the a-c generator which will be reproduced in its output. Most a-c motors are relatively free of interference sources; however, the wound-rotor type can produce some interference. This results from slip-ring and brush noise.

d. Electrical Controller Equipment Interference.—The controller equipment associated with electrical installations has as its function the control of the voltage and/or current fed to—or from an electrical system. The control system may be a refined device with continuous precision settings, or it may be as simple as an off-on switch. The continuous-type control will result in slow variations of waveforms, producing very little interference. However, an automatic or nonautomatic control with make-break contacts will produce rapid variations in the associated electrical waveforms. Because interference caused by the more rapidly changing waveforms is by far the more serious problem, only the discontinuous type control will be discussed.

(1) Gap Breakdown.—As a switch is operated, the breakdown effects across the contacts are responsible for the high level of interference produced. This breakdown is dependent upon the type of load being supplied. Both resistive and inductive loads will be discussed in subsequent paragraphs. Although this discussion will specifically involve a d-c supply voltage, it is also a good approximation for the a-c case if the time constant of the circuit is small in relation to the period of the a-c signal.

(a) Resistive Loads.—When a circuit with a resistive load is broken, the voltage across the switch will rise with no overshoot to a value equal to that of the d-c supply. This rise is due to charging of the stray capacitance across the switch through the load resistance. Since this capacitance is very small, the voltage rises very quickly. During this time, the switch contacts have moved only a very short distance. The resulting field is extremely high, so that breakdown occurs and the voltage is reduced. After the voltage is lowered, the arc is extinguished and the cycle repeats itself. As a result, the current will be interrupted and re-established several times during the initial phase of contact separation. When the switch is being closed, the moving contacts will be in close proximity to one another for a short time. The high field and breakdown phenomenon will give rise to several arcs before permanent contact is finally established.

(b) Inductive Loads.—When a switch in an inductive circuit is opened, a large electric field appears across the switch. As this field intensity reaches a critical level, breakdown occurs and the voltage is reduced. After the arc is extinguished, the voltage rises and the cycle re-occurs as in the resistive load case. With the resistive load, the maximum switch voltage is equal to the supply voltage but, with the inductive load, the voltage across the switch can rise to many times that of the supply, resulting in considerably more switch arcing. When closing a switch in an inductive circuit, the load resists any sudden change in current, and breakdown takes place less readily.

(2) Automatic and Nonautomatic Switches.—Manual switches are not operated frequently and are thus not a major source of interference. On the other hand, the automatic switch is a very serious offender. Devices such as voltage regulators open and close as many as 250 times a second, causing a continuous high-level interference. The recurrent breakdowns as the switch is operated produce voltage and current waveforms with very steep rise and fall times. These, in turn, cause broad band conducted and radiated interference. There are several techniques available for the reduction of this interference. The most successful methods involve reduction or elimination of the arc by an increase in circuit time constants and/or control of the peak current in the circuit. Refer to 3506.2a for a detailed discussion of the techniques.

e. Gasoline Engine Interference.—The modern gasoline-engine installation can be a source of radio interference. However, this interference has a relatively short range (of the order of 1000 feet) with energy distribution to 500 mc. The principal cause of the interference is the steep waveforms associated with ignition systems. The ignition system also has some self-resonant circuits that can contribute high-level interference over narrow bands. The principal sources of interference are the ignition system, the generator, and voltage-regulator systems.

(1) Ignition System.—The events in the ignition cycle of the modern gasoline engine are as follows (see Figure 35-2):

(a) The breaker points PT_1 close, permitting an exponential current to flow from the battery through the ignition coil primary L_1.

(b) A magnetic field is built up, storing an amount of energy equal to one-half of the

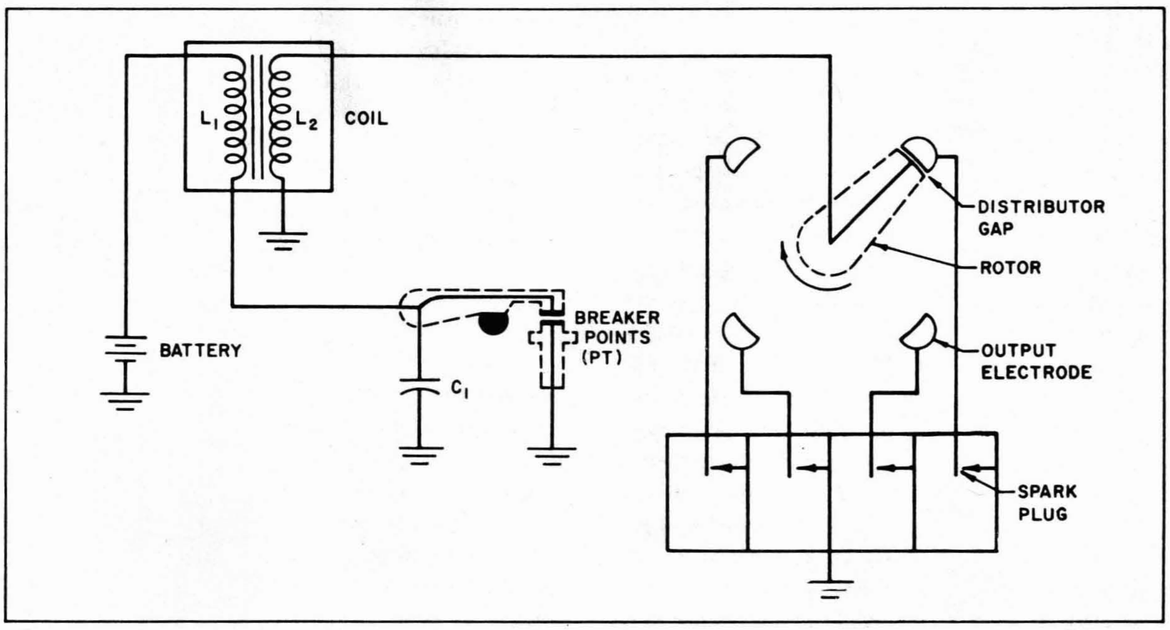


Figure 35-2.—*Typical Unsuppressed Ignition System.*

inductance L of the primary coil times the square of the current.

(c) The breaker points (PT) separate. The primary inductance (L_1) and the capacitor (C_1) form a series-resonant, high-Q circuit, dissipating all the energy stored in the coil through damped oscillations.

(d) Transformer action transfers the oscillation to the secondary coil (L_2), with an increase in voltage.

(e) As the secondary reaches a sufficiently large potential, the gap between the rotor and the cap breaks down, and the secondary voltage is impressed across the spark plug.

(f) After the voltage across the plug reaches a specific level, an arc occurs and there is a rapid change in all the voltage and current waveforms.

(2) Ignition-System-Interference Source Mechanisms.—As in the previous cases of arc breakdown, the ignition system generates both conducted and radiated interference. The four sources of this interference during the ignition cycle are located at the breaker points, the rotor gap, the spark plugs, and the ignition coil. After the ignition transient, the points open and the capacitor charges to the full battery potential. When the points are closed, the leads and the points have sufficient inductance to resonate with the capacitor at a frequency in the broadcast range. This type of radiation can be minimized by locating the capacitor and points within a grounded metal distributor casting. The peak current across the rotor gap, after the arc is formed, can be reduced by placing resistors on both sides of the gap. This will also reduce the rate of change of the voltage across the gap, and thus the radiated electromagnetic energy. The same type of arcing process takes place across the spark-plug gaps. A resistor of approximately 10,000 ohms in series with each spark plug will reduce the HF current. Resistor-type spark plugs are available which have such resistors built in. Some of the interference can be conducted back to the ignition switch and its complex of low-voltage wires. The most efficient method of reducing the interference signal is insertion of a feed-through capacitor or a aπ-type filter in the low-voltage line to the distributor. To complete the suppression of the ignition system, all components and wiring should be enclosed in a properly grounded shielding harness.

(3) Generators.—The generators used with automotive type engines are normally d-c machines. This type of device is discussed in CED 3502.4c(1). In less frequent usage are a-c generators with dry rectifiers. On the base of limited experience with such units, they produce relatively little interference.

(4) Voltage Regulators.—The voltage regulator is a form of electrical controller equipment. This type of equipment is discussed in CED 3502.4d. In addition to the corrective measures that are discussed, for best suppression, it is customary to shield the entire regulator system, including all wires leading to or from the regulator.

f. Welding Equipment Interference.—There are three general classes of electrical welders in use today. They are: arc welders, resistance or spot welders, and stabilized arc welders. Broad band interference is associated with all types. In addition, some narrow band interference is associated with r-f stabilized arc welders. The intensity of this type is generally much higher than that of the arc and resistance or spot welders. For this reason, the Federal Communications Commission (FCC) has authorized the use of unlimited power on specific industrial frequencies as described in CED 3512.1. The major problems, therefore, are the harmonic and spurious outputs.

(1) Arc Welders.—The arc generation process in electric arc welders can be classified as spark-, glow-, and arc-discharge. The spark-discharge uses high voltage (approximately 1000 volts) and low current, the glow-discharge a lower voltage (approximately 100 volts) with a somewhat higher current, and the arc-discharge the lowest voltage with a very high current. The spark-discharge is a good initiator of a glow-discharge which in turn can lead to an arc-discharge. This action can happen *only* if the external circuit can supply the necessary current: the interference energy available follows the

same progression, with the spark-discharge containing the smallest amount and the arc the largest. All three have current waveforms with exceedingly steep wavefronts, resulting in a very broad band of interference. A secondary source of interference is the acceleration of ionized particles within the arc itself. Unlike most other sources of arcs, these are sustained and can result in a broad band interference of long duration.

(2) *Resistance Welders.*—Resistance welding includes spot, projection, seam, and butt welding. All are similar in the principle of resistance power loss (I^2R loss) but differ in details of application. In most cases, the two pieces of metal are subjected to electrode pressure and an impulse of current is passed through the assembly. The voltage between the two electrodes is usually less than two volts with current values from 5000 amperes upward. This type of single-impulse welding is limited to sheets thinner than 1/8 inch—because of electrode heating. Thicker sheets are welded by using a number of spaced impulses. These impulses, which have an extremely high energy level, produce an exceptionally broad band signal extending well into the microwave region. When a number of impulses are used to weld the thicker sheets, a tone is produced in the victim receiver equal to the repetition rate of impulse application. This type of welder is used on a production line and hence may be the source of much of the interference in an industrial area.

(3) *RF Stabilized Welders.*—In the inert-gas, shielded-arc welding process, a HF wave is superimposed on the welding current. This HF energy performs two functions. First, it provides the high-voltage characteristic necessary for the creation of a spark discharge required to initiate the arc between the welding electrode and the base metal to be welded. Secondly, it is employed to stabilize a-c welders by providing a spark each half cycle when other ignition mechanisms do not function. From a welding point of view, the HF generator is very efficient; however, from the radio-interference point of view, it can provide undesired high-level signals. Recognizing this fact, the FCC has provided certain industrial, scientific and medical (ISM) frequencies upon which unlimited radiation is allowed. It has also provided certain rules limiting the maximum permissible level of spurious emissions. In order to comply with these rules, it is necessary to use filtered power supplies, bypassed power leads, and shielded leads and cabinets.

g. Industrial-Heating and Sealing Equipment Interference.—The two main classifications for this type equipment are induction and dielectric heaters. The equipment is used in many manufacturing applications, i.e., glue drying, plastic sealing, case hardening, heat treating, brazing, etc. In ideal operation, both type heaters radiate a carrier signal which, by proper design, can be confined to narrow-band limits. As in the case of arc welders, the FCC has allowed unlimited radiation on ISM frequencies. The major problem is the distortion of the output waveform. Any modulation of the output signal will increase the output band width and may cause the device to exceed the ISM band specified by the FCC. There is a second source of interference connected with the operation of this equipment—the transients resulting from the short-duration, on-off periods of operation. Since the equipment requires a moderate amount of power, a broad band interference signal can be produced. Further insight into this problem can be gained from CED 3502.4d.

(1) *Induction Heaters.*—The operation of these units is based on the heating of an object placed in an alternating electromagnetic field. With this type heater, the object is placed inside of the turns of the r-f tank coil and functions as the core material for the coil. It is also possible to place the object near the edge of a specially shaped coil. In either case, the coil must be at a location to which the work is accessible; this restricts the shielding possible. If any unit is to be operated on a frequency other than those in the ISM list, the unit *must* be located within a shielded enclosure.

(2) *Dielectric Heaters.*—The operation of these units is also based on the heating produced when an object is placed in an alternating electromagnetic field. In this case, the object is placed between the plates of a capacitor, and acts as a lossy dielectric. It is fairly easy to prevent excessive radiation in this type unit. First, the spacing between the plates can be reduced to confine the field. Secondly,

the lossy dielectric will be the preferred path for the electric field. When the equipment is operated on an ISM frequency, it must be well shielded and filtered to prevent excessive off-channel emissions. If any unit is not operated on an ISM frequency, it *must* be operated within a shielded enclosure.

h. Electro-Medical Equipment.—In recent years, the medical profession has acquired many new electrical aids in medical work. Some of the units necessitate large amounts of power, and their pulsating mode of operation can cause a large degree of conducted interference. Several of the new surgical and therapeutic units utilize the energy contained in an electromagnetic field. Particularly troublesome devices from the radio-interference standpoint are radiating units in the diathermy and electrosurgical category. All radiating units now come under the provisions of the rules of the FCC, Part 18. If the units are constructed and operated in accordance with these rules, they should not provide a source of interference to communication equipment.

(1) Diathermy Equipment.—The general name given to induction and dielectric heaters when used in therapy is diathermy. The therapeutic effects of the device result from the heat generated in the body tissues by the HF signal. Dielectric unit may be less prone to radiation than the induction type for these reasons noted in the section on industrial heaters. However, most units are a combination of both types. In order that the device meet the standards set up by the FCC, the oscillator must be very stable and the output cannot contain any off-frequency signals. To accomplish this result, most modern diathermy machines have a crystal-controlled or stabilized oscillator, a well-filtered power supply, by-passed power lines, and a well-shielded case.

(2) Electro-Surgical Apparatus.—Most devices in this area utilize a spark generated by an HF oscillator. The spark acts as a cauterizer at the surgical knife to keep blood flow to a minimum. The best cauterizing action occurs with a succession of damped-sine-wave pulses, generally produced by a spark gap. It is impossible to eliminate the sources of interference completely in this type device without complete shielding of the room in which the unit is being operated. However, it is possible to reduce this interference appreciably by filtering power leads and completely shielding the case and all leads. It would also be desirable if the cutting stylus and return electrode could be shielded, although normal operation will obviously not allow the cutting stylus to be covered.

i. Radio and Radar Transmitters as Sources of Interference.—In theory, a communication, navigation, or radar transmitter is required to radiate energy only over the band of frequencies necessary to convey the intelligence which it is processing. However, the practical transmitter may emit energy at a great number of spurious frequencies. These extraneous signals exist because of the general transmitter-system design employed. This system incorporates techniques involving the application of signals to nonlinear elements, resulting in an output which may contain the signal fundamentals and many harmonics and subharmonics of the signals. From the point of view of its contributions to the total environment, the transmitter represents a particular power spectrum, distributed over a geographical area during certain time periods. The major transmitter parameters affecting the environment are frequency, tunability, type of modulation (emission bandwidth), output power, stability, spurious emissions produced, and time on the air.

(1) Frequency.—The operating (carrier or fundamental) frequency determines the location of the transmitter's primary contribution to the frequency spectrum. A major cause of spectrum congestion is the fact that many systems, including some with dissimilar functions and characteristics, use the same frequency bands.

(2) Tunability.—This characteristic may be used to minimize spectrum congestion when it allows the operator (through the appropriate frequency coordination and control procedures) to select a clear channel in a dense area. However, many systems are forced to operate on a single frequency: conflicts are then inevitable. For example, many radars employ fixed-tuned magnetrons, and communication transmitters are frequently crystal controlled.

(3) Type of Modulation. — The type of modulation influences the emission bandwidth; wider

emissions require additional spectrum space. Narrow pulses with fast rise times normally produce broader emission spectra than do wide pulses. In the attempt to select the best modulation type for individual systems, much care is necessary to avoid increasing spectrum congestion.

(a) Communications Transmitters. — Frequency modulation (FM) requires more bandwidth than the commonly used double-side-band amplitude modulation (AM), which in turn uses more spectrum than single-sideband. Pulse coding, a sophisticated approach to modulation, may reduce the vulnerability to interference of the system using it, but it may also tend to cause interference in less sophisticated systems. Many coding processes require rather broad emission bandwidths. Codes may be in the form of pulse groups, tone groups, or frequency shifts such as pulse-to-pulse frequency shift. Each pulse or group of pulses may use a different r-f carrier or frequency shift within a single pulse.

(b) Radar Transmitters.—Radar transmitters are the primary sources of interference to other radar systems. This is largely due to the radiation at the fundamental frequency, and also because of the number of sidebands which are generated. An ideal rectangular modulator pulse which linearly amplitude-modulates an r-f oscillator will produce a symmetrical spectrum as shown in Fig. 35-3(A). The first zeros, or null points, of the spectrum are separated by an amount equal to twice the reciprocal of the modulator pulse width, while all other nulls are separated by half this amount. Figure 35-4 shows the energy contained in the various portions of this spectrum. Radar receivers are normally designed so that they only use the power contained in the main lobe. The other sidebands are not used and actually reduce the effective power of the radar. Moreover, these sidebands can cause an appreciable degree of interference to other equipment. As an example, note that the third side lobe on one side of the carrier contains 0.43 percent of the total radiated energy. Assuming a radar with a one-mega-watt peak power, this sideband contains approximately 4.3 kw. The sensitivity of a normal radar receiver is 10^{-13} watts; thus, the transmission path between the radar receiver tuned to this sideband and transmitter must provide at least 167 db of attenuation.

[1] Several other factors are present which can influence the amplitude and number of sidebands generated. The first is the shape of the modulator pulse. Rather than being an ideal rectangle, it is often trapezoidal in nature. This modifies the r-f output spectrum as shown in Fig. 35-3(B).

[2] A second important deviation from the ideal is the tendency of the average magnetron or klystron to shift frequencies during modulation. This periodic shift in frequency introduces frequency modulation into the r-f output spectrum. Figures 35-3(C) and (D) show the effects of the frequency modulation.

[3] In most cases, both effects are present, resulting in a spectrum similar to Figure 35-3(E). Recent studies have shown that the number of sidebands and their amplitudes can be reduced by using cosine-squared or other shape pulses.

[4] Since many modulator pulses are extremely short (two microseconds or less), their spectrums can extend well into the HF and even VHF regions (see Figure 35-4). Thus, they can provide a major source of interference to communications equipment operating in these bands and located within a few hundred yards of the radar. Primary sources of this type of interference are the modulator case, pulse cable, and other modulator power and control cables.

(4) Output Power.—As equipment output power increases, a wider emission bandwidth is normally produced. Significant amplitudes of sidebands, due to modulation information and to spurious emissions, are usually increased when higher power is used without taking specific precautions. Higher power thus denies a larger portion of the spectrum to other users. An example of wide emitter bandwidth is provided by Figure 35-5 which shows typical S-band beacon emission spectra. In addition, Figures 35-6 and 35-7 show typical magnetron outputs for L-band and X-band, respectively.

(5) Stability.—All transmitters drift, and, the higher the frequency, the more difficult it is to maintain stability. Crystal-controlled devices (ordinarily used below the microwave region) can maintain stabilities of the order of 0.01. percent or better.

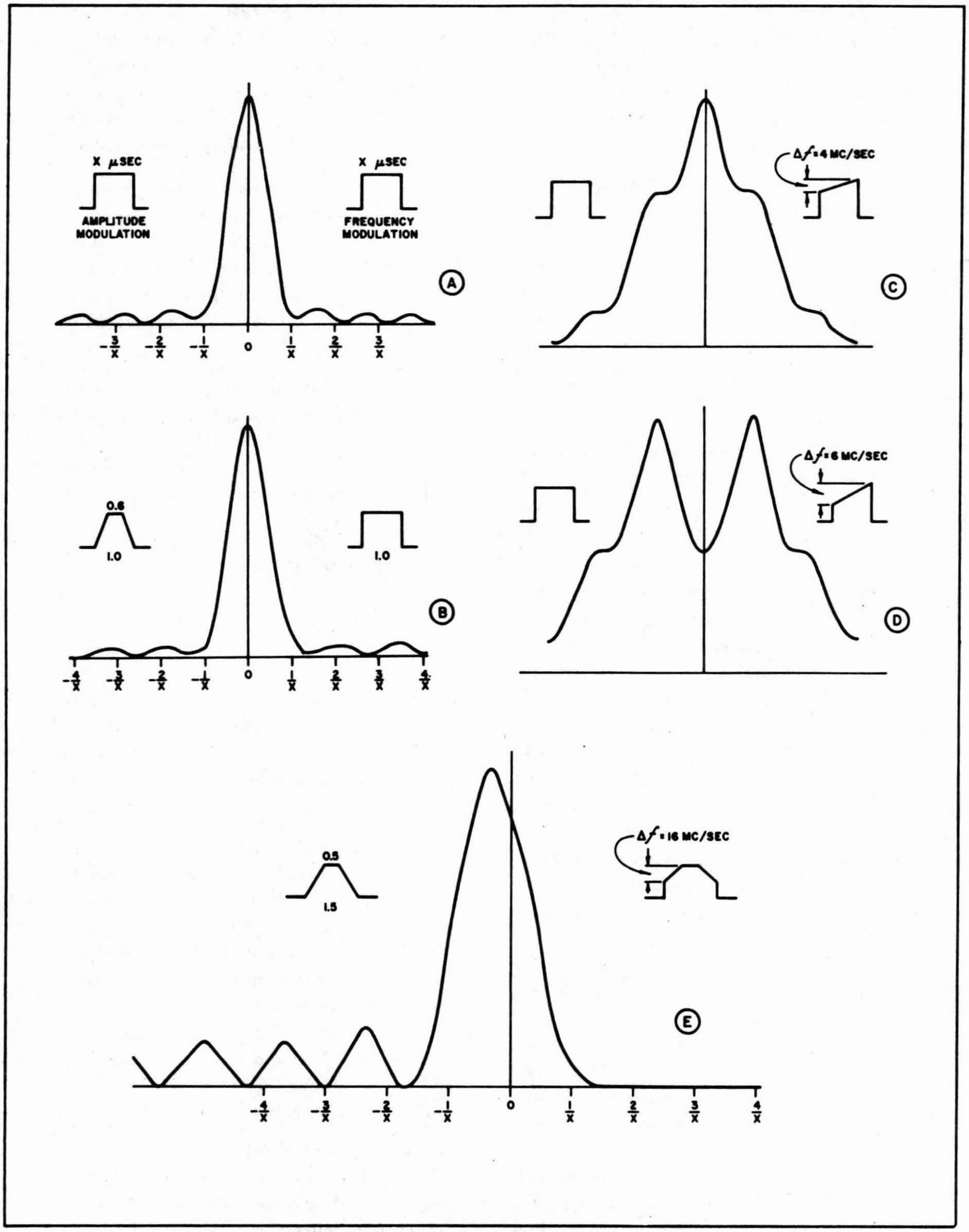


Figure 35-3.—*Representative Pulse Spectra.*

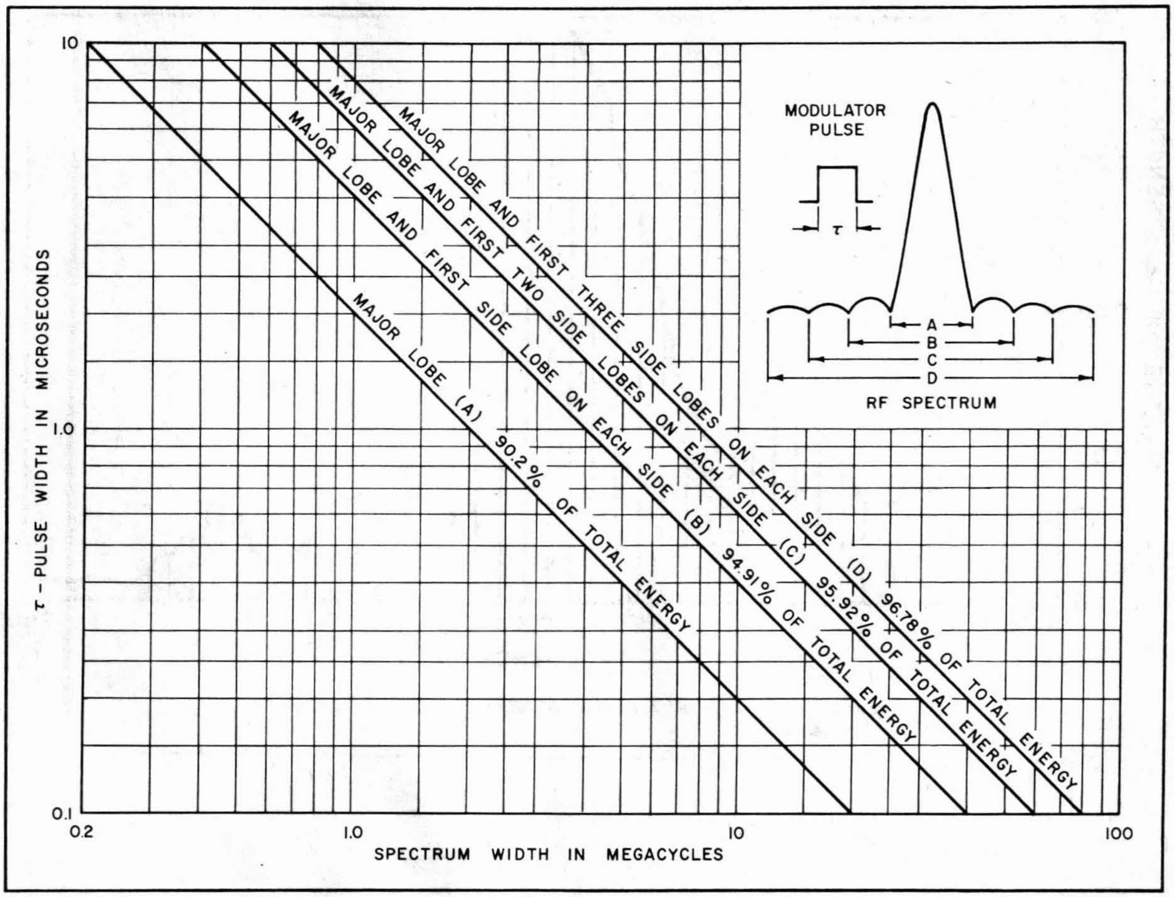


Figure 35-4.—*Pulse-Width to Spectrum-Width Conversion.*

Higher frequencies present more difficult control problems. For example, one type of magnetron can maintain its tuned frequency within 0.1 percent for short periods of time, but may drift considerably over longer periods and create a difficult frequency-assignment problem. The QK-338, an S-band magnetron used by the AN/FPS-6 height finder, may drift 40 to 50 mc during the course of its normal operating lifetime of one or two weeks.

(6) Spurious Emissions Produced. — As mentioned earlier, many techniques employed in r-f signal generation result in the generation of harmonics and subharmonics of the desired signal. In addition, circuit resonances can result in output signals unrelated to the system tuning.

(a) Communications Transmitters. — Overdriven linear amplifiers and class-C power amplifiers produce many harmonically related components. When good frequency stabilization is required (particularly in the HF band), a LF crystal oscillator is used, and its frequency is multiplied to obtain the desired output frequency. The multiplication of frequency requires a nonlinear device, allowing the generation of many undesired signals.

[1] Transmitter transients and sideband splatter may also be major causes of extraneous interference. Transients are associated with an abrupt change in waveform i.e., rapid variation, and cover a broad spectrum of frequencies. Sideband splatter is the radiation of a transmitter on adjacent channels

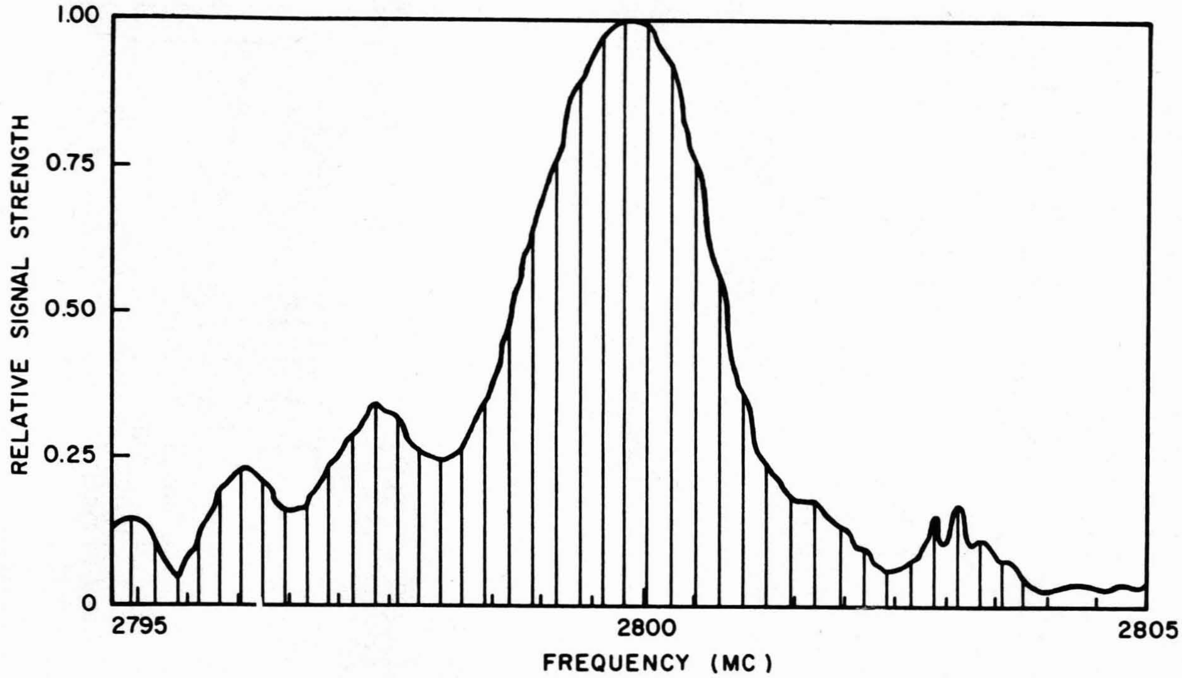


Figure 35-5.—*Typical Emission Spectra of S-Band Beacon.*

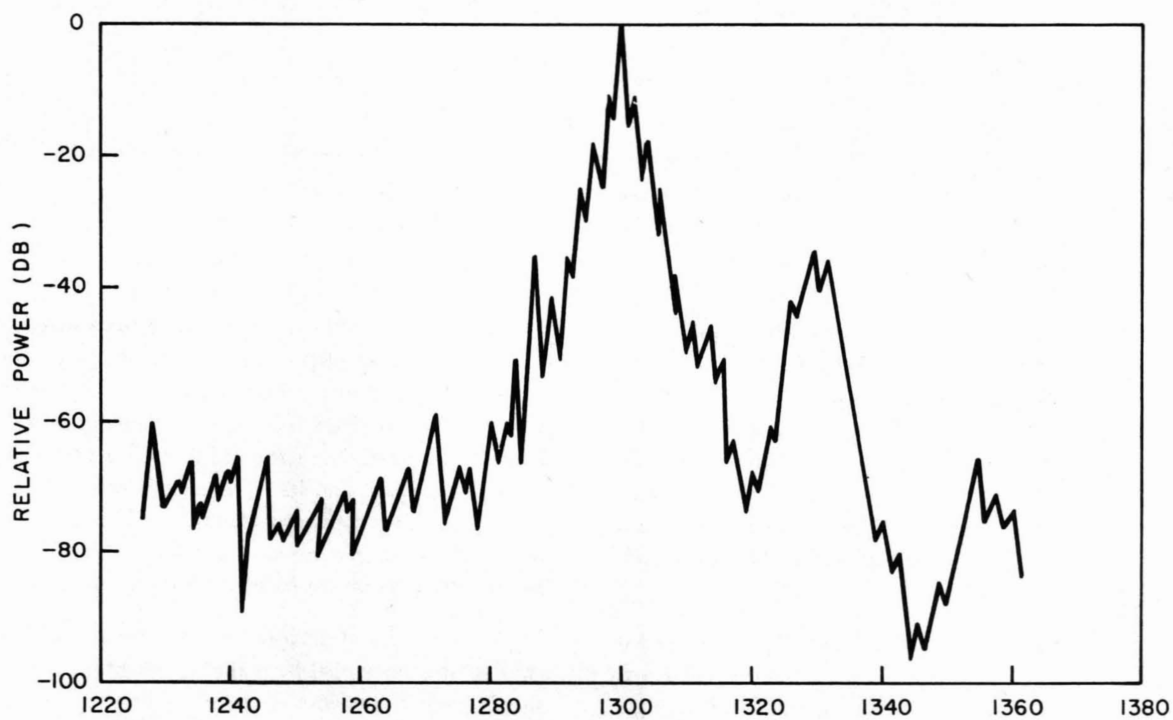


Figure 35-6.—*Typical Output of L-Band Magnetron.*

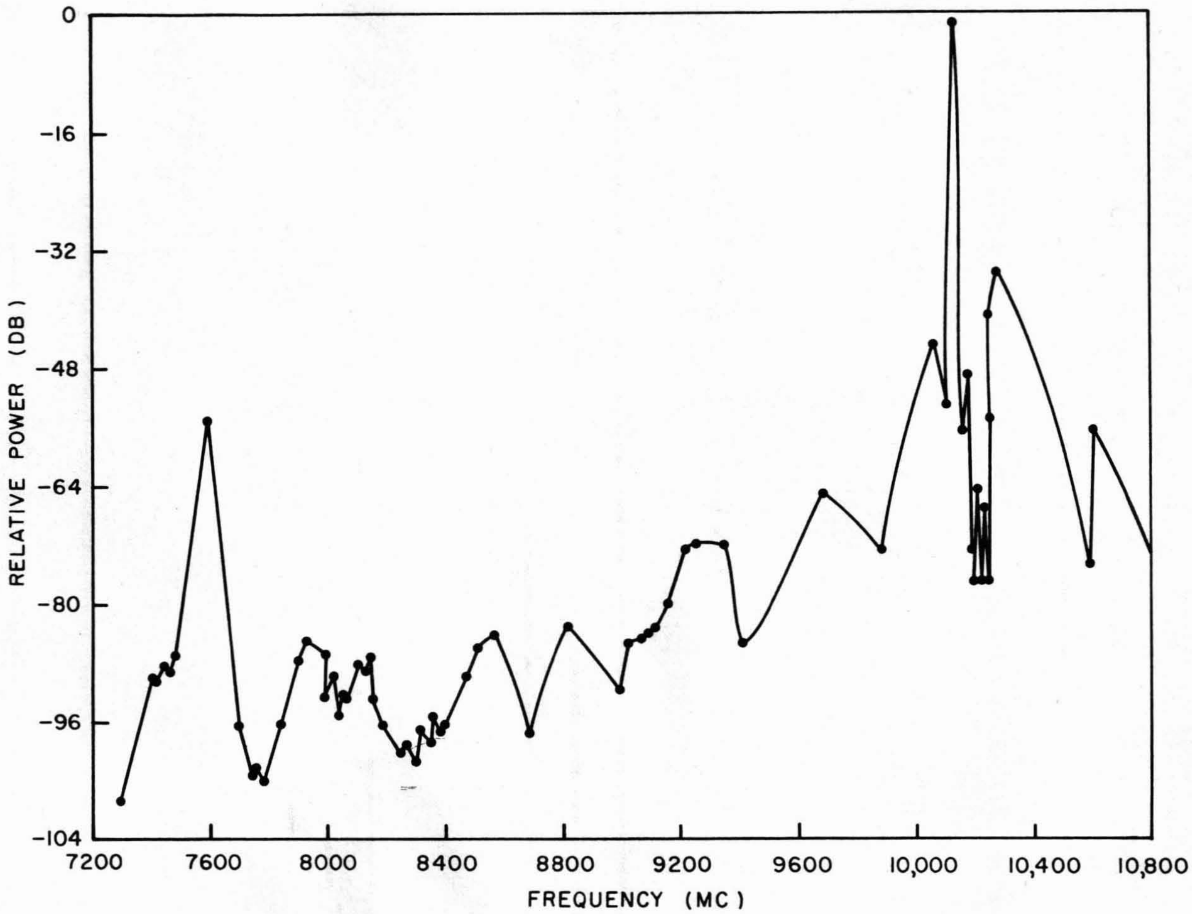


Figure 35-7.—*Typical Output of X-Band Magnetron.*

due to over-modulation, excessive modulator bandwidths, and modulator nonlinearities. Both AM and FM systems can produce the unwanted sidebands; however, AM transmitters are particularly serious offenders. The practical AM process allows distortions which, although very small, can cause considerable sideband splatter. If the distortions are small, the undesired sideband spectrums for the AM and singe-sideband (SSB) systems will be somewhat better than those for FM or PM. However, large distortions or overmodulation will result in a spectrum whose spurious sideband content is far greater for AM than for normal FM or PM. In present-day communications transmitters, special circuitry is often used to limit the modulation in AM or SSB and the deviation in FM. In cases where overmodulation is suspected, such limiting circuits should be investigated.

[2] Noise generated in the modulator tube may cause undesired sidebands. These undesired emanations, which are sometimes called "carrier noise," are generally 70 to 140 db below the carrier level, and can be picked up in nearby adjacent-channel receivers. Since the noise is random in nature, it will have a receiver audible indication similar to that of atmospheric noise. The noise sources, which often result from a noisy grid resistor, can be located by careful examination of the modulator circuits.

[3] Transmitter intermodulation and cross-modulation can also be causes for spurious emissions. These effects may occur when two transmitting antennas or their feed lines are located near each other. The energy from one transmitter is fed into the tank circuit of the second, and the signals

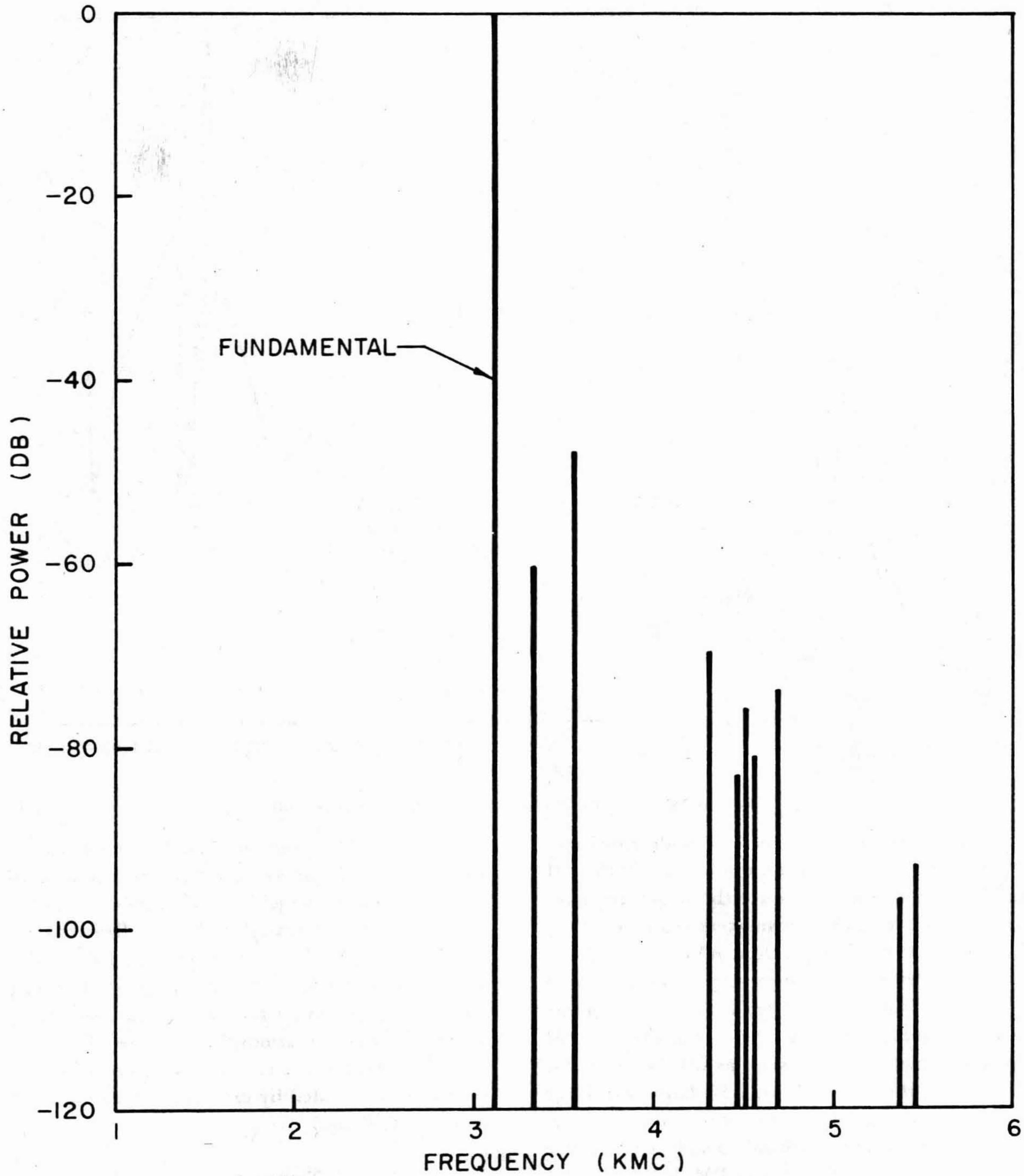


Figure 35-8.—*Typical Spurious Output of Radar.*

are mixed as a result of the nonlinearity of the final stage. If the cross-modulation products are near the resonant frequency of the tuned circuit, high energy levels may be radiated and can act as an interference source. The number of cross-modulation-product frequencies decrease as the magnitude of the interfering signal decreases and/or as the frequency spacing between the two transmitters increases.

Cross-modulation can easily be determined because the removal of an interfering signal also means the cross-modulation signal will disappear.

(b) Radar Transmitters. — Magnetron moding outputs may contain spurious components at frequencies adjacent to, as well as some distance from, the desired carrier. The significant moding components above the carrier often are not appreciably suppressed and can be detected at considerable distances (see Figure 35-8). Figures 35-5, 35-6, and 35-7 indicate that significant magnetron outputs are also observable below the carrier. However, waveguides generally reject most of the components below the lower sidebands. Representative harmonic outputs, the most common undesired transmitter output, are shown in Figure 35-9. Strong harmonic and spurious outputs from magnetrons or klystrons may be only 40 db below the fundamental signal level.

[1] If a radar emits 100-kw peak power with a 40-db antenna gain, a 50-db spurious rejection gives an effective radiated spurious power of 10 kw. These spurious contributions can interfere with close-in receiving systems operating from relatively low signal amplitudes and tuned to the spurious frequencies. Typical radar receivers provide about 70-db rejection to distant-channel signals (see Figure 35-20). Seventy db below 10 kw is 0 dbm, or 1 mw. Typical radar returns are much weaker than this figure—for example, −70 to −90 dbm.

(7) Time on the Air.—This transmitter parameter can be manipulated to minimize interference. If a transmitter is normally on the air for specific periods of time, it may be possible to coordinate its schedule with that of other intermittently-operating equipments. Also, the low duty cycles of many pulse transmitters might be synchronized to produce less interference.

j. Radio and Radar Receivers as Sources of Interference.—Radio and radar receivers also contribute to the active environment. Local oscillators can produce milliwatts of power that can affect nearby receivers if not adequately shielded. Normally, receivers with r-f preselection and adequate oscillator shielding are not offenders.

3503. PRINCIPLES OF ELECTRONIC INTERFERENCE —TRANSMISSION.

.1 Introduction.—The energy contained in an interference signal is transferred or coupled from

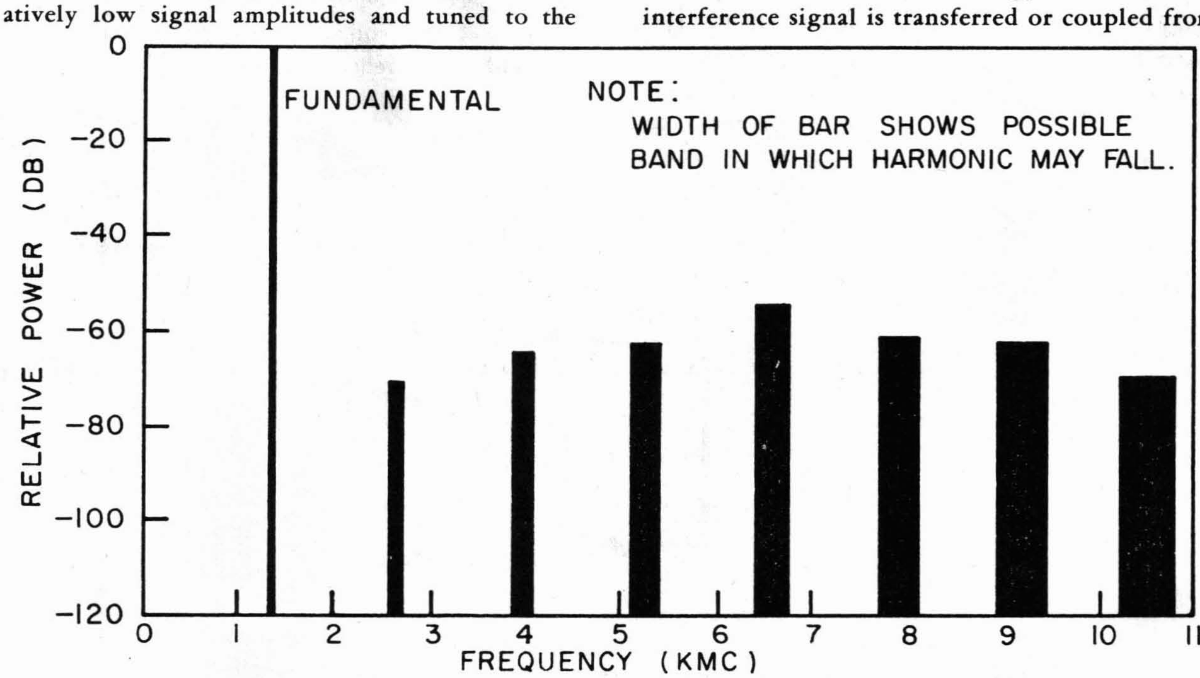


Figure 35-9.—*Typical Harmonic Output of Radar.*

point to point in a manner similar to that for desired signals. Two circuits are said to be coupled when the currents or voltages in one produce corresponding currents or voltages in the other. This transfer of energy can take place by free-space radiation, conduction, inductive or capacitive coupling, or by any combination of these methods.

.2 Conduction Routes. — Conduction is the coupling or transfer of undesired energy along a metallic conductor from an interference source to a susceptible receiver. It is necessary that two metallic conductors be present between the circuits before a conduction current may flow. Although conduction is thought of only in the sense of direct coupling, a conduction current *must exist* before any other type of coupling can exist. Thus, it is at the point where the interference is conducted that a filter might be used to reduce or eliminate the unwanted signal. In modern communications-electronics equipment, there are three predominant routes for conduction currents. They are power supply leads, control and accessory cables, and grounding systems.

a. Power Supply Leads.—A common example of conduction is the transmission of an interfering signal through power supply lines. The source of interference energy is usually the primary power source or a noisy instrument on the line. However, it may be a device which is coupled to the line by one of the other coupling methods. Figure 35-10 illustrates how an interfering signal may be transported from an interference source to a receiver if both are connected to the same power supply.

b. Control and Accessory Cables.—Control and accessory cables can also have the same effect as far as energy transmission is concerned. Figure 35-11 shows how interference energy can be conducted along a control cable into a radio transmitter. This situation is particularly bad when the line carries the intelligence signal used to modulate the transmitter. In this case, the extraneous signal will also modulate the transmitter, adding unwanted sidebands.

c. Grounding Systems. — Improperly grounded systems may also provide a path for conducted interference. A grounding system connects all metallic parts to an earth potential to ensure that all connected parts have the same potential. There are two major grounding circuits.

(1) The first, called the single ground circuit, provides a path to a single ground point. Figure 35-12(A) illustrates how each circuit or chassis is provided with a short jumper or strap which is connected to a common point, and then a single line connects the equipment to earth ground. Only a single earth ground path is provided and no ground-loop currents can flow.

(2) However, if additional ground paths are provided as shown in Figure 35-12(B), ground-loop currents may flow. The second major grounding

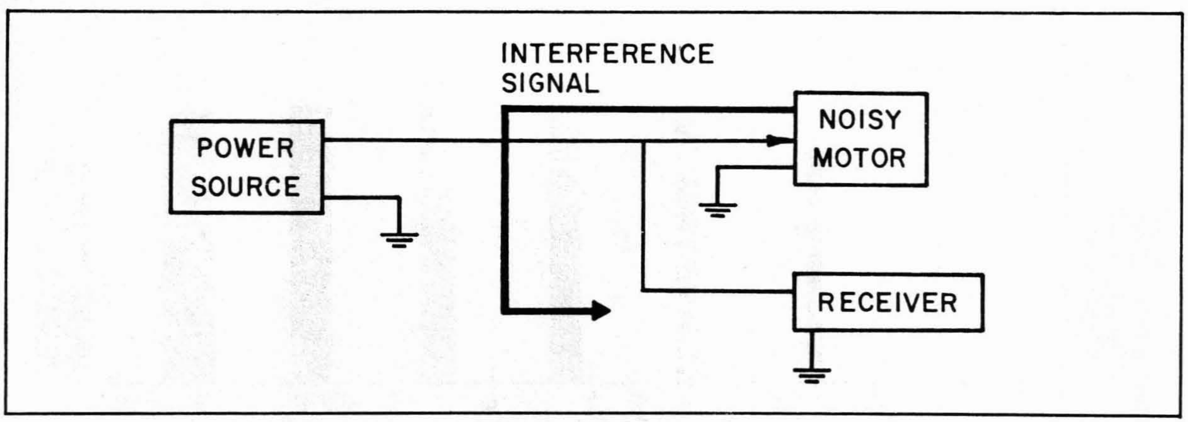


Figure 35-10.—*Interference Conduction Along Power Leads.*

method is called the multiple ground circuit. Multi-ground circuits as shown in Figure 35-12(C) provide separate ground returns. However, if electrical contact is established between the chassis as shown in Figure 35-12(D), ground-loop currents may flow. For application techniques relative to particular grounding problems, refer to CED 3505.5.

.3 Inductive Coupling; Low-Impedance Circuits.—Inductive coupling occurs when a conductor is present in an electromagnetic field set up by interference energy in a nearby conductor. It is important to note that mutual inductance exists only between two complete circuits, each a complete loop. However, the return portion of the loop of

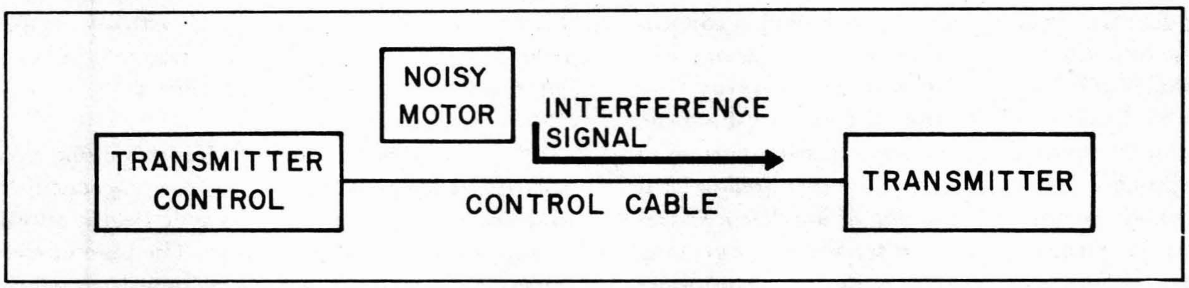


Figure 35-11.—*Interference Conduction Along a Control Cable.*

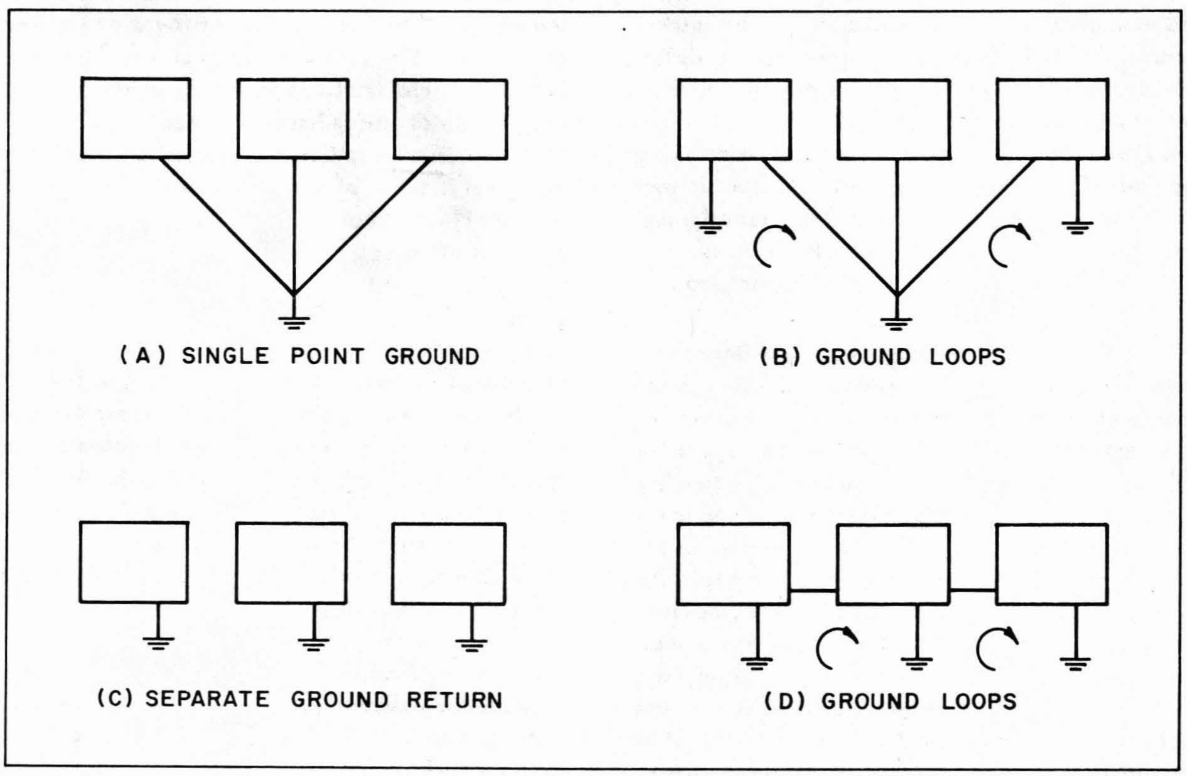


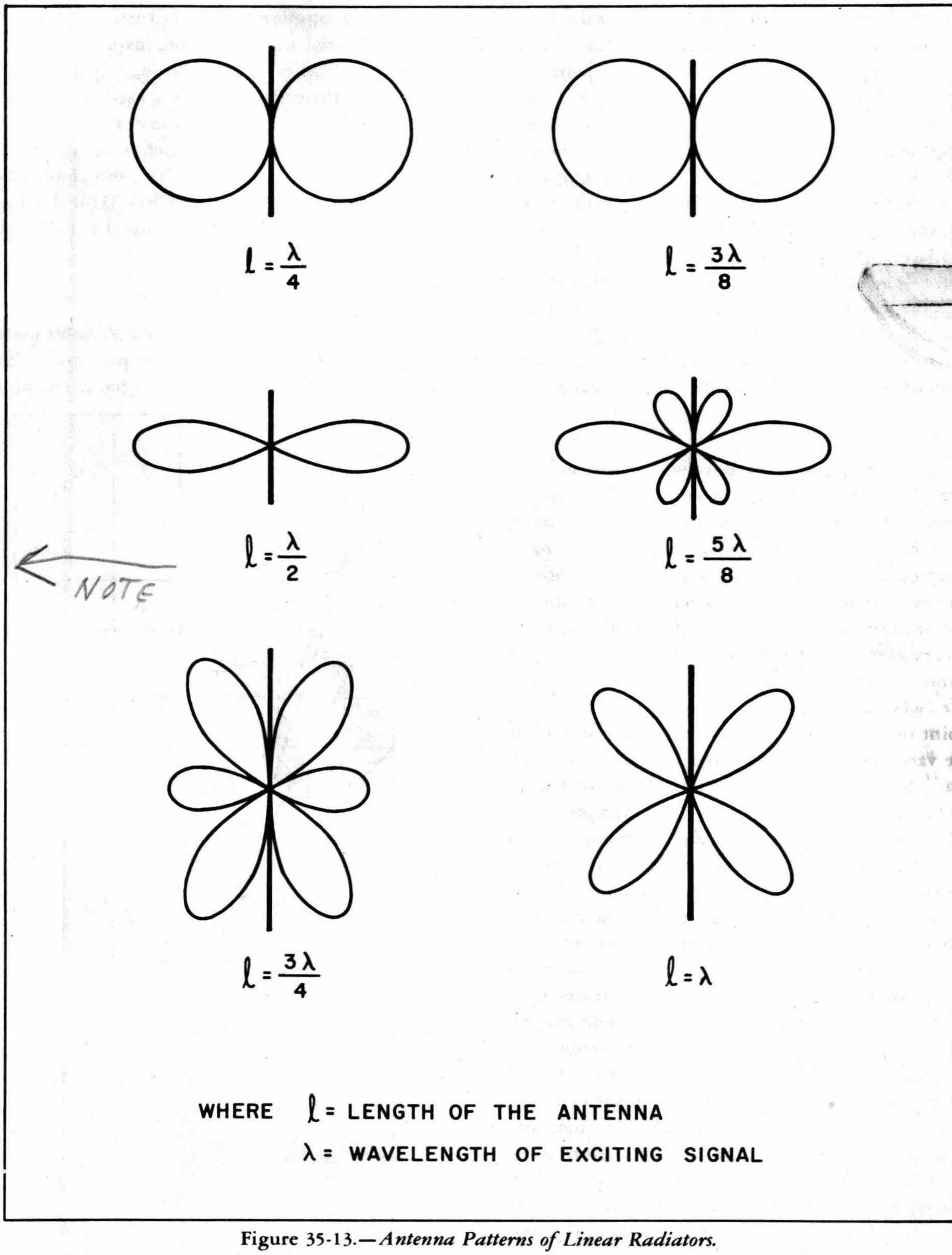
Figure 35-12.—*Grounding Circuits.*

the circuit may be far removed from the inductive field and, in such a case, it is common practice to speak of the voltage induced into a wire. Analysis of the mutual inductance between two circuits shows that it varies in a complicated fashion dependent upon the geometrical configuration of the circuits, although; when the separation distances involved become large, the mutual inductance falls off inversely as the square of that distance. At smaller distances, mutual inductive coupling is comparable to ordinary transformer action. A varying current in one loop of wire sets up a varying field around that loop. In turn, the varying field can induce a varying voltage and resulting current in a second loop of wire. There are two predominant methods of inductive coupling of interference to receivers, through transformers and through long parallel lines. Because of core losses, a transformer normally will pass LF a-c signals and act as a low-performance filter against HF interference. The parallel-line arrangement represents a special case of a transformer consisting of single turn primary and secondary windings. When two such lines are feeding different pieces of equipment from different sources, interference voltages present in either line can be induced into the other line. This situation allows the interference to be distributed along the entire line and thus affect any susceptible part of a system, receiver, or circuit. For example, primary power leads located near a B+ lead may induce a-c hum into the receiver via the d-c circuit.

.4 Capacitive Coupling; High-Impedance Circuits. — Capacitive or electrostatic coupling is the linking of one circuit with another by means of the capacitance existing between them. The degree of coupling depends on the voltage and the frequency of the interference as well as the value of the interconnecting capacitance. At low frequencies, an extremely large capacitor is required to couple the noise; at radio frequencies, only a small capacitance is required. Again, it should be noted that a complete path is necessary for this type of coupling and it is normally the common ground connection for both leads which provides the return path. Multiconductor cables act as especially good capacitive couplers at radio frequencies. If radio interference is present on a single lead of a multiconductor cable, the interference may appear on all conductors of the cable. Stray capacitances at the input circuit of a high-impedance, high-gain amplifier can introduce interference into the system.

.5 Radiation.—The term, radiated interference, is commonly used to mean any interfering signal transferred through a medium by an electromagnetic field. Technically speaking, however, the *radiation field* represents the energy which actually escapes from a source and spreads out in free space according to the laws of wave propagation.

a. The Radiation Field.—A varying electric field is always accompanied by a magnetic field and, conversely, a varying magnetic field is always accompanied by an electric field. The ratio of electric-to-magnetic fields is the wave impedance which, for the radiation field, is equal to the impedance of the medium in which the wave propagates. The impedance of space is approximately 377 ohms. In the radiation field, the electric-or magnetic-field intensity is an inverse function of the distance from the source. The field intensity at any point in a radiation field is also a function of the size and orientation of the radiator. In order for any body to be an efficient radiator, its electrical dimensions must be at least of the order of one-half wavelength. Thus, although some sources have copious amounts of energy within the low frequency spectrum, little of it may be radiated because of short, ineffective antenna lengths. (However, it must also be remembered that the extremely high sensitivities of modern receivers allow weak radiation fields to exhibit interference effects in the receiver).The radiation pattern is a useful way of comparing the spatial energy distribution of radiating bodies. Vectors are plotted radially from a point representing the source, with the length of each vector being proportional to the field strength at a fixed distance from the antenna in the direction indicated by the vector. The curve connecting the ends of these vectors has been called the radiation pattern. Let us examine the radiation pattern of a dipole antenna of varying length while the frequency of the radiating source is held constant (see Figure 35-13). Several important observations can be made from the patterns: increasing the antenna length up to $\ell = 5\lambda/8$



NOTE

Figure 35-13.—*Antenna Patterns of Linear Radiators.*

tends to increase the directivity and the gain of the antenna; for lengths greater than 5 $\lambda/8$, the normal gain decreases and the major lobe of the pattern is directed at some angle to this normal; the radiation patterns for lengths $\ell = \lambda/2$ or less contain no side lobes; and for lengths greater than 5, ℓ $\lambda/8$, the major lobe (that one having the largest gain) approaches a direction along the antenna. The problem of determining the radiated interference at some point in space is not so simple as this representation because—the radiator is usually not a well-defined structure, and—the interference signal is seldom a sine wave. Of course, the first is a far greater restriction: any arbitrary periodic waveform can be reduced to the sum of a number of sine waves.

b. Distinction Between Induction and Radiation Fields.—Except in very simple cases, the mathematical description of the total fields around a conductor carrying a varying current is very complicated and cannot be solved. It can be shown, however, that the fields at a remote point due to the uniform current flow in a short, thin wire (or a very small, circular loop) have three types of terms. There are terms that vary as $1/r^3$, $1/r^2$, and $1/r$ (where r is the distance from the source to the point of observation). The relative importance of the various terms depends upon the ratio of r to the wave length of the radiation as shown in Figure 35-14. In order to clarify these field concepts physically, let us introduce three fundamental quantities of length. They are: A—the radius of the smallest sphere that can enclose all of the source; r—the distance to the point of observation from the center of the source, and λ—the wave length of the radiation. Now, let us consider the field where r is much larger than A. When r/λ is much greater than $1/2\pi$, the radiation $(1/r)$ field is predominant. When r/λ is equal to $1/2\pi$, the induction components $(1/r^2, 1/r^3)$ and the radiation $(1/r)$ field are equal. When r/λ is much smaller than $1/2\pi$, the radiation $(1/r)$ term is negligible. In summary, it must be remembered that the separation of the total field into induction and radiation fields is an analytical process and the physical measurement of these fields will always yield a measure of the total field.

.6 Propagation Effects. — Interference radiation, like desired signal radiation, involves the transmission of electrical signals through space. As the space above the earth's surface is used as the transmission medium, the propagation characteristics are effected by the phenomena which occur in this region. The topic of propagation has been amply covered in other references (see CED 3514.-Bibliography) therefore, only a few general conclusions are presented in this manual.

a. Frequency Bands and Variables.—In the LF and VLF bands, wave propagation takes place via ground waves—electromagnetic radiation

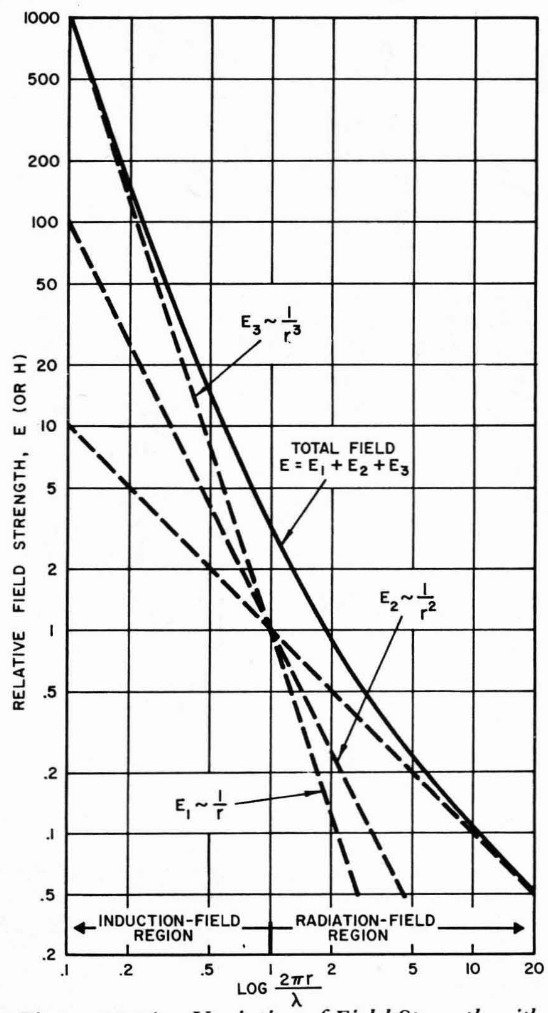


Figure 35-14.—*Variation of Field Strength with Distance for Small Dipole Antenna.*

propagated along the earth's surface. At these frequencies, the ionosphere absorbs rather than reflects any radiation, while ground wave paths may be used over long distances. The MF band is transitional in nature, with ground-wave capabilities at the lower end and some skywaves (waves reflected from the ionosphere) at the other. In the HF band, propagation may be either by ground or sky waves, depending upon the equipments, physical configuration, frequency, and ionospheric conditions. In this band, ground-wave propagation proves the most reliable, but the distance coverage is limited to approximately 100 miles. On the other hand, sky-wave propagation has an unlimited range, depending upon the parameters outlined above as frequencies increase above 30 mc, the energy reflected from the ionosphere decreases and eventually disappears. Thus, in the VHF, UHF, SHF, and EHF bands, transmission depends mainly upon free-space propagation. Propagation beyond the horizon is possible in the VHF and UHF bands from atmospheric scattering. Propagation, particularly sky wave propagation, is a complex subject concerned with many variables. These include (1) the focusing effect of the ionospheric layers, (2) fading due to multipath propagation, (3) polarization fading, (4) loss of energy due to ground and ionospheric absorption, and (5) losses due to dust, water, gasses, and the dielectric of the media.

b. The Free-Space Propagation Equation. —The free space propagation equation is a mathematical relationship between the power transmitted and the power received. It can be expressed as follows:

$$P_r = \frac{P_t G_t G_r \lambda^2,}{(4\pi r)^2} \qquad (4)$$

Where:

P_t = power at the transmitter's antenna terminals,

G_t = gain (over an isotropic antenna) of the transmitter's antenna at the transmitting frequency in the direction of the receiver,

G_r = gain (over an isotropic antenna) of the receiving antenna at the transmitted frequency in the direction of the transmitter,

λ = the wave length of the transmitted signal,

r = the distance between the two antennas.

The graph shown in Figure 35-15 is a plot of this equation which has been normalized to a range of 100 feet and a frequency of 1 kilomegacycle. Correction factors for range and/or frequency are given in the lower right-hand corner. As an example of the use of this graph, assume the following information has been obtained from an equipment manual:

P_t = 100 watts, G_t = 6 db, G_r = 4 db, f = 300 mc. Assume that the distance between antennas has been measured and is 100,000 feet.

$$P_t\,(\text{dbm}) = 10 \log\left[\frac{P_t\ (\text{in watts})}{10^{-3}\ \text{watts}}\right] = 10 \log\left(\frac{10^2}{10^{-3}}\right)$$

$$= 10 \log\,(10^5) = 50\ \text{dbm}. \qquad (5)$$

$$G_a = G_t + G_r = 6 + 4 = 10\ \text{db}. \qquad (6)$$

By use of the graph, the uncorrected power at the receiver input is found to be −2 dbm. From the plot of correction factors it is found that the correction factor for frequency is +10 db, and for range is −60 db. Therefore, the corrected power at the receiver input is: $P_{rc} = -2 + 10 - 60 = -52$ dbm. The receiver can now be checked for the effect of this input signal by the methods outlined in 3504. The equation above is an approximation that does not include any mismatch or transmission-line losses. For further information on these topics, refer to CED 3509.

3504. PRINCIPLES OF ELECTRONIC INTERFERENCE —RECEPTION.

.1 Paths of Signal Entry.—When interference is not suppressed at the source and is transmitted to the vicinity of a receiver, it can effect the operation of the receiver only if it finds a suitable path of entry. The four basic paths through which a signal can enter a receiver are: the antenna system; the power and control leads; the output leads; and through case penetration.

a. The Antenna.—Since a large portion of the interference energy is transmitted by radiated electric and magnetic fields, the antenna is by far the most susceptible interference path to the receiving system. In addition, antenna-conducted signals are applied to the most sensitive part of the receiver. The sensitivity and directional qualities of the antenna are a function of its effective length or aperture, and the frequency of the interference signal. Advantageous use can often be made of these factors to increase the effective transmission-path loss. The antenna lead-in must also be considered as a path for interference entry. As shown in Figure 35-16, this consideration is especially important if a long lead-in is run close to an interference source with an inductive field.

b. Power and Control Leads.—As was noted in CED 3503.2, the power and control leads can provide a path of interference entry to the receiver (see Figures 35-10 and 35-11). The power lines are a particularly important source of interference because of the possibility of direct connection to many interference sources. Although control lines normally do not have such a direct connection, they can be inductively or capacitively coupled to interfering sources. This effect is intensified if the control line is long, if it is a high-impedance line, or if it carries a low-level signal.

c. Output Leads.—Output leads are usually required for transporting an output signal to a remote meter or actuator. They can also provide transmission paths for the interference signal. In Figure 35-17, the interference signal has entered an output cable, and can either produce a false actuating pulse in the remote unit, or can enter the receiver and possibly effect its performance.

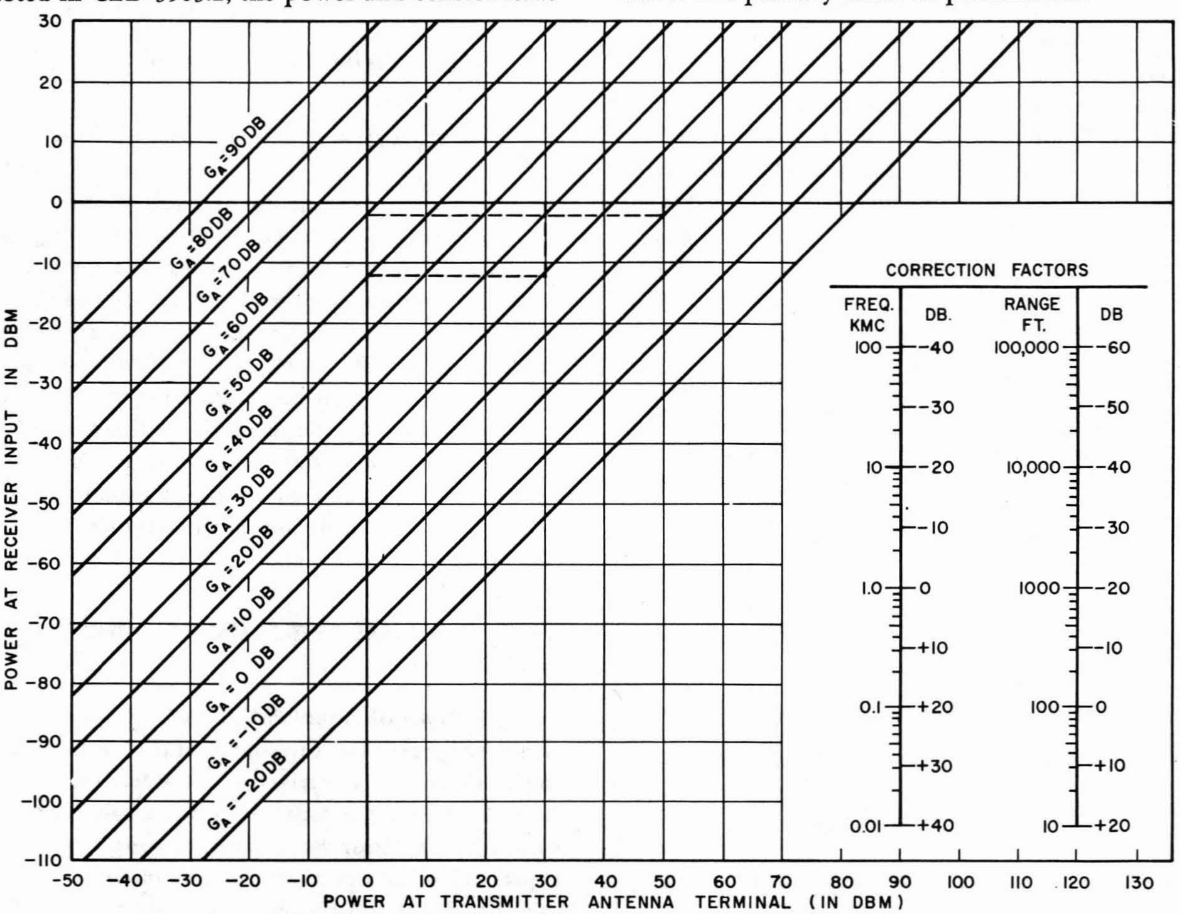


Figure 35-15.—*Aid to Calculation of Free-Space Propagation.*

d. Case Penetration.—In some instances, the attenuation of a signal when passing directly through a case may be far less than that for spurious-frequency antenna-conducted signals. In assessing the ability of an interfering signal to penetrate an equipment enclosure, it is important to know the magnitude of the interference electric field relative to that of the magnetic field. As was noted above, the impedance of the interfering signal is the ratio of the electric to magnetic field strengths of the wave. A high impedance means large electric and small magnetic fields; on the other hand, a low impedance means small electric and large magnetic fields. High-impedance fields are normally generated by small conductors which are short compared to a wave length, and low-impedance fields are generated by small loop currents or loop antennas. The shielding effectiveness of common case materials is not the same for both low- and high-impedance fields. It is usually very low for magnetic fields, therefore, most receivers are very susceptible to low-impedance fields. An additional problem is presented by the joints and/or holes in the case. These holes can provide an excellent means of entry for an undesired signal, particularly of the higher frequencies. In general, the maximum dimension of the hole must be limited to a very small fraction of the interference wavelength in order not to violate the shield. If larger holes are necessary, they should either be covered with a metal screening material, or be constructed as a waveguide beyond cutoff. Further information on shielding techniques is available in CED 3505.4.

.2 Receiver Characteristics Relevant to Interference.—A receiver accepts certain forms of electromagnetic energy and rejects others. However, a receiver is not a simple sorter of energy types. For

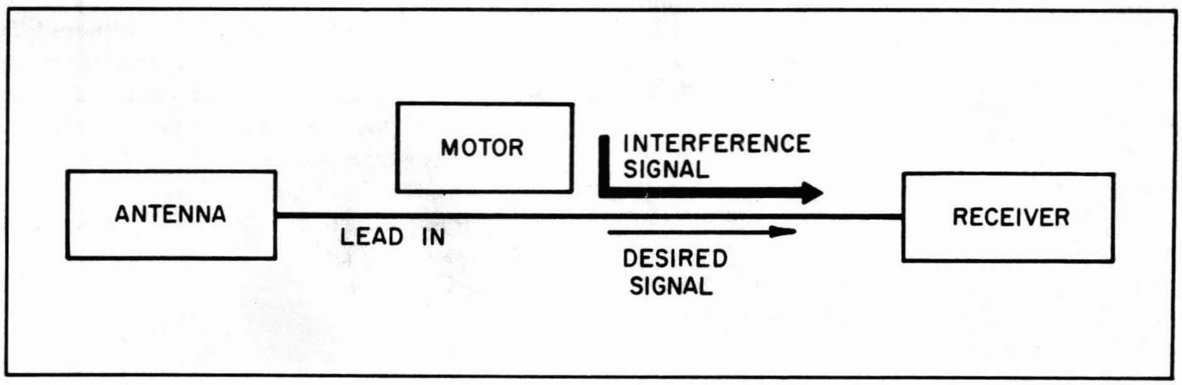


Figure 35-16.—*Interference Coupled to Antenna Lead-In.*

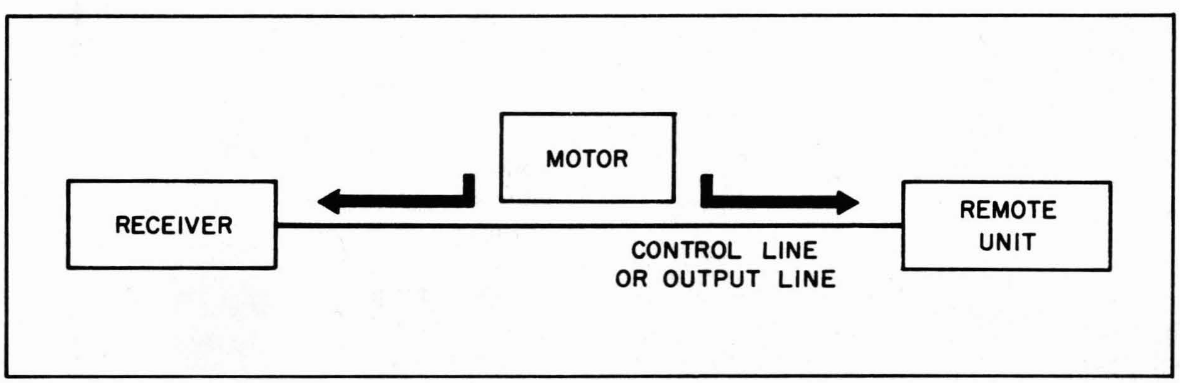


Figure 35-17.—*Interference Coupled to Control or Output Leads.*

example, if A is a desired signal and B and C are undesired signals, the receiver may reject B only if A and B are present, or C if only A and C are present, but may experience serious interference if A, B, and C are present simultaneously. In receivers, major factors relevant to interference include sensitivity, selectivity, undesired responses, desensitization, and similar characteristics. Many of these factors are treated in considerable detail in numerous publications on radio and radar receivers; therefore, they are discussed briefly in this manual. The considerations that are peculiar to the radio-interference field are emphasized.

a. Sensitivity.—The sensitivity of a receiver is a measure of its ability to receive low-level signals. The sensitivity is defined as the input signal level that must be supplied to the receiver to establish a reference output ratio of signal to noise. In most receivers, this level is determined by the noise generated in the input stage.

(1) Noise Figure. — By definition, the noise figure of a receiver is the ratio of the total noise power output of the receiver compared to the noise power output that would be present if the receiver were theoretically perfect, i.e., did not generate noise. Noise figure is expressed as a power ratio or, more commonly, in decibels. The "noiseless" receiver, if it were to exist, would have a noise figure of one, or 0 db,

(a) Below 30 Mc.—The noise figure of a receiver varies with the particular receiver design. Below about 30 mc, noise figures of the order of 2 (3 db) can be achieved by employing tuned r-f amplification between the input terminals of the receiver and the mixer. The best noise figure is obtained when the tuned r-f amplifier employs triode tubes in either a neutralized, grounded-grid or cascode circuit. Pentode amplifiers result in a somewhat increased noise figure.

(b) 30 Mc to 1000 Mc.—In the frequency range 30 to 1000 mc, a low noise figure can still be realized by the use of tuned radio-frequency amplification, but only with increasing difficulty. At these frequencies, induced grid noise becomes a factor. This type of noise increases with frequency and, at the same time, the amplification per stage that can be realized drops because of the lower tube input conductance at the higher frequencies. A low noise figure can be achieved in this frequency range by the use of a low noise mixer, combined with tuned r-f amplification employing tubes having low transit time. Even then, the noise figure gradually becomes larger as the frequency increases until, at about 1000 mc, the best vacuum-tube amplifier available will introduce about as much additional noise as does a crystal mixer. Best results are then obtained by omitting the amplifier.

(c) Above 1000 Mc.—The best noise figure obtainable in microwave receivers using crystal mixers is in the order of 10 (10 db) at 3000 mc, with noise figures of 100 (20 db) frequently encountered. These noise figures cannot be improved by use of a Klystron r-f amplifier, since such amplifiers are fairly noisy.

(d) Input Impedance.—Although the ideal receiver has the best noise figure when the receiver terminals present an open circuit to the antenna system, this is not true when input tube and mixer noises are present in the receiver. Under these conditions, the best figure will be obtained when the input impedance of the receiver is intermediate between an open circuit and an impedance match with the antenna system.

(2) Determination of Noise Figure of Vacuum Tubes.—The method for determination of the noise figure of circuits employing vacuum tubes given in this manual is basically that advanced by Metelman. (See CED 3514.51).

(a) Theoretical Background.

[1] First, consider equivalent noise conductance. An electron needs time to travel from cathode to grid and from grid to plate. An electron leaving the cathode sees an accelerating field. It will move toward the grid but, before reaching it, the voltage on the grid may change. When the voltage goes negative, the electron will be decelerated. "Stopping" the previously-accelerated electron effectively induces voltage on the grid tending to charge the grid opposite to its sense of changing.

The electron flow acts against the controlling grid voltage. This damping effect introduces a noise voltage on the grid due to the randomness of the electron flow. The magnitude of this effect varies directly with the frequency squared, and is usually described in terms of the transit time conductance G_t. G_t can be calculated from the geometry of the tube; however, it must be multiplied by a temperature factor B when it is used in the noise equations. The value of the factor B has been given as 5 for oxide cathodes. The equivalent noise conductance G_n is identified as being equal to BG_t.

(2) A second source of noise is the equivalent noise resistance referred to the grid, R_{eq}. This part of the noise originates in the plate, and one can visualize this noise by thinking of the single electrons hitting the plate like raindrops hit a roof. The random nature of this action produces continuous noise. This noise may be referred to the grid circuit by assuming an equivalent noise voltage at the grid, represented by the random thermal noise of a resistor as expressed by

$$e^2 = 4kTBR \qquad (7)$$

The factor 4kTB includes temperature and noise bandwidth considerations. With this expression, the noise on the plate can be considered equivalent to that generated by a resistor in the grid.

(b) Calculations.—Knowing these two noise parameters, the lowest possible noise figure for every frequency can be calculated; also, the source impedance at which this occurs. The formula used to calculate the optimum source impedance ($R_{s\ opt}$) and minimum noise figure ($F_{1\ min}$) are:

$$R_{s\ opt} = \frac{f_o}{f}\sqrt{\frac{R_{eq}}{G_n}}, \qquad (8)$$

$$\bar{F}_{1min} = 1 + 2\ \frac{f}{f_o}\ \sqrt{R_{eq}\,G_n}. \qquad (9)$$

The value of f_o is the frequency (mc) at which G_n has been determined, and f the frequency (mc) at which the values of $R_{s\ opt}$ and $F_{1\ min}$ are to be determined.

(c) Typical Values. — Figure 35-18 shows the predicted noise figure and the optimum source impedance of a number of UHF tube types, as determined on small samples of commercially available tubes. Values of R_{eq} and G_n for a number of tube types are shown in Figure 35-19(A) as measured under published typical operating conditions; and, in Figure 35-19(B), using a 68-ohm cathode resistance with the plate voltage adjusted for a plate current of 15 ma in each case. Production differences may result in changes in these noise parameters.

b. Selectivity.—Selectivity refers to the ability of the receiver to ignore signals at some frequencies while accepting signals at other frequencies. Conventional selectivity curves describe receiver response to a single signal as it is varied in frequency about the tuned frequency. Additional selectivity curves may be required to describe the response of a receiver to interfering signals.

(1) Conventional Selectivity. — Consider the means for obtaining a conventional selectivity curve. A carrier signal is applied to the input of a receiver, and the signal frequency and amplitude are slowly varied in a manner to maintain constant the resulting receiver output. The graphical representation of amplitude versus frequency of the input

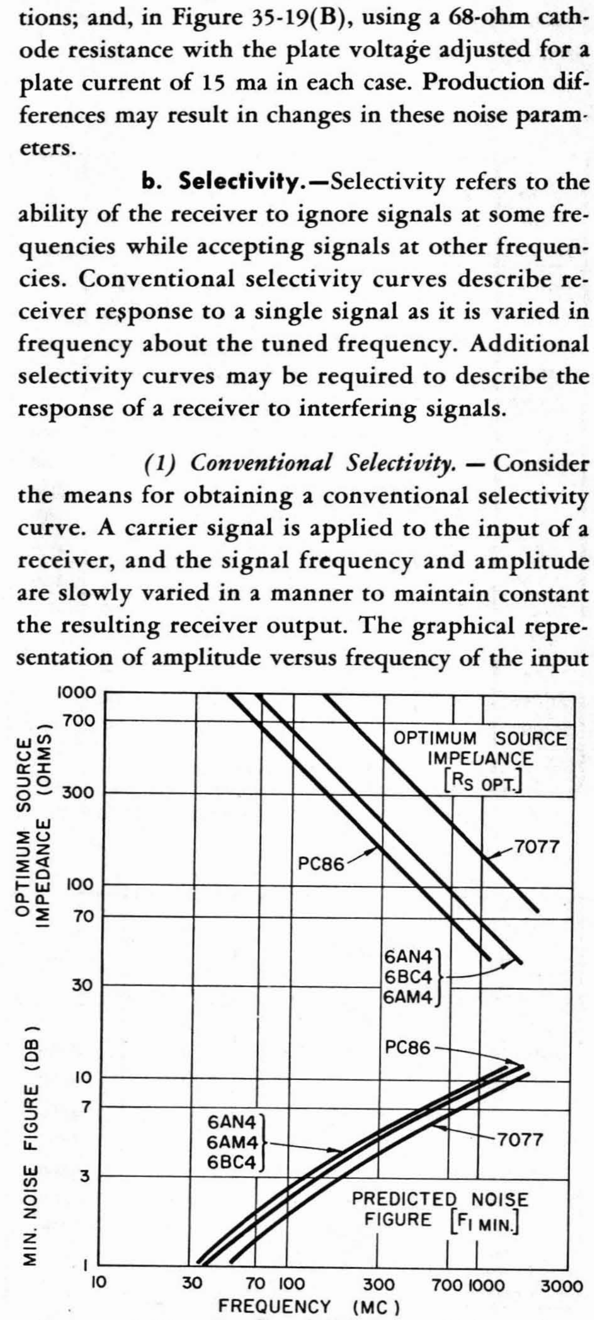


Figure 35-18.—*Predicted Minimum Noise and Optimum Source Impedance for Several Tubes.*

signal can be considered as the receiver selectivity curve. The most obvious property of such a curve is its indication of how much stronger an off-frequency carrier signal must be than an on-frequency carrier signal to provide the same receiver output level. Such a curve depends only on the receiver selectivity.

Tube Type	R_{eq} ohms	G_a μmhos	E_b volts	R_k ohms	G_m μmhos	I_b ma.
6AM4	260	600	200	100	9,800	10.0
6AN4	250	550	200	100	10,000	13.0
6BC4	260	540	150	100	10,000	14.5
6BC8	600	320	150	220	6,200	10.0
6BK7A	240	520	150	54	9,500	18.0
6BN4	420	390	150	220	6,930	9.0
6BQ7A	435	290	150	200	7,040	9.0
6BS8	390	330	150	220	7,300	10.0
6BZ7	490	350	150	220	6,800	10.0
8CE5*	650	1200	200	180	5,700	11.0
2CY5*	525	840	125	150	6,640	10.0
6201	600	320	250	200	5,300	10.0
7077	350	140	150	82	10,000	6.5
PC88	170	710	175	125	9,800	10.0
PCC88	280	540	150	220	15,000	12.0
E180F*	120	1160	150	82	19,000	15.0

*Pentode or tetrode measured in triode connection

(a) R_{eq} AND G_a AT 90 MC UNDER PUBLISHED TYPICAL OPERATING CONDITIONS

Tube Type	R_{eq} ohms	G_a μmhos	E_b volts	G_m μmhos
6BC8	340	520	135	9,600
SBK7A	355	580	130	8,700
6BO7A	460	520	135	8,500
6BS8	345	530	1220	9,800
6BZ7	420	540	120	8,800
6BZ8	385	700	165	10,000
PCC88	180	820	100	13,800
2CY5*	370	700	100	9,900
6BC5*	455	1500	150	9,500

*Pentode or tetrode measured in triode connection.

(b) R_{eq} AND G_a AT 90 MC FOR $I_p = 15$ MA

Figure 35-19.—*Noise Parameters of Vacuum Tubes.*

(a) Broad Band Receivers.—Deliberately broad receiver selectivity is often used in simplified-design receiver systems. The crystal-video receiver in some missile beacons possesses such broad selectivity that, if the beacon is used at high altitudes, its receiver may detect the emissions of thousands of relatively powerful transmitters. Laboratory analysis of one S-band beacon indicates (Figure 35-20) that reception is possible at many frequency ranges from 30 mc through the X-band. The crystal-video receiver's broad selectivity permits associated tracking radars to tune at will throughout a wide band, but this in turn makes coordination of operations employing specific channels quite difficult. The crystal-video receiver has low sensitivity, which permits rejection of many weak signals

(b) Selective Receivers.—The superheterodyne receiver is more selective than the tuned r-f superregenerative, or crystal-video receiver. Typical r-f selectivity characteristics of an X- and an L-band radar superheterodyne receiver are shown in Figure 35-21.

(2) Spectrum-Selectivity.—Spectrum-selectivity is a special concept particularly important in dealing with a pulsed system (also applicable to non-pulsed systems), such as radar, which is not responsive to CW signals. Hence, a conventional selectivity curve is not descriptive of performance. Consider a pulsed CW signal, *i.e.,* a series of narrow pulses of r-f energy such as those transmitted from a pulsed radar. If such a signal is now used to obtain a receiver selectivity curve in a manner similar to that described above for the carrier signal, the resulting curve will be dependent, not only on the receiver response curve, but also upon the spectrum of the pulsed signal. Therefore, such a curve is called a spectrum-selectivity curve. If, as is usually the case for radars, the signal spectrum is broad compared with the receiver bandwidth, the spectrum-selectivity curve will be broader than the conventional receiver selectivity curve. In fact, very often in the case of pulse radar equipments, the transmitter bandwidth is so much broader than the receiver bandwidth that the spectrum-selectivity curve is approximately the same as the envelope of the transmitter spectrum.

(3) *True Selectivity.*—The term true selectivity does not imply that a conventional selectivity curve is invalid for a single (desired) signal, but it does denote a special evaluation of receivers employed to deal effectively with two input signals, one desired and one undesired, or both undesired. This information is useful to determine the effects of signal mixing in nonlinear circuits. Techniques for obtaining true selectivity curves are given in CED 3512.3d.

(a) *AM Receiver.* — The two signal generator test setup of Figure 35-165 is used to obtain the true selectivity curve from which much interference-prediction data is obtained for an AM receiver. This test is described in CED 3512.3d. A typical true selectivity curve is shown in Figure 35-22. The vertical lines separated by more than one or two mc from the tuned frequency represent spurious responses. The curves near the tuned frequency represent the combined effects of desensitization, cross-modulation, and break-through. A better way of describing this portion of the curve is that *it reveals the true-selectivity of the receiver in the presence of interference.*

(b) *FM Receivers.*—Typical results of the true selectivity FM receiver test are shown in Figure 35-23. This curve is obtained in two parts because of FM receiver characteristics. The upper plotted points on the vertical lines represent the amount of desired signal necessary to negate all interference effects, while the solid curves are the desired signal necessary to produce a 6-db (S+N)/N ratio in the receiver output. It was necessary to do this because it is difficult to obtain a given (S+N)/N ratio at a spurious response frequency. A 12- to 15-db reduction in the desired signal results in complete capture by the undesired signal at the spurious response points in most receivers. This effect is shown by the lower point on the spurious responses. Thus, the interference-free condition is related to the captured condition by a constant. If the desired signal level to obtain a 6-db (S+N)/N ratio at the spurious response points is wanted, this can be obtained by subtracting approximately 6 to 8 db from the desired-signal magnitudes obtained in the above manner. Figure 35-24 shows the response of a particular receiver over the range from one mc below the tuned frequency down to 150 kc—and from one

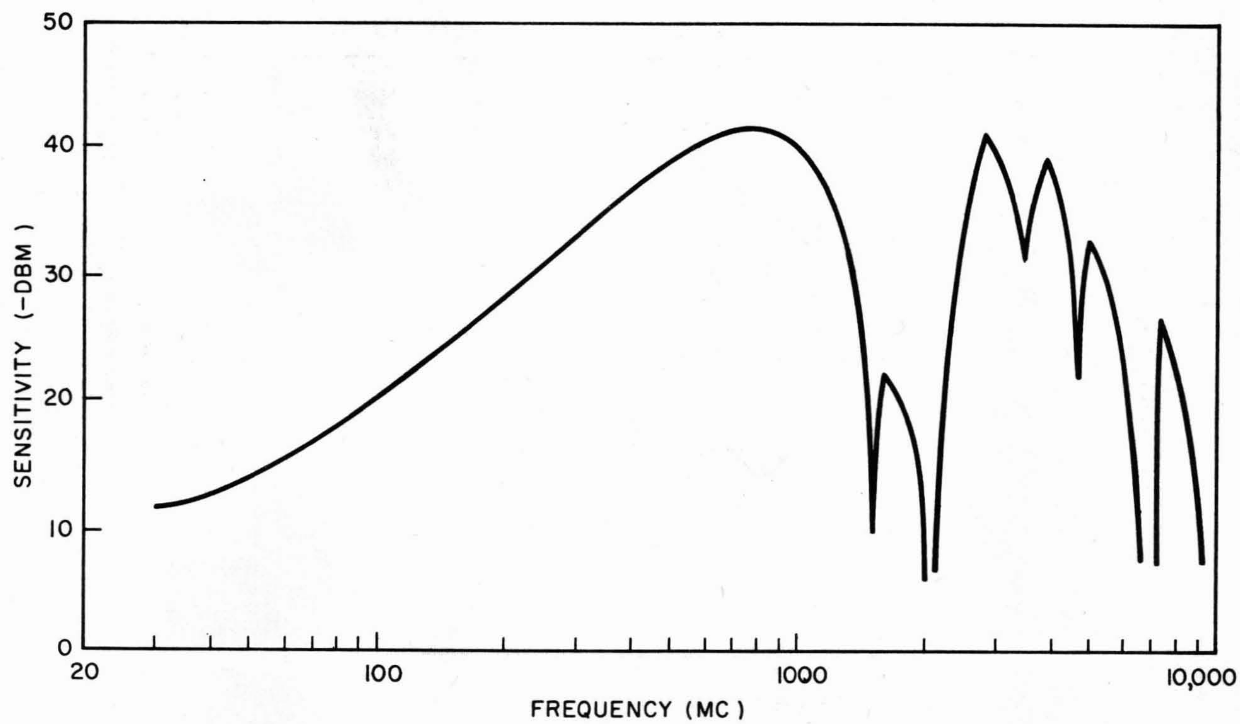


Figure 35-20.—*Typical Spectral Response of Radar Crystal-Video Receiver.*

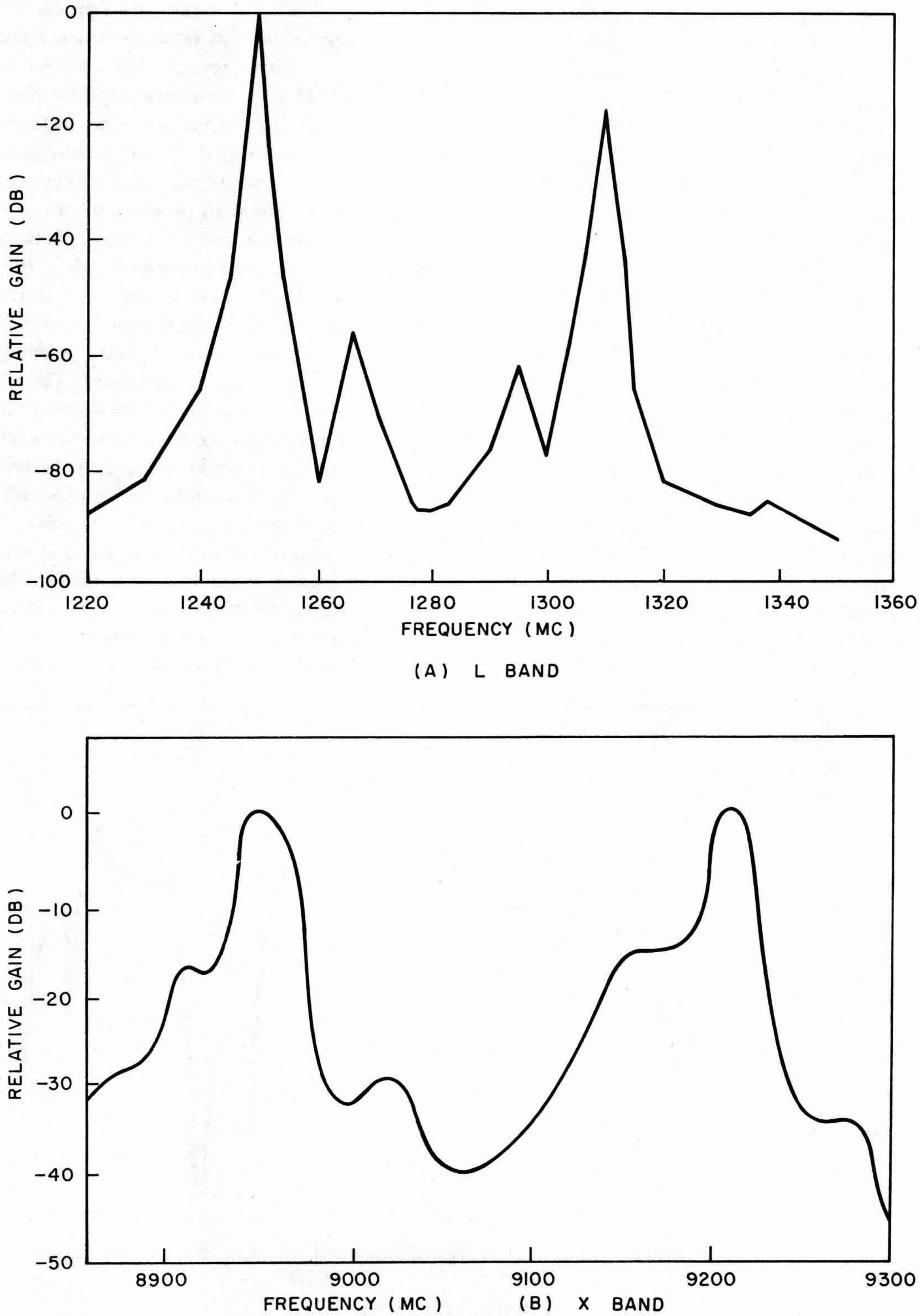


Figure 35-21.—*Typical Spectral Response of Radar Superheterodyne Receiver.*

mc above the tuned frequency up to 1000 mc. Due to the large number of spurious responses near the tuned frequency, the spurious responses inside the range $F_0 \pm 1$ mc are expanded in Figure 35-24.

[1] The results of applying different types of modulation would cause little deviation in the test data, because interference to the FM receiver has been found to be largely independent of modulation, except in the case of co-channel interference. The effects of different types of modulation of the interfering signal in the co-channel case are shown in Figure 35-25. (Refer to co-channel test of CED 3512.5b). This curve shows that the co-channel capture is relatively independent of the interfering signal modulation when the desired signal is weak; however, for strong desired signals, the capture slope is greater for modulated signals as compared with unmodulated types. In any case, the difference is not significant.

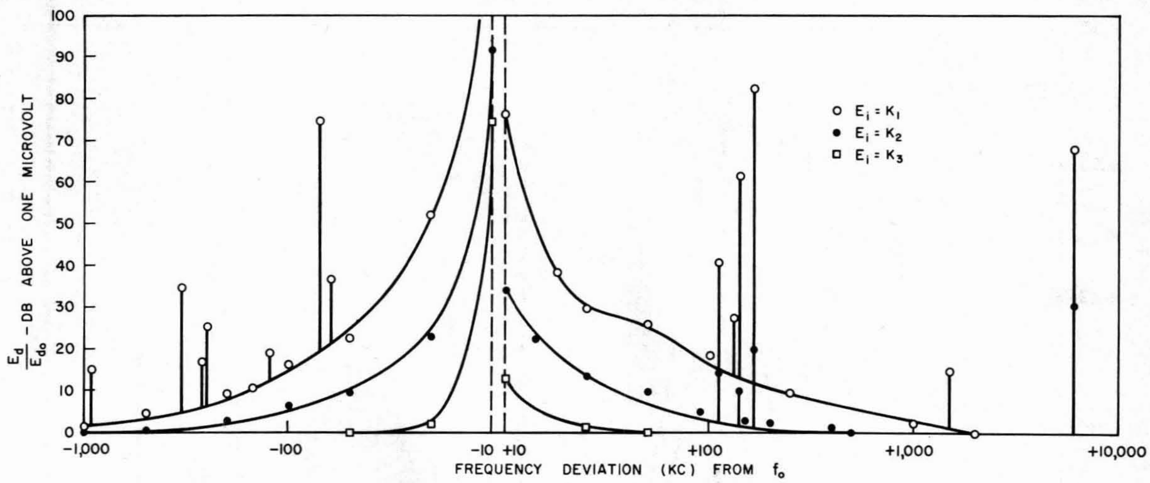


Figure 35-22.—*AM Receiver True Selectivity Curve.*

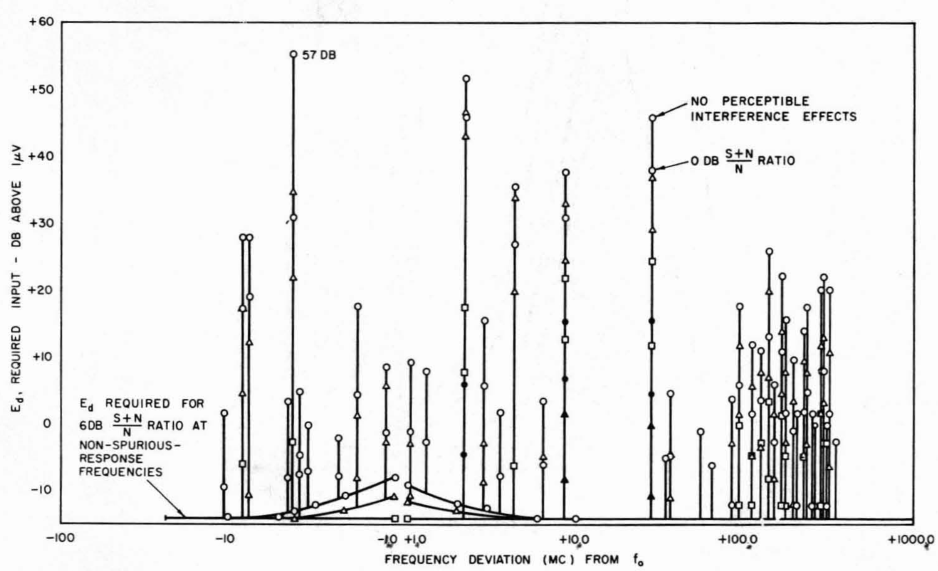


Figure 35-23.—*FM Receiver True Selectivity Curve.*

c. Undesired Responses.—It was already noted that receiver bandwidth is normally wider than transmitter fundamental emission bandwidth by a considerable factor to allow for, among other factors, transmitter instability. However, broadband receivers can increase difficulties arising from significant adjacent- and distant-channel response characteristics, which are shown in Figures 35-20 and 35-21.

(1) *Image Rejection.*—In the superheterodyne receiver, an undesired signal appearing at the receiver image frequency can frequently be seen in addition to the desired signal. If adequate preselection is not available, two channels, rather than one, may require protection. Many radars have relatively little image-rejection capability, as can be seen in Figure 35-21; while others may have 60- to 70-db rejection.

(2) *IF Isolation.*—Extraneous signals may bypass the r-f stages and enter the i-f amplifier directly. An X-band tracking radar with a nominal 60-mc i-f, in common use by military agencies,

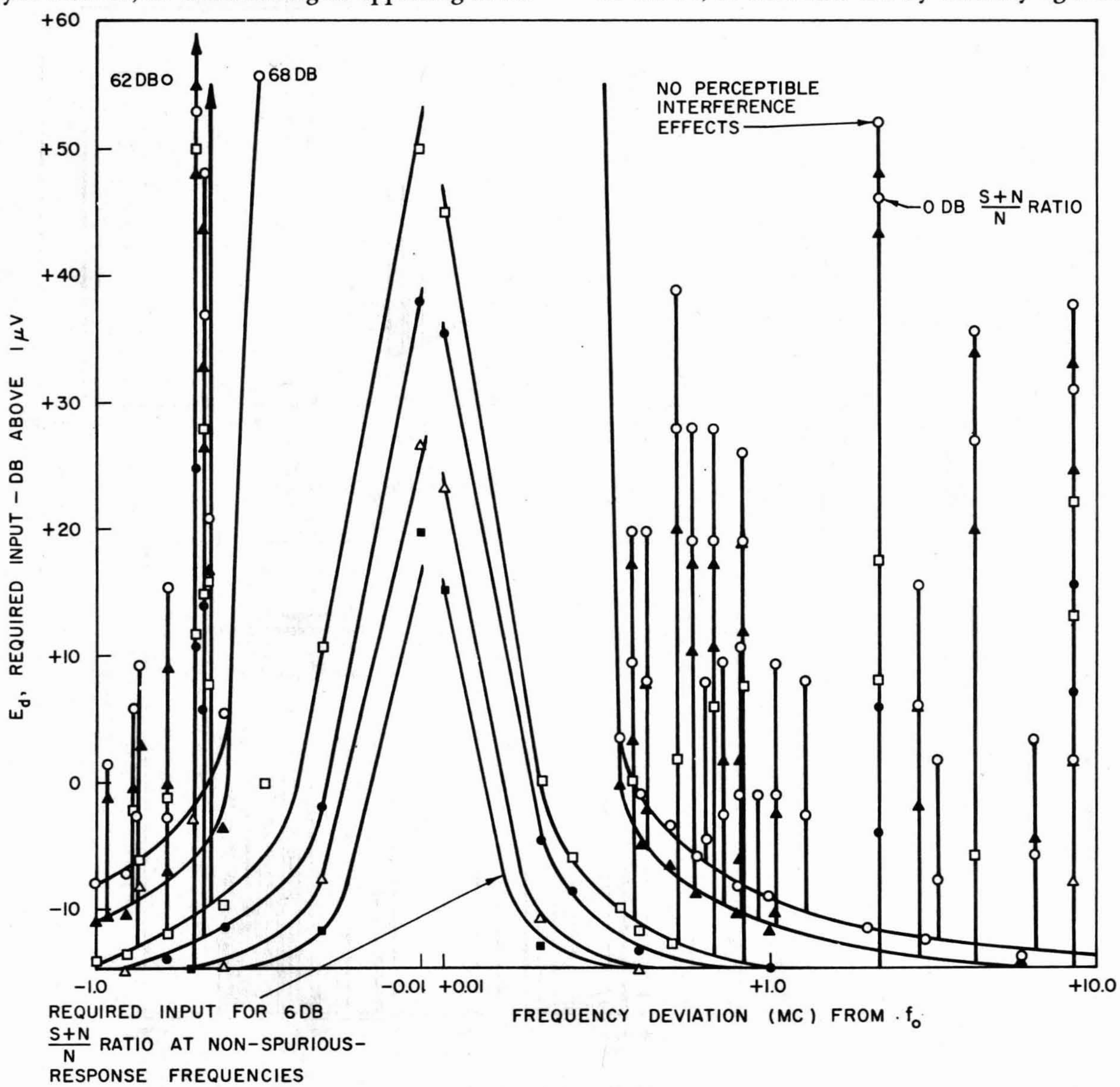


Figure 35-24.—*Expanded Portion of Figure 35-23.*

could experience serious interference from any strong 50- to 70-mc CW emitter within a few miles of the radar. Commercial TV, which employs extremely high-power emissions in the VHF band, can be a source of serious interference.

(3) *Spurious Linear Responses.*—Superheterodyne receivers may also respond at submultiples of the operating frequency as well as to harmonics of the local oscillator frequency. In addition, they may respond to r-f harmonics in combination with harmonics of the heterodyning frequency or the local oscillator frequency.

(4) *Spurious Nonlinear Responses.*—Nonlinear effects may result in responses caused by interaction between the desired signal and one or more undesired signals; also between two or more undesired signals. It is pointed out in CED 3502.-2a(2)(a) that a sinusoidal signal which is impressed upon a nonlinear impedance can effectively be replaced by a linear impedance with a number of harmonically-related sinusoidal signals. In other words, the nonlinear impedance generates signals at new frequencies. When two sinusoidal signals are simultaneously applied to a nonlinear impedance, a mixing action takes place. The resulting output signal consists of the sum and difference of the two frequencies as well as the sum and difference frequencies of the harmonics of the original signals. In general, the frequencies generated by mixing action can be expressed mathematically as:

$$f_a = \pm Af_1 \pm Bf_2 \pm Cf_3 \pm Df_4 \ldots\ldots Nf_i \ldots\ldots, \quad (10)$$

where:

A, B, C, are any positive integers (called coefficients),

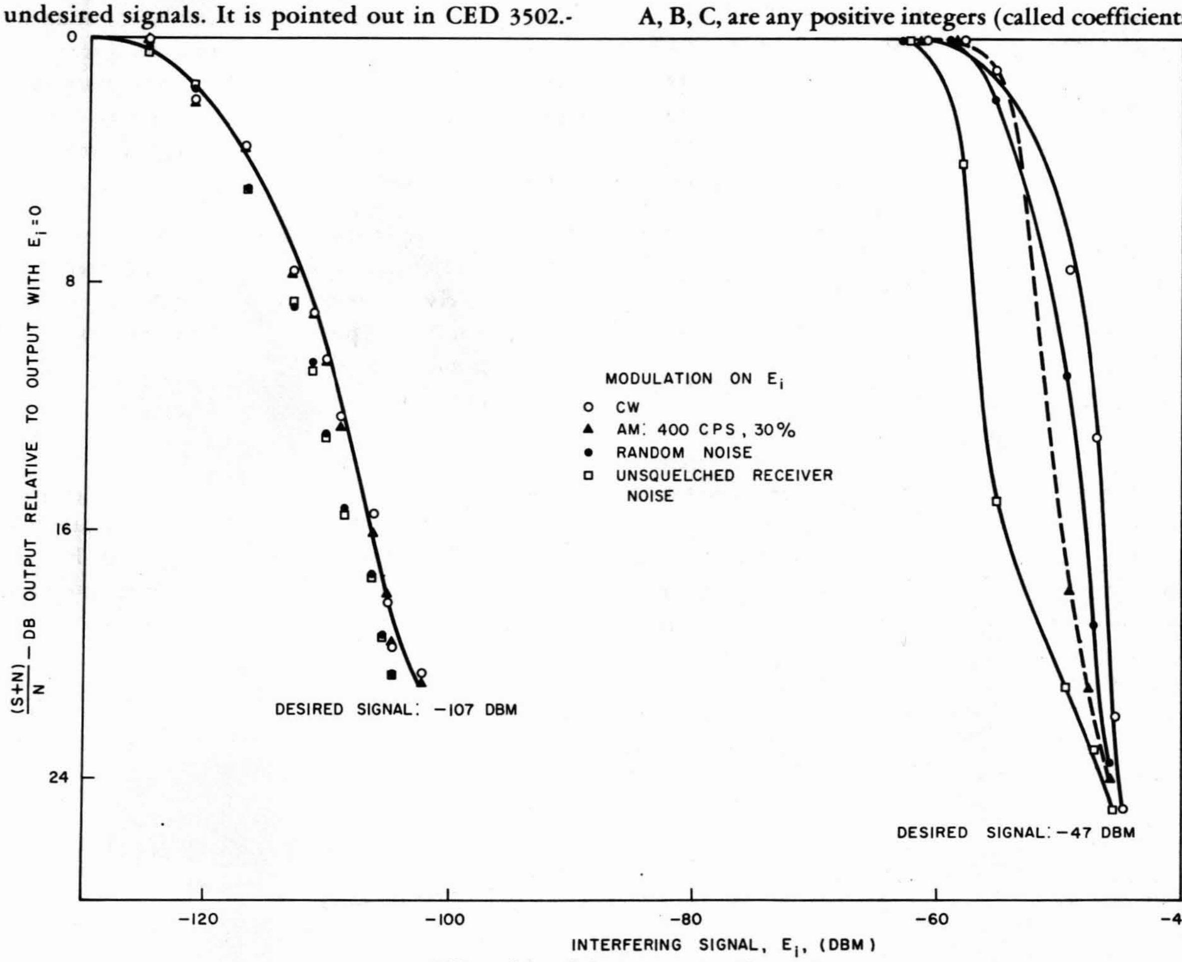


Figure 35-25.—*Effect of Modulation on Co-Channel Interference.*

f_1, f_2, f_3 are the frequencies of the incident signals,

f_a is the frequency of the output signal.

Theoretically, this equation could contain an infinite number of terms. Practically, however, most of these terms are normally far below background noise level. The amplitude of the mixing product is dependent upon the type of nonlinearity, and the level of the incident signals. Investigations have shown that the level of the mixing products decrease with increasing coefficients. For convenience in dealing with frequency conversion, the nonlinear spurious process is considered under two classifications; intermodulation and cross modulation.

(a) Intermodulation.—Intermodulation can be defined as the mixing of *two or more undesired signals* in a nonlinear (impedance) element. For convenience, the intermodulation products are classified according to the order of their coefficients, for example:

Second order, $f_{a1} = f_1 \pm f_2$, (11)

Third order, $f_{b1} = f_1 \pm 2f_2$ or $fb_2 = 2f_1 \pm f_2$, (12)

Fourth order, $f_{c2} = 2f_1 \pm 2f_2$ or $f_{c2} = 2f_1 \pm 2f_c$,

or $f_{c3} = 3f_1 \pm f_2$. (13)

The level of the intermodulation product decreases with increasing order. Moreover, experimental investigations have shown that the second and third orders provide the major sources of spurious interference energy. Intermodulation must take place in a nonlinear element. Predominant sources of nonlinearity are: corroded wires (fences, antennas, guy wires, etc.); the junction of dissimilar metals (cases, tiepoints, etc.,); and the mixer stage of a receiver. The first two are usually functions external to a receiver and their effects are obviously unpredictable. However, the last is an inherent function of a receiver and can be measured as outlined in CED 3512.

(b) Cross-Modulation.—The words intermodulation and cross-modulation are often used interchangeably. For the purpose of this manual, cross-modulation will be defined as the mixing of a *desired and undesired signal* in a nonlinear element. It is generally less important than intermodulation in communications receivers, since the frequency of the interfering signal must be so far removed from the receiver passband. It must be considered, however, in receivers employing broad band input circuitry, such as spectrum-sweeping receivers and some radar receivers. For computational purposes, cross-modulation may be treated as a special case of intermodulation, where one of the signals involved is the desired one.

(c) Desensitization and Receiver Blocking.—Desensitization is the reduction in the sensitivity of a receiver due to the presence of an undesirable signal. This type of interference occurs if the incoming undesired signal saturates the first active receiver amplifier (r-f or i-f stage), or if it is detected and passed through to the AGC circuit. If the receiver is subjected to an extremely high level signal, a high negative bias may develop on the grid of the input tube which will stop the flow of plate current and completely block the signal path. The test procedure for determining the desensitization characteristics of a receiver is given in CED 3512.3d.

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SECTION III—INTERFERENCE REDUCTION

3505. GENERAL INTERFERENCE-REDUCTION TECHNIQUES.

.1 Introduction.—If adequate care is taken in initial design and development, it is frequently possible to obtain resulting equipment which is sufficiently free of extraneous signal emanations and has low susceptibility to undesired signals. Under these conditions, little or no mutual electromagnetic interference will be experienced. Good basic design of this nature will minimize problems due to equipment installation and operation, and will also minimize or eliminate the need for the consideration and application of suppression techniques at a later time. Since the C-E officer has no control over such basic design, he may be required to correct or compensate for equipment deficiencies by utilizing remedial interference techniques both during and after equipment installation.

.2 Equipment Interaction. — A basic requirement of good system installation combines the optimum resultant operation of individual equipments—with a minimum of undesirable interaction between them. Operating convenience may be served by a functional grouping of equipment, which frequently would position equipments close to one another. However, such close spacing may result in mutual interference between equipments having incompatible signal source and susceptibility characteristics. In some instances, such as equipment installed in aircraft, the C-E officer may have no control over equipment arrangement and their relationship to antennas and ancillary units. In other instances, such as in some fixed installations, he may be able to arrange placement which is most consistent with interference-reduction requirements. Once equipment placement has been established, other means must be employed to effect the required system suppression. Techniques applicable under these circumstances include filtering and bypassing undesired signals, shielding against them electromagnetically, and bonding equipment and transmission lines to ground by some low-impedance path. These specific methods are discussed in CED 3505.3 through .5. Additional interference-reduction techniques are reviewed in CED 3506 and CED 3512.

.3 By-Pass Capacitors and Filters.—By-pass capacitors and filters prevent interference from reaching sensitive receivers by introducing a high impedance into the path of the interfering currents, or by shunting them to ground through a low impedance. Ideally, these units should be used to suppress the interfering currents, while leaving unaffected those currents that are essential to the operation of the concerned equipment. This latter factor is a most important consideration, since filter elements are incorporated directly into the circuits of the equipment. Because of this, the effectiveness of a capacitor or filter cannot be measured alone in terms of the impedance offered to interfering currents. Instead, the convenient concept of insertion loss is more widely used.

a. Insertion Loss.—At a given frequency, the insertion loss of a filter inserted into a system is defined as the logarithmic ratio of voltages appearing across the line immediately beyond the point of filter insertion before and after insertion; *e. g.,* at M_1 on Figure 35-26. Alternatively, insertion loss is repesented as the logarithmic ratio of input voltages required to obtain constant output voltage with and without the filter. In equation form,

$$\text{Insertion Loss (db)} = 20 \log_{10} (E_1/E_2), \qquad (14)$$

where:

E_1 = output voltage of a signal generator with the filter in the circuit,

E_2 = output voltage of the signal generator with the filter not in the circuit.

b. Capacitors.

(1) *Ideal Capacitor.*—An ideal capacitor contains only pure capacitive reactance and has an impedance characteristic that is inversely proportional to frequency. For suppression purposes, this characteristic would be advantageous, since the insertion loss would increase with frequency, as in Figure 35-27. Interfering frenquencies are generally much higher than the power or control currents involved in the normal operation of the equipment. Thus, the presence of a high-impedance element in shunt would not affect the low-frequency power and control currents, but would essentially short-circuit the r-f interference currents to ground.

(2) *Actual Capacitors.*—Actual capacitors differ from the ideal because they contain resistance and inductance as well as capacitance. The impedance of a capacitor decreases with frequency until

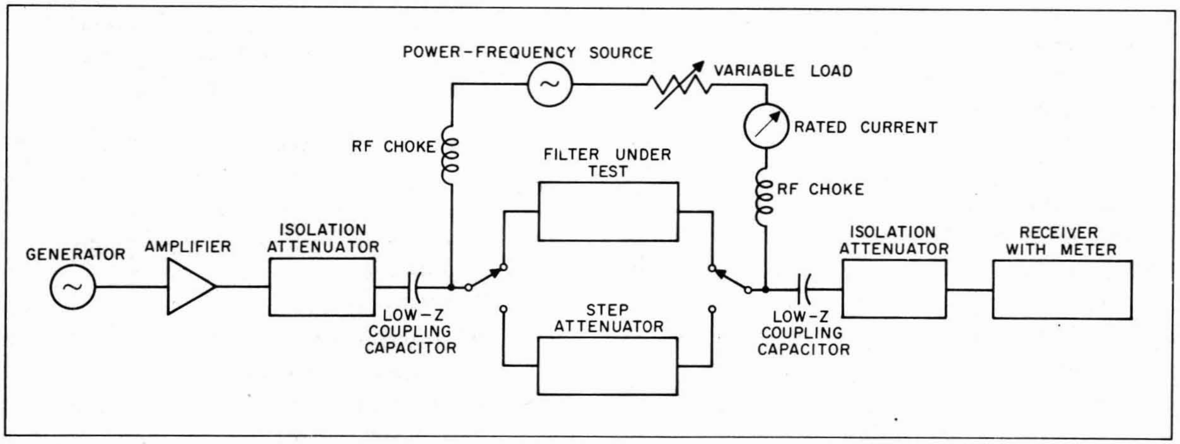


Figure 35-26.—*Circuit for Measurement of Insertion Loss.*

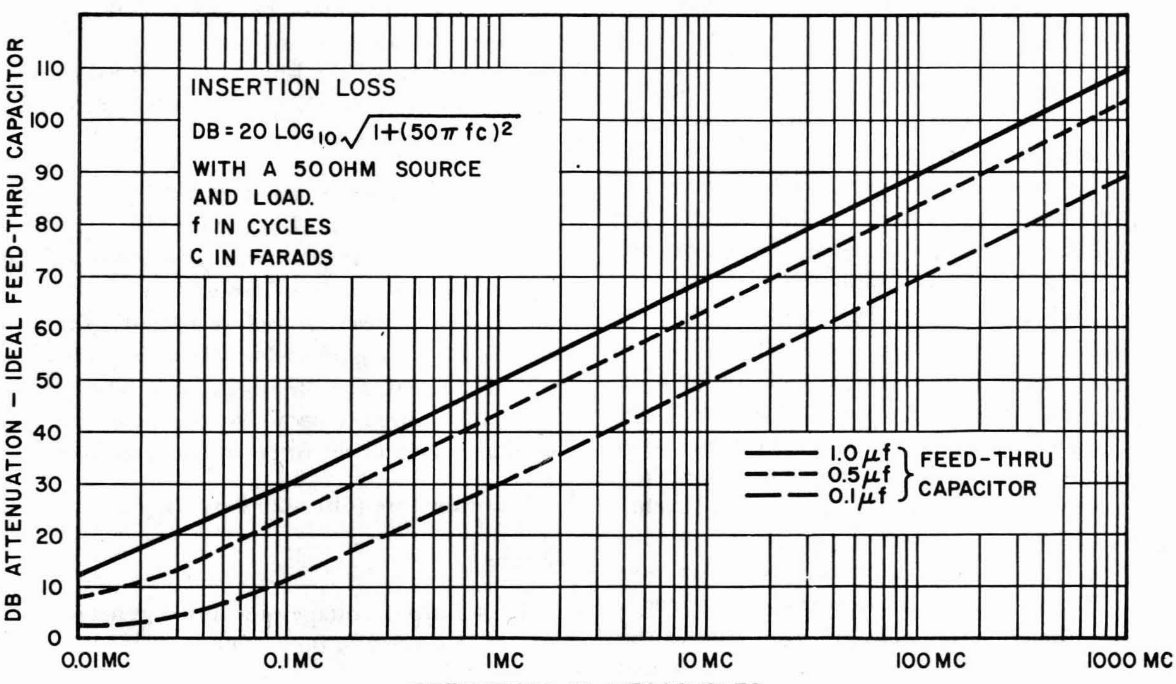


Figure 35-27.—*Insertion Loss of Ideal Capacitors.*

a minimum impedance is reached; then the inductance causes an impedance rise again. At the capacitor resonant frequency, the impedance is only the resistance of the capacitor. Thus, the insertion loss reaches a maximum at the capacitor resonant frequency as illustrated in Figure 35-28. For this reason, a capacitor ceases to be an effective by-pass element at frequencies much above its resonant frequency. If capacitors contained capacitance alone, the designer would select the largest possible capacitor for the effective bypassing of r-f currents. Actually, four factors limit the size of a capacitor that can be used in a given application. The first is capacitor inductance, which usually increases with the size of the capacitor. Therefore, the high-frequency performance of a smaller capacitor is better than that of a larger unit, because a lower inductance causes the smaller capacitor to have a higher resonant frequency. While an ideal capacitor of 1 mfd would be 10 times more effective than a 0.1 mfd capacitor in eliminating radio-interference current, in actuality the smaller unit is likely to be more effective at higher frequencies. The second limitation is the amount of current drawn by the capacitor in a-c circuits. Larger capacitors take higher currents that may constitute an excessive drain on the system. A third deterrent to the use of large-size capacitors is frequently their adverse effect on the contacts of relays and switches employed in the equipment. Fourth, even if these first three factors were a problem, limitations may be imposed by a confined area in which the capacitor must be placed.

(3) *Feed-Through Capacitors.*—The inductance of a conventional by-pass capacitor, such as that of Figure 35-29, is made up of the internal inductance of the rolled material and the external inductance of leads. Internal inductance is fixed, but the designer can obtain some reduction in inductance by utilizing the shortest possible axial leads. At this point, it is of interest to note some of the characteristics of the feed-through capacitor, Figure 35-30. It consists of a feed-through bus that

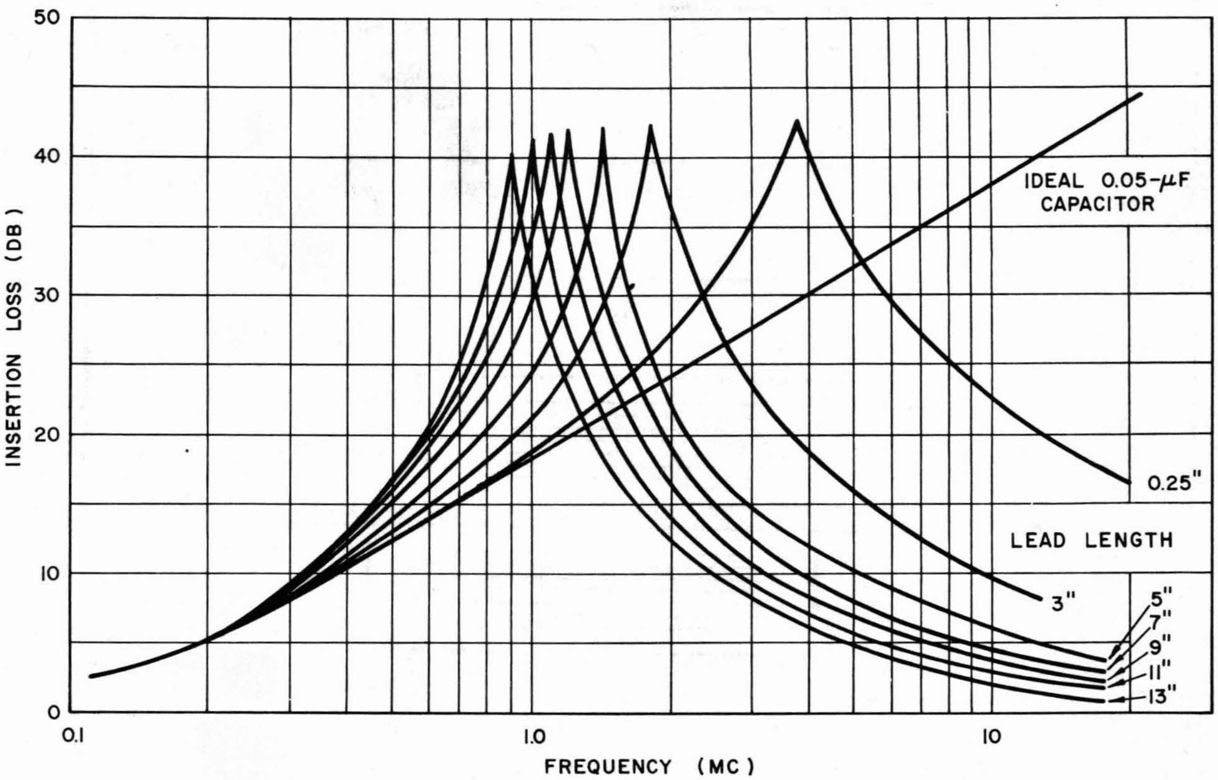


Figure 35-28.—*Insertion Loss of Actual 0.05-uf Capacitor.*

passes through the center of the rolled foil and dielectric. Alternate foils on each side of the feed-through bus are soldered together. One set is soldered to the housing and the other to the bus. In this way, internal inductance is minimized, and external inductance is reduced because there is no input lead. It is also possible to install the capacitor so that there is no output lead. For example, when mounted in a hole through a shield wall, the capacitor is grounded through a continuous circular path around its housing. Figure 35-31 illustrates the potential superiority of a feed-through type of capacitor over a conventional foil type at frequencies above 10 mc.

c. Filters.—Filters are more complicated and more expensive than capacitors alone. They combine the by-passing action of capacitors with

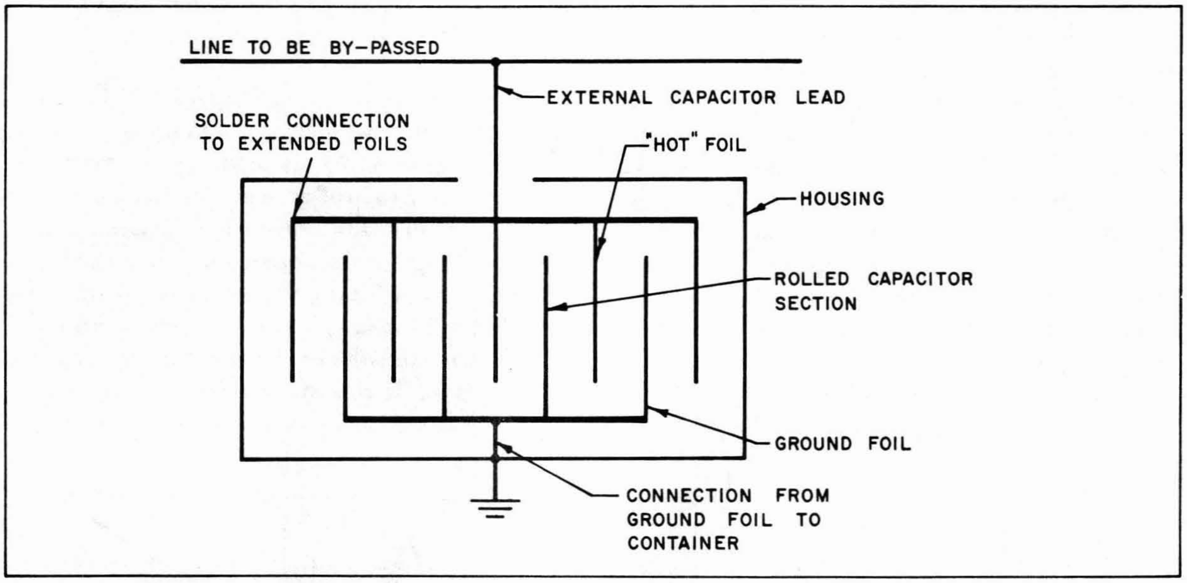


Figure 35-29.—*Construction of Typical By-Pass Capacitor.*

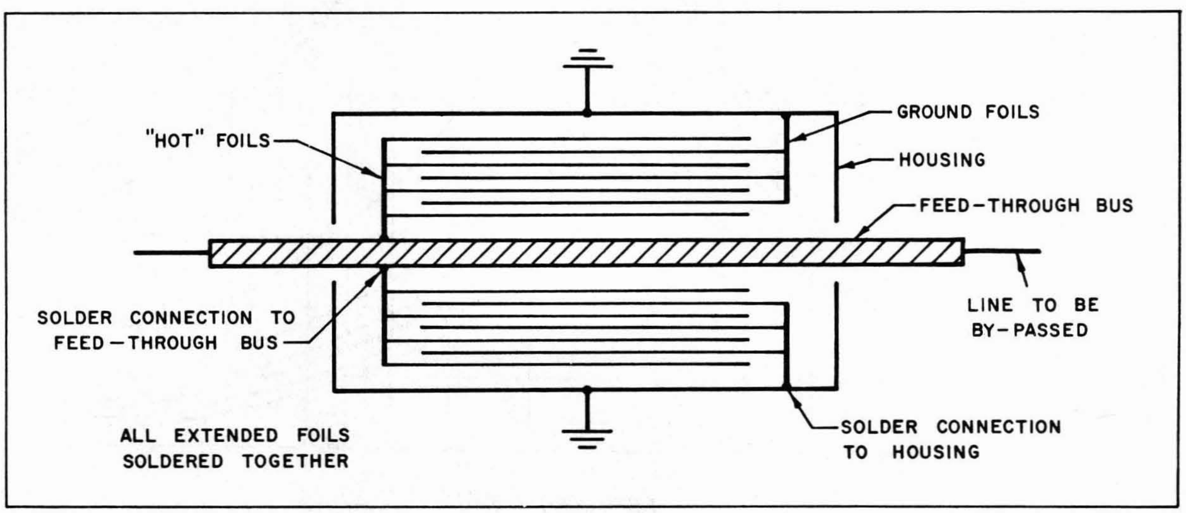


Figure 35-30.—*Construction of Feed-Through Capacitor.*

the impeding action of inductors. Properly chosen filters provide greater insertion loss than by-pass capacitors over the frequency range for which they are designed. Since filters contain capacitances as elements, the inherent inductance of a capacitor is a limiting factor here also. Moreover, filters also contain inductance coils, whose distributed capacitances impose further limitations on the design. However, it is possible to take these stray elements into consideration during design: a well-engineered and carefully constructed low-pass filter will remain effective as a suppression element to frequencies well above 1000 mc.

(1) Low-Pass Filter.—The most frequently used interference filter for power-line applications is a low-pass unit with a cutoff frequency in the region from 1 to 10 kc. This unit is intended to have very low insertion loss for d-c, power frequency, and other relatively low-frequency currents, but will attenuate currents above its cutoff frequency.

(2) High-Pass Filter.—A high-pass filter, which suppresses all frequencies below a certain cut-off frequency, is sometimes used as a suppression component. This unit is intended to have a very low insertion loss for high-frequency (generally radio-frequency) currents above some cut-off frequency, but will attenuate currents below this cutoff frequency.

(3) Band Filters.—Special filters are sometimes useful in the solution of specific radio-interference problems. Band-pass filters, which allow a certain band of frequencies to pass and suppress all others, might be used in the antenna circuit of receivers in order to increase their selectivity and improve their interference rejection. They may also be used in the output circuits of transmitters or oscillators in order to suppress harmonics and other spurious frequencies. Band-elimination filters, which suppress a certain band of frequencies and pass all others, find application when the interference to be suppressed contains only a relatively narrow band of frequencies, such as a specific transmitter harmonic.

d. Installation.—The principles to be followed in the installation of suppression components

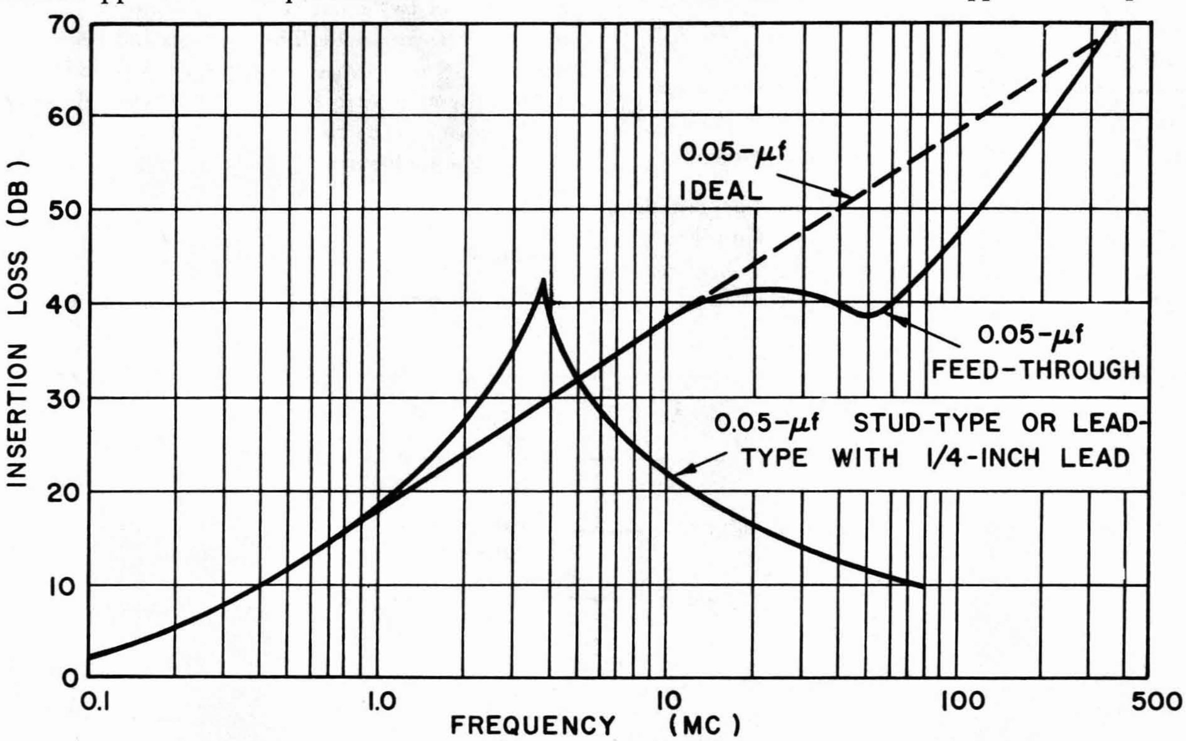


Figure 35-31.—*Insertion Loss of Feed-Through Capacitor.*

are the same for filters and capacitors. They follow directly from a consideration of two basic facts: that the lead from the interference source to the suppression element carries interference currents; and that the impedances of the connections to the filtering element and from the element to ground are in series with the by-passing portion of the element. From the first, it follows that the suppression component must be installed as close to the source as possible (see Figure 35-32), and that all other leads, in particular the "clean" output lead B, is kept as far away from lead A as is practicable. In severe cases, lead A should be shielded. From the second, it follows that lead C, if present (the lead C is absent if the suppression element is a filter or feed-through capacitor) must be as short as possible, and that the ground connection D must be a very low impedance. This means that good bonding—as discussed in CED 3505.5—is extremely important in the installation of filters and capacitors. The use of power line filters and capacitors requires some safety precautions. In each case, it is common practice to connect such elements in a manner that considerable capacitance exists between power lines and any chassis or shielding case on which the filters or capacitors are mounted. The equipment case *must be grounded* to prevent shock through capacitors, unless the capacitor is so small as to limit the current to a small fraction of a milliampere.

.4 Shielding Techniques. — The purpose of shielding is to prevent the coupling of undesired radiated electromagnetic energy into equipment that would otherwise be susceptible to it.

a. Shielding in Aircraft. — One of the most difficult shielding problems occurs in aircraft or missile systems where many transmitters, receivers, and other sensitive equipment must be mounted closely together, and where weight must be reduced as much as possible. This problem is being accentuated as the growing electronic demands of future air and space vehicles requires the integration of more electronic functions within one compact enclosure. In aircraft, structural shielding effects can range from 20 to 100 db; this amount of shielding is generally not sufficient to protect receiving antennas from undesired signals generated within the aircraft. Signal generating equipment must also be shielded in order to protect other equipment. Transmitter equipment cases must provide a shielding effectiveness of at least 100 db in order to reduce harmonic and spurious leakage via this path.

b. Calculation of Shielding Effectiveness of Materials.—Shielding behavior for transverse electromagnetic waves can be analyzed by use of transmission-line equations. The source of signal is considered to be a point source encased in a spherical shield, or two parallel current filaments encased in a cylindrical shield. This analysis has been rearranged and the results are presented here in condensed form so as to be applicable, with good approximation, to the choice of materials in the design of shielded enclosures.

(1) Terms.—Shielding terms are defined as follows:

S = Shielding effectiveness or insertion

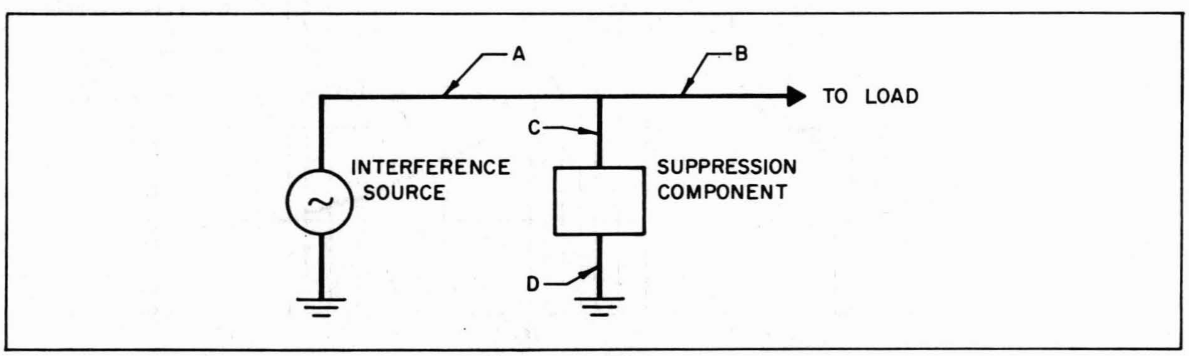


Figure 35-32.—*Installation of Suppression Component.*

loss, representing the reduction (expressed in db) of the level of an electromagnetic wave at a point in space after a metallic barrier is inserted between that point and the source. Measurements are made in real powers, reactive powers, voltages, or currents.

$$S = R + A + B, \qquad (15)$$

where:

R = Total reflection loss in db from both surfaces of the shield, neglecting the effect of multiple reflections inside the barrier,

A = Penetration or absorption loss in db inside the barrier,

B = A positive or negative correction term which need not be taken into account when A is more than 15 db. It is caused by the reflecting waves inside the shielding barrier, and is calculated in db. When a metallic barrier has an A or less than 15 db, it is designated as "electrically thin".

(2) Shielding Expressions. — All of the terms in the previous shielding-effectiveness equation (15) may be expressed as functions of the material conductivity g and permeability u, relative to copper, and the frequency f in cps, as well as the physical relationships that exist.

(a) Reflection Loss.—The reflection loss R depends upon the electrical nature of the source and upon the distance r in inches of the shield from the source, as shown in Figure 35-33. Equations 16, 17, and 18 are used in finding the reflection loss. They are stated in Figure 35-33.

(b) Penetration Loss.—The penetration loss A depends not only upon u, f, and g, but also upon the thickness d in inches of the shielding material.

$$A(db) = 3.34\sqrt{ufg}\,d \qquad (19)$$

(c) Correction Term for Internal Reflections.—If A is equal to 15 or more, the correction term B may be neglected. However, if A is less than 15, the correction for multiple reflections within the shielding material must be made. This correction term B is complicated, since it depends on all

Nature of Source	Reflection Loss, R		Condition
Low Impedance (Such as loop at distance $<< \lambda/2\pi$)	$20 \log_{10}\left[\frac{0.462}{\sqrt{\frac{fg}{\mu}}\,r} + 0.136\sqrt{\frac{fg}{\mu}}\,r + 0.354\right]$	(16)	$fr << 2 \times 10^9$
High Impedance (Such as rod at distance $<< \lambda/2\pi$)	$354 - 20 \log_{10}\left(\sqrt{\frac{\mu f^3}{g}}\,r\right)$	(17)	$fr << 2 \times 10^9$
Plane Wave (Such as rod or loop at distance $>> \lambda/2\pi$)	$168 - 20 \log_{10}\left(\sqrt{\frac{\mu f}{g}}\right)$	(18)	$fr >> 2 \times 10^9$

Figure 35-33.—*Expressions for Reflection Loss.*

Nature of Source	Correction Factor, χ	
Low Impedance	$4\,\frac{(1-m^2)\;-2m^2-j\,2\sqrt{2}m\,(1-m^2)}{[1+(1+\sqrt{2}m)^2]\;]^2}$, where $m = 0.766\sqrt{\frac{fg}{\mu}}\;r$ $= 1$ for $m << 1$, $= 1$ for $m >> 1$. In practical application, $m >> 1$ and $\chi = 1$, except for very low frequencies. For m between 0.05 and 20, consult Figure 35-39.	(21)
High Impedance	$4\,\frac{(1-n^2)^2\;-2n^2-j\,2\sqrt{2}n\,(1-n^2)}{[1+(1-\sqrt{2}n)^2]^2}$, wherein $n = 0.520 \times 10^{-18}\sqrt{\frac{\mu f^3}{g}}\;r$ $= 1$ for $n << 1$. For all presently known shielding materials used throughout the radio spectrum, $n << 1$ and $\chi = 1$.	(22)
Plane Wave	1	(23)

Figure 35-34.—*Correction Factor in Correction Term for Internal Reflections.*

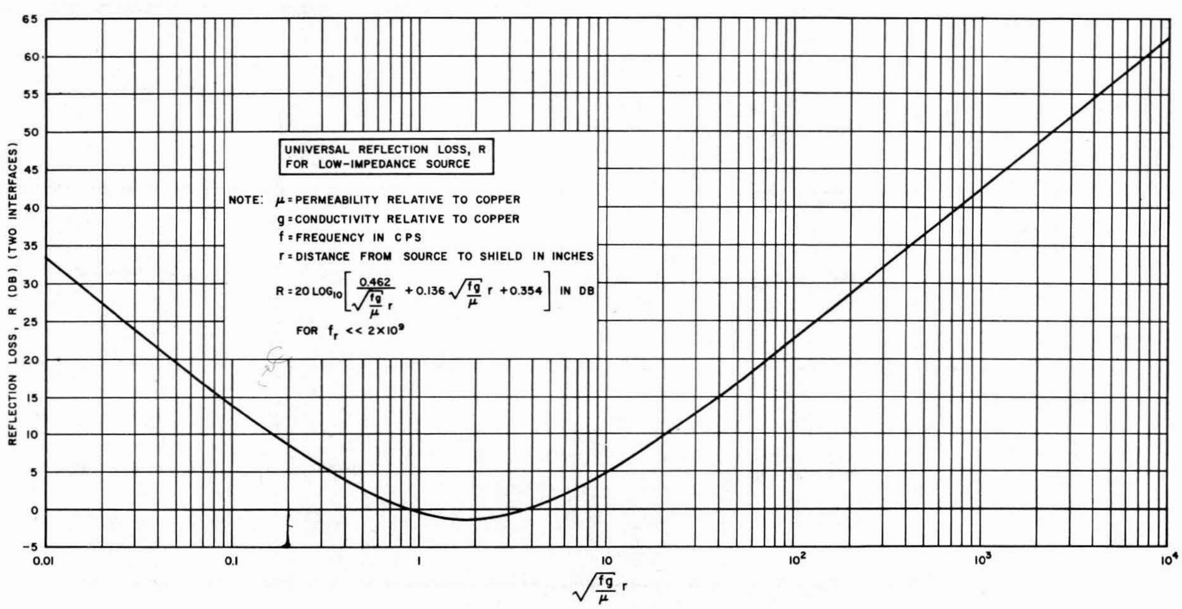


Figure 35-35.—*Universal Reflection Loss for Low-Impedance Source.*

material, dimensional, and frequency parameters. In the general case,

$$B(db) = 20 \log_{10} \left[1 - \chi 10^{-\frac{A}{10}} (\cos 0.230\, A - j \sin 0.230 A)\right], \qquad (20)$$

where the factor χ is a real and imaginary function of u, f, g, and r. Expressions for χ are given in Figure 35-34. In almost all *practical* cases, $\chi = 1$. The only notable exception is the special case of extremely low-frequency shielding against low-impeddance (chiefly magnetic) fields. Values of χ for this case are given in Figure 35-39.

(3) *Universal Curves of Shielding Performance.*—Universal curves for R and A are given in Figures 35-35 through 35-38. Furthermore, the

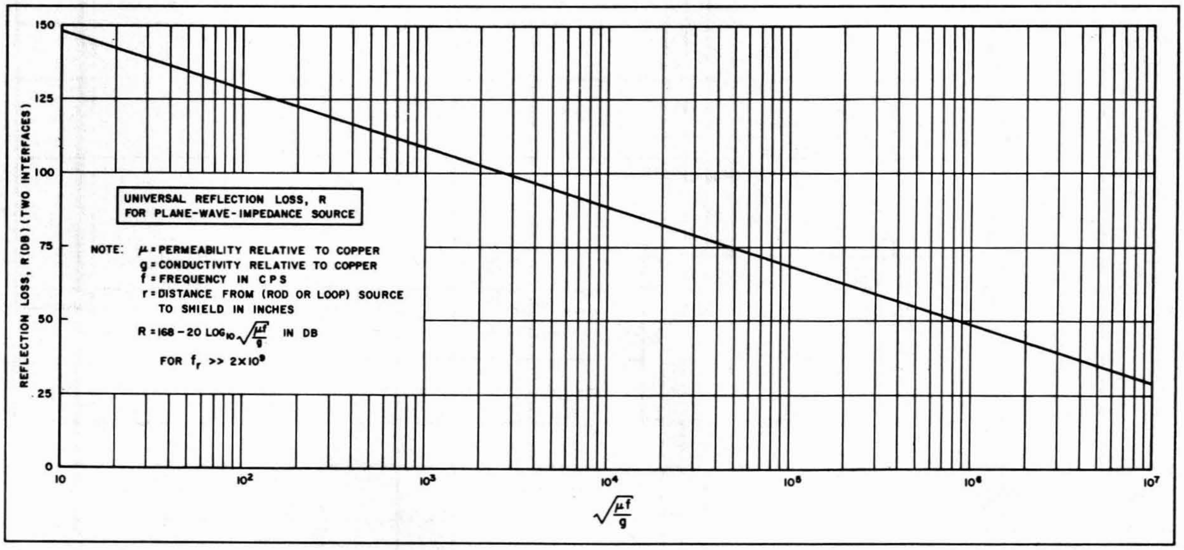


Figure 35-36.—*Universal Reflection Loss for Plane-Wave Impedance Source.*

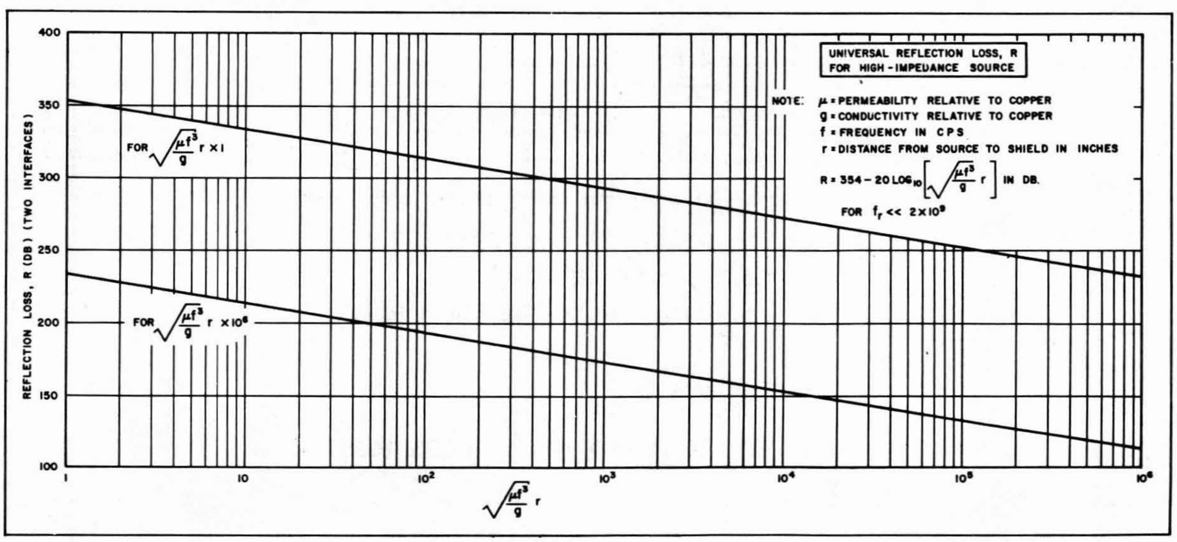


Figure 35-37.—*Universal Reflection Loss for High-Impedance Source.*

sum of A+B may also be obtained from Figure 35-38 for the common case of $\chi = 1$. If χ is not equal to one, it may be determined from Figure 35-39 and B must then be calculated from equation (20).

(4) Calculated Data.—Material properties such as those given in Figure 35-40 may be used to calculate the shielding effectiveness of various materials. Effectiveness of copper and iron from 60

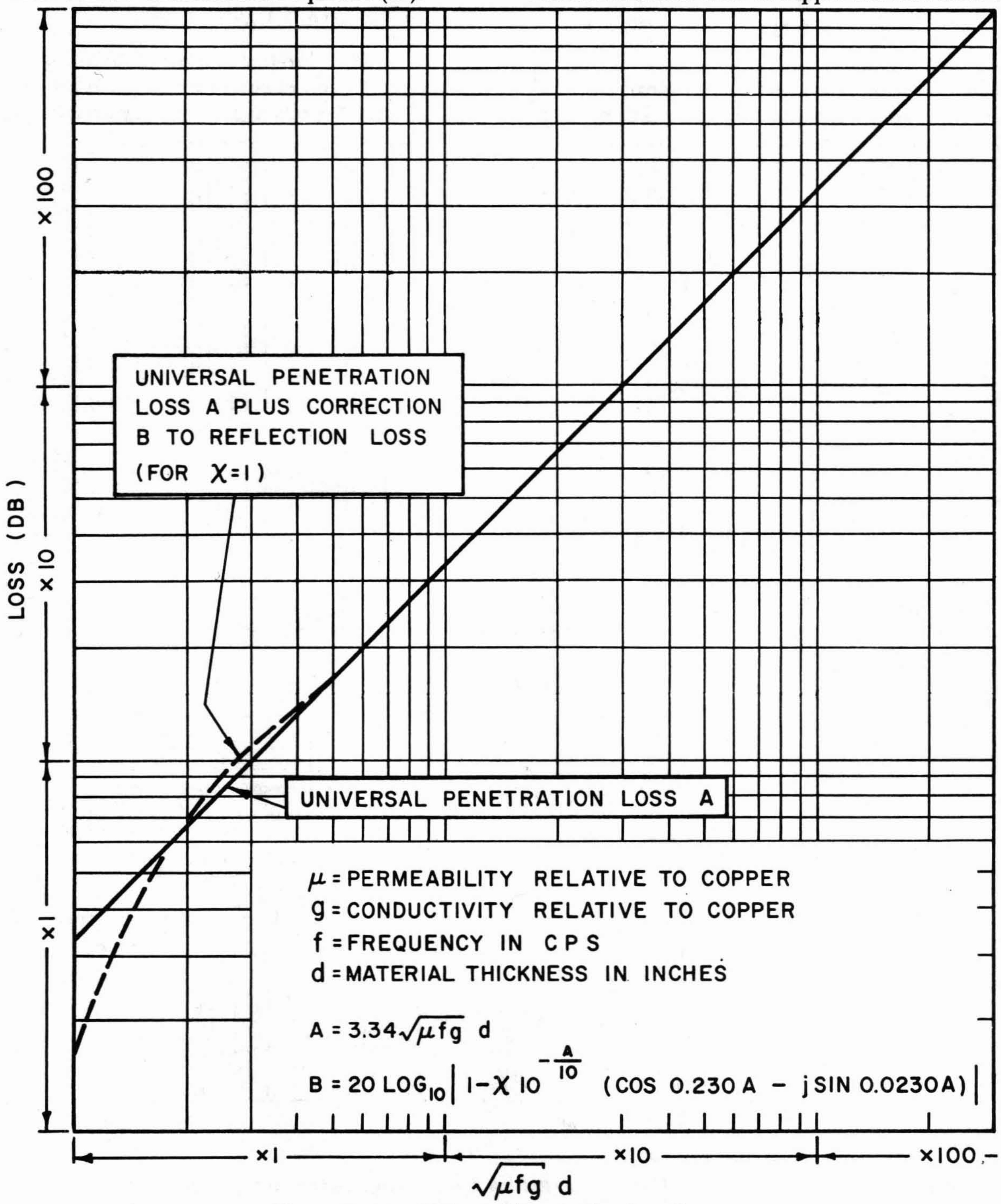


Figure 35-38.—*Universal Penetration-Loss Curve.*

cps to 10,000 mc is given in Figures 35-41 through 35-46 and graphically presented in Figure 35-47. The effective wavelengths of various frequencies of electromagnetic energy in copper and iron are given in Figure 35-48.

(a) For distances between the signal source and the shielding material other than those shown in the above data, corrections must be made by using the established formulas previously given. If the distance is much less than 12 inches, the reflection loss to magnetic fields will be smaller and the reflection loss to electric fields greater.

(b) In practically all cases, the total shielding effectiveness is greater than absorption, or penetration, loss alone. Despite this fact, many designers ignore reflection losses, and thus design a shielded enclosure to be much thicker than necessary. The available reflection loss should be included in the calculations in order to prevent over-designing the enclosure. In aircraft applications, this consideration can result in important weight savings.

(c) At frequencies as low as 60 cps, both penetration loss and reflection loss become small for magnetic fields, indicating that, for lower frequencies approximating d-c, very thick metallic barriers would be necessary to shield against magnetic fields. For example, the tables indicate that, in order to obtain a shielding effectiveness of 100 db at 60 cps for magnetic fields, it will be necessary to provide a metallic barrier made of iron with a permeability of 1000 and a thickness of about 300 mils.

c. Measured Performance of Shielding Materials.—Actual measurements of shielding effectiveness against low-impedance, plane, and high-impedance waves have been performed by various experimenters and results obtained by them are tabulated in Figures 35-49 through 35-51.

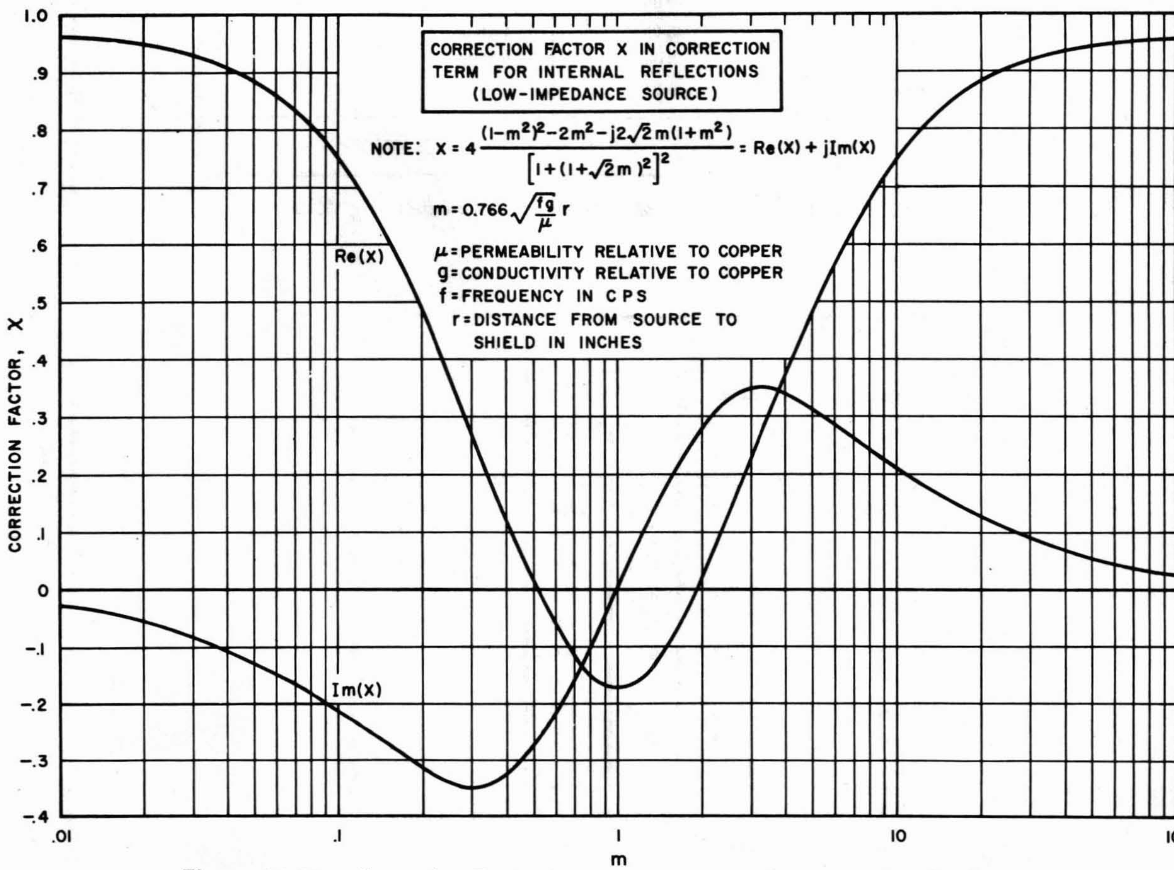


Figure 35-39.—*Correction Factor in Correction Term for Internal Reflections.*

Metal	Relative Conductivity	Relative Permeability	Penetration Loss/Mil at 150 kc (db)
Silver	1.05	1	1.32
Copper, Annealed	1.00	1	1.29
Copper, Hard-Drawn	0.97	1	1.26
Gold	0.70	1	1.08
Aluminum	0.61	1	1.01
Magnesium	0.38	1	0.79
Zinc	0.29	1	0.70
Brass	0.26	1	0.66
Cadmium	0.23	1	0.62
Nickel	0.20	1	0.58
Phosphor-Bronze	0.18	1	0.55
Iron	0.17	1000	16.9
Tin	0.15	1	0.50
Steel, SAE 1045	0.10	1000	12.9
Beryllium	0.10	1	0.41
Lead	0.08	1	0.36
Hypernick	0.06	80,000	88.5
Monel	0.04	1	0.26
Mu-Metal	0.03	80,000	63.2
Permalloy	0.03	80,000	63.2
Steel, Stainless	0.02	1000	5.7

Note: Use equation (19) for penetration loss at other frequencies.

Figure 35-40.—*Electrical Properties of Various Shielding Materials.*

Frequency	Material				Penetration Loss/Mil Thickness (db)	
	Copper		Iron			
	g	μ	g	μ	Copper	Iron
60 cps	1	1	0.17	1000	0.026	0.334
1000 cps	1	1	0.17	1000	0.106	1.37
10 kc	1	1	0.17	1000	0.334	4.35
150 kc	1	1	0.17	1000	1.29	16.9
1 mc	1	1	0.17	700	3.34	36.3
15 mc	1	1	0.17	400	12.9	106.0
100 mc	1	1	0.17	100	33.4	137.0
1500 mc	1	1	0.17	10	129.0	168.0
10,000 mc	1	1	0.17	1	334.0	137.0

Note: Other values of μ for iron are 600 at 3 mc, 500 at 10 mc, and 50 at 1000 mc.

Figure 35-41.—*Penetration Loss of Single Solid Metal Shield.*

Frequency	Material				Reflection Loss (db)	
	Copper		Iron			
	g	μ	g	μ	Copper	Iron
60 cps	1	1	0.17	1000	22.4	−0.9
1000 cps	1	1	0.17	1000	34.2	0.9
10 kc	1	1	0.17	1000	44.2	8.0
150 kc	1	1	0.17	1000	56.0	18.7
1 mc	1	1	0.17	700	64.2	28.1
15 mc	1	1	0.17	400	76.0	42.2
100 mc	1	1	0.17	100	84.2	56.5
1500 mc	1	1	0.17	10	*	*
10,000 mc	1	1	0.17	1	*	*

* At these frequencies the fields approach 377 ohms in impedandce and become plane waves. See Figure 35-43.

Notes: 1. Shielding material must be of sufficient thickness to provide 15 db penetration loss or better. Otherwise, the total reflection loss has to be corrected by the B factor as indicated in equation (20) and Figure 35-45.

2. The signal source distance is 12 inches. For other distances, the reflection loss must be recalculated using formula (16).

3. The reflection loss for iron is zero at 620 cps and at 60 cps is a negative quantity. It is again zero at 31.5 cps and then becomes a positive quantity for still lower frequencies.

Figure 35-42.—*Reflection Loss of Single Metal Sheet (Both Surfaces) for Low-Impedance Source.*

Frequency	Material				Reflection Loss (db)	
	Copper		Iron			
	g	μ	g	μ	Copper	Iron
60 cps	1	1	0.17	1000	150.0	112.7
1000 cps	1	1	0.17	1000	138.0	100.5
10 kc	1	1	0.17	1000	128.0	90.5
150 kc	1	1	0.17	1000	117.0	78.8
1 mc	1	1	0.17	700	108.2	72.1
15 mc	1	1	0.17	400	96.4	62.7
100 mc	1	1	0.17	100	88.2	60.5
1500 mc	1	1	0.17	10	76.4	58.8
10,000 mc	1	1	0.17	1	68.2	60.5

Notes: 1. See Note 1, Figure 35-42.

2. Strong plane waves below 1.6 mc (with the exception of 550- to 1600-kc radio broadcast signals) seldom exist in the vicinity of a shielded room.

Figure 35-43.—*Reflection Loss of Single Metal Sheet (Both Surfaces) for Plane-Wave Impedance Source.*

Frequency	Material				Reflection Loss (db)	
	Copper		Iron			
	g	μ	g	μ	Copper	Iron
60 cps	1	1	0.17	1000	278.7	241.0
1000 cps	1	1	0.17	1000	242.0	204.4
10 kc	1	1	0.17	1000	212.0	174.0
150 kc	1	1	0.17	1000	176.8	139.0
1 mc	1	1	0.17	700	152.0	116.0
15 mc	1	1	0.17	400	116.9	83.1
100 mc	1	1	0.17	100	92.0	64.4
1500 mc	1	1	0.17	10	*	*
10,000 mc	1	1	0.17	1	*	*

* Above 100 mc, the fields approach plane waves with an impedance of 377 ohms. See Figure 35-43.

Note: 1. See Notes 1 and 2, Figure 35-42.

Figure 35-44.—*Reflection Loss of Single Metal Sheet (Both Surfaces) for High-Impedance Source.*

Shield Thickness (mils)	B-Factor (db)					
	60 cps	100 cps	1 kc	10 kc	100 kc	1 mc
Copper, μ=1, g=1, Magnetic Fields						
1	−22.22	−24.31	−28.23	−19.61	−10.34	−2.61
5	−21.30	−22.07	−15.83	−6.98	−0.55	+0.14
10	−19.23	−18.59	−10.37	−2.62	+0.57	0
20	−15.35	−13.77	−5.41	+0.13	−0.10	
30	−12.55	−10.76	−2.94	+0.58	0	
50	−8.88	−7.07	−0.58	0		
100	−4.24	−2.74	+0.50			
200	−0.76	+0.50	0			
300	+0.32	+0.53				
Copper, μ=1, g=1, Electric Fields and Plane Waves						
1	−41.52	−39.31	−29.38	−19.61	−10.33	−2.61
5	−27.64	−25.46	−15.82	−6.96	−0.55	+0.14
10	−21.75	−19.61	−10.33	−2.61	+0.57	0
20	−15.99	−13.92	−5.37	+0.14	−0.10	
30	−12.73	−10.73	−2.90	+0.58	0	
50	−8.81	−6.96	−0.55	+0.14		
100	−4.08	−2.61	+0.51	0		
200	−0.62	+0.14	0			
300	+0.14	+0.58				
Iron, μ = 1000, g = 0.17, Magnetic Fields						
1	+0.95	+1.23	−1.60.	−1.83		
5	+0.93	+0.89	−0.59	0		
10	+0.78	+0.48	+0.06			
20	+0.35	+0.08	0			
30	+0.06	−0.06				
50	0	0				
Iron, μ = 1000, g = 0.17, Electric Fields and Plane Waves						
1	−19.53	−17.41	−8.35	−1.31		
5	−6.90	−5.17	+0.20	0		
10	−2.56	−1.31	+0.36			
20	+0.16	+0.54	0			
30	+0.58	+0.42				
50	+0.13	0				

Note: This B-factor correction has to be applied to the reflection loss values shown in Figures 35-42, 35-43, and 35-44 when the total penetration loss obtained from Figure 35-41 is $<$15 db.

Figure 35-45.—*B-Factor Correction for Single Metal Sheet.*

d. Shield Discontinuities.—Unfortunately, a shielded equipment case cannot be constructed with one continuous metallic sheet; some discontinuities are necessary to accommodate input and output lines, power lines, antennas, front-panel seams, control shafts, ventilating holes, etc., as illustrated in Figure 35-52. The design and construction of these discontinuities become very critical when it is found necessary to incorporate them without appreciably reducing the shielding effectiveness of the overall shielded enclosure. Some design and construction considerations are given below.

(1) Seams—No Gasket.—Clean metal-to-metal mating surfaces, together with good pressure contact obtained by use of set screws or rivets, are necessary to prevent electromagnetic leakage. Corrosion or anodizing cannot be tolerated.

(2) Seams—Metallic Gasket.—Considerable shielding improvement can be obtained by using various types of metallic gaskets, which are flexible, resilient, conductive materials placed between shielding surfaces to be jointed. They are frequently made of knitted wire-mesh. Clean metal-to-metal mating surfaces and a good pressure contact are required. Experimental evidence indicates that an optimum pressure on various conducting gasket materials is approximately 20 psi. A typical variation of shielding insertion-loss with pressure

Material	Frequency	Type of Field	Metal Thickness (mils)	R Reflection Loss (db)	A Penetration Loss (db)	B Correction Term (db)	Total Shielding Effectiveness S = R+A+B (db)
Copper	60 cps	Magnetic	1	22.4	0.026	−22.2	0.23
	60 cps	Magnetic	10	22.4	0.26	−19.2	3.46
	60 cps	Magnetic	300	22.4	7.80	+0.32	30.52
	1 kc	Magnetic	10	34.2	1.06	−10.37	24.89
	10 kc	Magnetic	10	44.20	3.34	−2.62	44.92
	10 kc	Electric	10	212.0	3.34	−2.61	212.73
	10 kc	Plane Waves	10	128.0	3.34	−2.61	128.73
	10 kc	Magnetic	30	44.20	10.02	+0.58	54.80
	150 kc	Magnetic	10	56.0	12.9	+0.5	69.4
	150 kc	Electric	10	176.8	12.9	+0.5	190.2
	150 kc	Plane Waves	10	117.0	12.9	+0.5	130.4
	1 mc	Magnetic	10	64.2	33.4	0	97.6
	1 mc	Electric	10	152.0	33.4	0	185.4
Copper	1 mc	Plane Waves	10	108.2	33.4	0	141.6
Iron	60 cps	Magnetic	1	−0.9	0.334	+0.95	0.38
	60 cps	Magnetic	10	−0.9	3.34	+0.78	3.22
	60 cps	Magnetic	300	−0.9	100.0	0	99.1
	1 kc	Magnetic	10	0.9	13.70	+0.06	14.66
	10 kc	Magnetic	10	8.0	43.5	0	51.5
	10 kc	Electric	10	174.0	43.5	0	217.5
	10 kc	Plane Waves	10	90.5	43.5	0	134.0
Iron	10 kc	Magnetic	30	8.0	130.5	0	138.5

Figure 35-46.—*Typical Calculated Values of Shielding Effectiveness.*

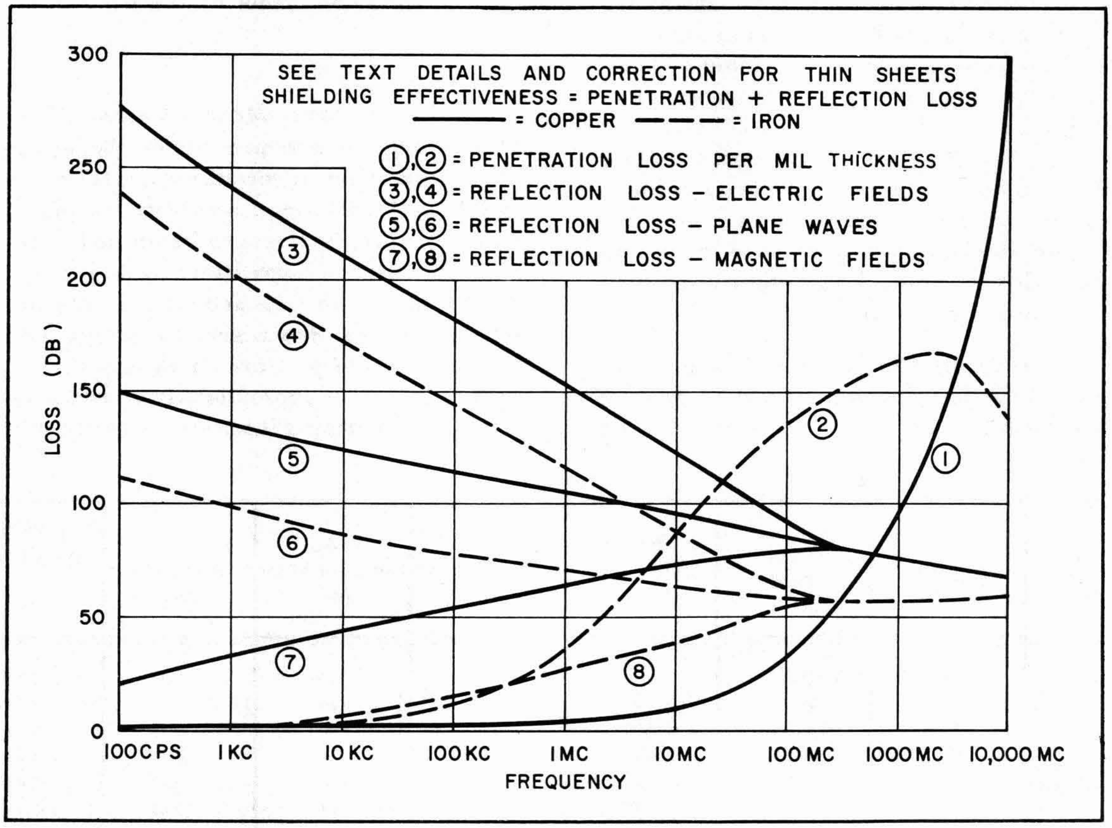


Figure 35-47.—*Shielding Effectiveness of Metal Barriers.*

Frequency	Wavelength (mils)	
	Copper	Iron
100 mc	1.64	0.399
10 mc	5.20	0.561
1 mc	16.4	1.51
100 kc	52.0	39.9
10 kc	164	126
1 kc	520	399
100 cps	1640	1260
10 cps	5200	3990

Figure 35-48.—*Wavelengths of Electromagnetic Waves in Copper and Iron.*

is shown in Figure 35-53. Instead of knitted wire mesh, another type r-f gasket is sometimes employed. Essentially, it is a 10-mil strip of beryllium copper, perforated to have jagged points on both surfaces. It can be imbedded in rubber and requires very little pressure to give a good metal-to-metal contact of low r-f impedance. Its advantages are that it does not require clean metal-to-metal mating surfaces, and it will tolerate a large degree of corrosion, or anodizing on the mating surfaces.

(3) Holes and Screening.—Any holes in the equipment used for ventilation or for any other purpose will materially decrease the shielding effectiveness of the case. The larger the diameter of the hole and the higher the applied frequency, the greater will be the leakage. Holes must be kept as small as possible—not larger than those in 22-mesh,

15-mil copper screening, if more than a nominal 50-db shielding effectiveness is required up to 1000 mc.

(4) Waveguides.—Waveguides are hollow conducting tubes which are capable of propagating electromagnetic energy with little attenuation above some cut-off frequency and severely attenuating such energy below the cut-off frequency. The latter property is often used in the construction of shielded enclosures to permit airflow without negating electromagnetic-shielding effectiveness. Constructions which appear somewhat like automobile radiator cores are frequently used as a parallel assembly of waveguides permitting adequate air-flow at a high cut-off frequency. For 100-db of attenuation, the length of the waveguide must be at least 3 times the diameter of the hole. The maximum permissible diameter (d max) can be obtained by dividing the wavelength (λ min) for the highest frequency under consideration by 3.4, where both diameter and wavelength are expressed in the same units.

$$d_{max} = \frac{\lambda min}{3.4} \qquad (24)$$

(5) Control Shaft—Grounded.—Metallic control shafts protruding through the equipment case must be grounded to the case by use of a gasket or serrated metallic fingers.

Form		Material	Thickness (mils)	Nominal Effectiveness (db)					
General	Detail			0.1 kc	1kc	10kc	85kc	1mc	10mc
Solid Sheet		Cu	125	8	22	58			
			63				97		
			31	4	11	29	59	120	
			4.5				34	55	
		Al	125	5	18	50			
			63	1	16	35	78		
			31	1	10	24			
		Steel (u = 242)	63	25	40	80			
			31	4	28	59	94	92	120
		Brass	31				42		
	Clad 2 sides	Cu-Clad Steel	31				107		
	1 Side only		94				103		
Mesh (Screening)	2 layers 1 inch apart	Cu (oxi dized)		2	6	18			
	No. 22	Cu					31	43	43
	No. 16	Bronze					18		
	No. 4	Galvanized Steel					10	17	21

Figure 35-49.—*Effectiveness of Shielding Materials Against Low-Impedance Waves.*

(6) *Control Shaft — Not Grounded.* — A control shaft made of insulating material can protrude through the case by insertion inside a waveguide attenuator.

(7) *Fuse Receptacle.*—The fuse receptacle necessitates a large hole, and should be provided with a metallic cap.

(8) *Phone and Meter Jacks.*—These jacks should be provided with metallic caps.

(9) *Panel Meter.*—The panel meter requires a large hole in the case which should be modified as shown in Figure 35-53 to provide a continuous shield. All meter leads should be filtered.

(10) *Pilot Lamp.*—The pilot lamp should be properly filtered, or covered with screening material or perforated metal.

(11) *Filtered Lines.*—All unshielded lines should be properly filtered with pi-section filters or feed-through capacitors. The degree of attenuation required of the filter depends on the level of undesired signals present in the lines themselves. For additional filter considerations, refer to CED 3506.3.

(12) *Unfiltered Lines.*—Open wiring may be a point of excessive leakage when not filtered. Such lines can be tolerated only if they do not carry high levels of undesired signals, or if they do not

<table>
<tr><th colspan="2">Form</th><th rowspan="2">Material</th><th rowspan="2">Thickness (mils)</th><th colspan="12">Nominal Effectiveness (db)</th></tr>
<tr><th>General</th><th>Detailed</th><th colspan="4">200kc</th><th colspan="4">1 mc</th><th colspan="4">5mc</th></tr>
<tr><td rowspan="5">Solid Sheet</td><td></td><td>Cu</td><td>2.5</td><td colspan="4">109</td><td colspan="4">106</td><td colspan="4">114</td></tr>
<tr><td></td><td>Al</td><td>5</td><td colspan="4">107</td><td colspan="4">109</td><td colspan="4">118</td></tr>
<tr><td></td><td>Stainless Steel</td><td>18</td><td colspan="4">97</td><td colspan="4">95</td><td colspan="4">99</td></tr>
<tr><td></td><td>Steel ($U_r = 250$)</td><td>4.5</td><td colspan="4">105</td><td colspan="4">99</td><td colspan="4">101</td></tr>
<tr><td></td><td>AA-Conetic Foil ($U_r = 10,000$)</td><td>3.5</td><td colspan="4">97</td><td colspan="4">130</td><td colspan="4"></td></tr>
<tr><td rowspan="2">Perforated Sheet</td><td rowspan="2">45 mil dia, 225 sq. inch</td><td rowspan="2">Al</td><td rowspan="2">20</td><td colspan="6">3040 mc</td><td colspan="6">9380 mc</td></tr>
<tr><td colspan="6">60</td><td colspan="6">62</td></tr>
<tr><td rowspan="3">Mesh (Screening)</td><td>No. 16</td><td>Al</td><td>dia = 13</td><td colspan="6">34</td><td colspan="6">36</td></tr>
<tr><td rowspan="2">No. 22</td><td rowspan="2">Cu</td><td rowspan="2">dia = 15</td><td colspan="3">200 kc</td><td colspan="3">1 mc</td><td colspan="3">5 mc</td><td colspan="3">100 mc</td></tr>
<tr><td colspan="3">118</td><td colspan="3">106</td><td colspan="3">100</td><td colspan="3">80</td></tr>
</table>

Figure 35-50.—*Effectiveness of Shielding Materials Against Plane Waves.*

<table>
<tr><th colspan="2">FORM</th><th rowspan="2">MATERIAL</th><th rowspan="2">THICKNESS (mils)</th><th colspan="3">NOMINAL EFFECTIVENESS [1] (db)</th><th rowspan="2">OPEN AREA (%)</th><th colspan="2">AIR-FLOW STATIC PRESSURE (inches of water)</th></tr>
<tr><th>GENERAL</th><th>DETAILED</th><th colspan="3">14 kc to 1000 mc</th><th>200 cu ft/min</th><th>400 cu ft/min</th></tr>
<tr><td>Hexcell</td><td>1/4-inch cell, 1 inch thick</td><td>Al</td><td>3</td><td colspan="3">>90</td><td></td><td>0.06</td><td>.26</td></tr>
<tr><td>TV Shadow Masks (Photo-Etched)</td><td>9-mil holes, 28-mil centers</td><td>95% Cu 5% Ni</td><td>7</td><td colspan="3">>90</td><td>12</td><td>>2</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3"></td><td>50</td><td>0.2</td><td>0.4</td></tr>
<tr><td></td><td></td><td>100% Ni</td><td>3</td><td colspan="3">>90</td><td>50</td><td>0.2</td><td>0.5</td></tr>
<tr><td>Lektromesh</td><td>40 count</td><td>Cu-Ni</td><td>7</td><td colspan="3">>90</td><td>36</td><td>0.4</td><td>1.7</td></tr>
<tr><td></td><td>25 count</td><td></td><td>5</td><td colspan="3">78</td><td>49</td><td>0.2</td><td>0.5</td></tr>
<tr><td></td><td>40 count</td><td>Cu</td><td>3</td><td colspan="3">78</td><td>57</td><td>0.2</td><td>0.5</td></tr>
<tr><td></td><td>25 count</td><td></td><td></td><td colspan="3"></td><td>56</td><td>0.2</td><td>0.4</td></tr>
<tr><td>Perforated Sheet</td><td>1/8-inch dia., 3/16-inch centers</td><td>Steel</td><td>60</td><td colspan="3">58</td><td></td><td>0.27</td><td>>0.6</td></tr>
<tr><td></td><td>1/4-inch dia., 5/16-inch centers</td><td>Al</td><td>60</td><td colspan="3">48</td><td>46</td><td></td><td></td></tr>
<tr><td></td><td>7/16-inch dia., 5/8-inch centers</td><td></td><td>37</td><td colspan="3">35</td><td>45</td><td></td><td></td></tr>
<tr><td>Mesh (Screening)</td><td>No. 16 16 x 16/sq.in.</td><td>Al</td><td>20 (dia)</td><td colspan="3">55</td><td>36</td><td></td><td></td></tr>
<tr><td></td><td>No. 22</td><td>Cu</td><td></td><td colspan="3">65(14 kc to 60 mc)</td><td></td><td></td><td></td></tr>
<tr><td></td><td>No. 12</td><td></td><td>20 (dia)</td><td colspan="3">50</td><td>50</td><td></td><td></td></tr>
<tr><td></td><td>No. 16</td><td>Bronze</td><td></td><td colspan="3">45(14 kc to 60 mc)</td><td></td><td></td><td></td></tr>
<tr><td></td><td>No. 10</td><td>Monel</td><td>18 (dia)</td><td colspan="3">40</td><td></td><td></td><td></td></tr>
<tr><td></td><td>No. 4</td><td>Galvanized Steel</td><td>30 (dia)</td><td colspan="3">35 [2]
28 [2] (14 kc to 40 mc)</td><td>76</td><td></td><td></td></tr>
<tr><td></td><td>No. 2</td><td></td><td></td><td colspan="3">24</td><td>88</td><td></td><td></td></tr>
<tr><td>Coatings</td><td></td><td>Silver Paint</td><td></td><td>85 kc
>120</td><td>1 mc
114</td><td>10 mc
90</td><td>0</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Graphite</td><td></td><td>86</td><td>67</td><td>50</td><td>0</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Conducting Glass</td><td></td><td>73</td><td>53</td><td>39</td><td>0</td><td></td><td></td></tr>
</table>

[1] These data have been obtained by various experimenters.

[2] Different values obtained by different experimenters.

Figure 35-51.—*Effectiveness of Shielding Materials Against High-Impedance Waves.*

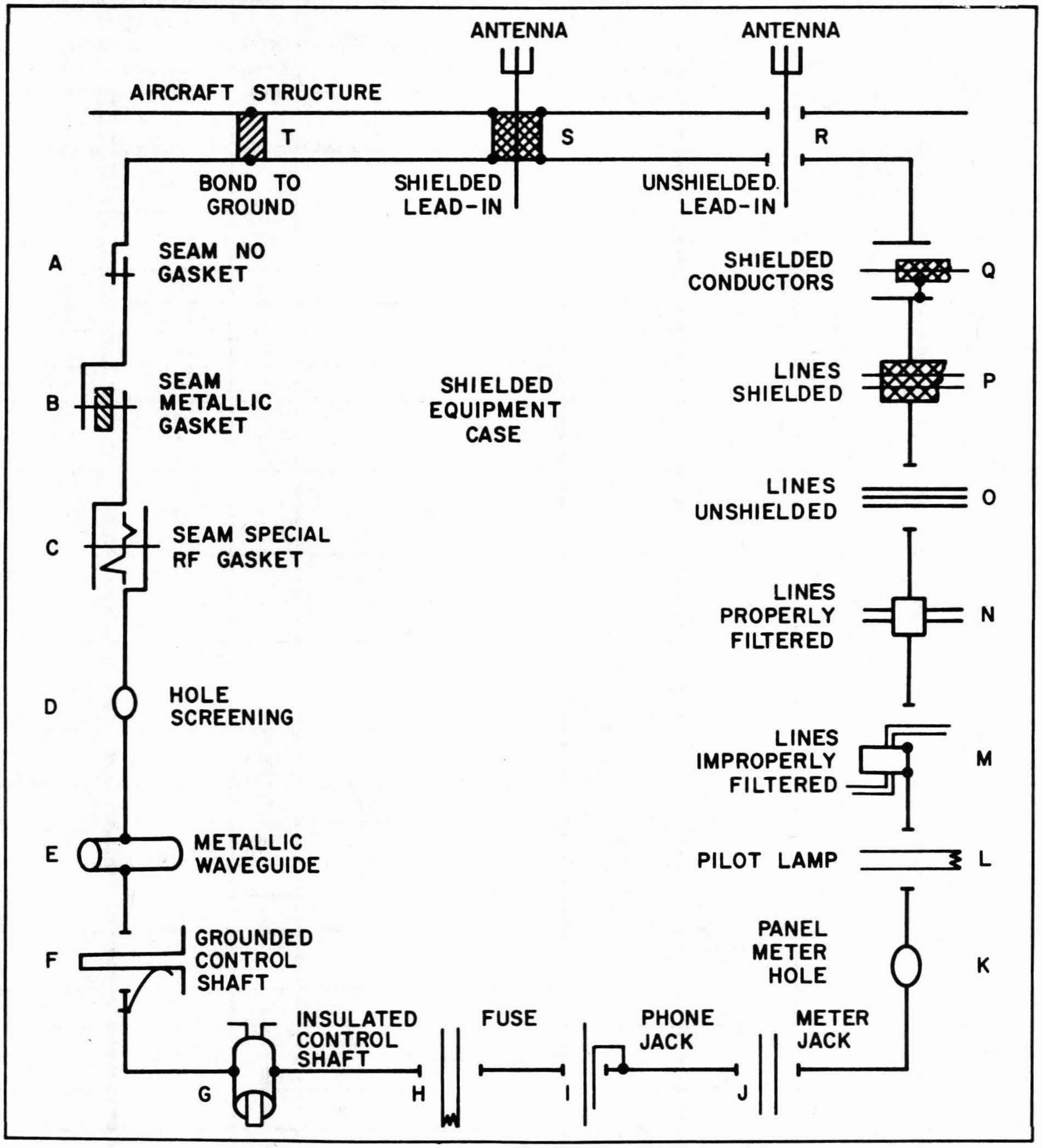


Figure 35-52.—*Typical Shielded-Enclosure Discontinuities.*

provide an easy r-f entry into the equipment. It may be necessary to provide shielded conduit or shielded transmission lines with an outer wall having a shielding effectiveness as high as that of the shielded enclosure itself. At connectors, the braid shielding of all conductors should be carried well into the connector wall and grounded to it.

(*a*) ***Antenna Lead-Ins.*** — Unshielded antenna lead-ins are undesirable and are not permitted under the design requirements of Specifications MIL-I-26600 and MIL-I-6181D. Shielded antenna lead-ins are satisfactory, provided the shielding effectiveness of the transmission line is as effective as that of the shielded case itself.

.5 Bonding Techniques.—As far as radio interference is concerned, bonding serves one main purpose: to provide a path of low impedance for the radio-interference currents. It has been found in practice that a necessary condition for the existence of a good bond is very low d-c resistance. On the other hand, because of the importance of inductance and capacitance at radio frequencies, low d-c resistance alone does not assure a good bond. For

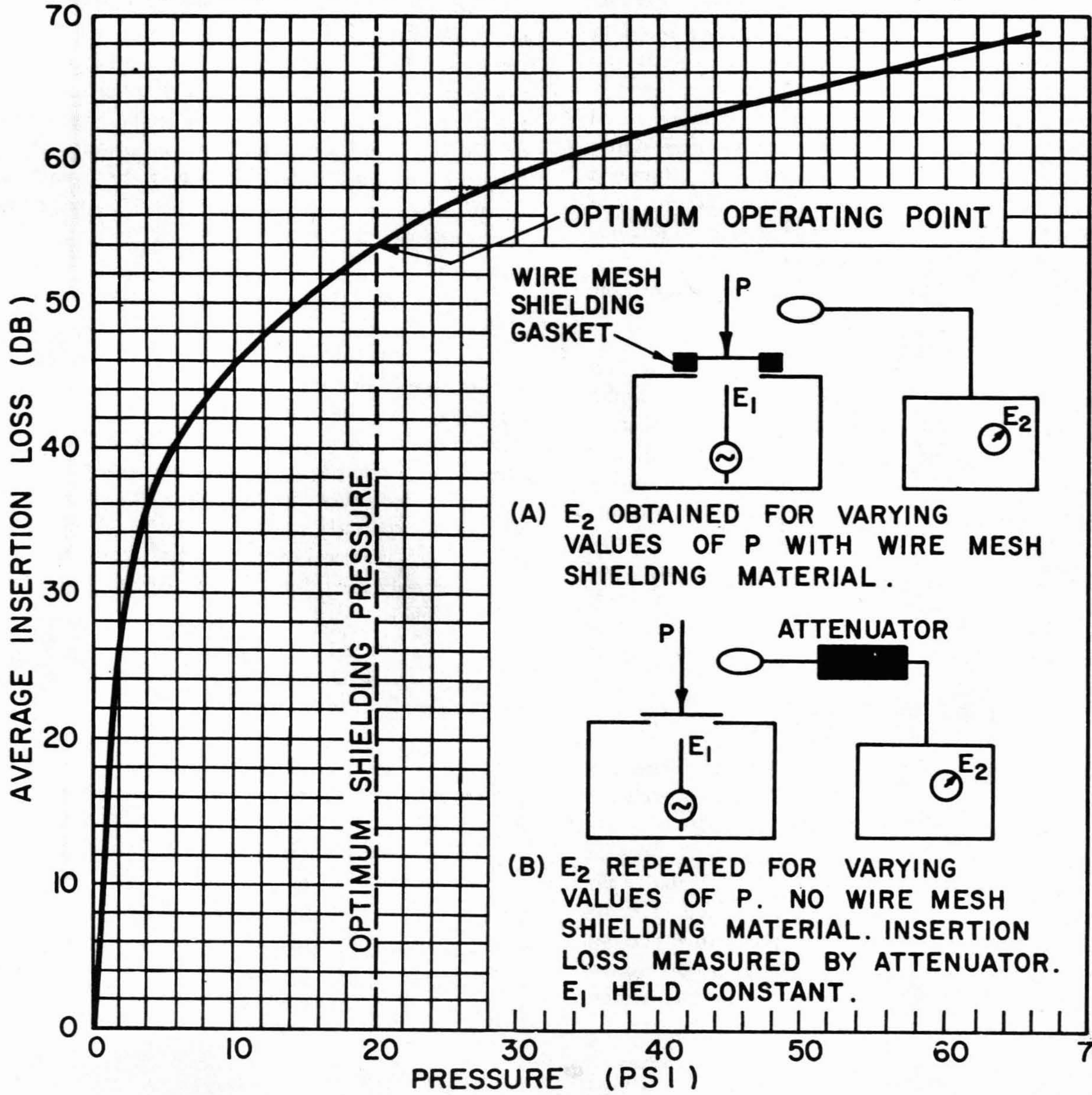


Figure 35-53.—*Typical Insertion Loss as a Function of Gasket Pressure.*

r-f, the proper installation of a very low inductance band is necessary least the system capacitance combine with the bond inductance to produce a very high impedance. However, because of the difficulties in measuring r-f impedances of bonds, the d-c resistance is normally used as a measure of the effectiveness of the bond.

a. Types of Bonds.—In general, the two types of bonding are direct bonding, and bonding by means of jumpers. Direct bonding consists of a permanent or semipermanent metal-to-metal contact between the members to be bonded. If this method is practical, it is always preferable. But if clearance between the bonded members must be maintained for mechanical reasons, or if the equipment to be bonded is shock-mounted, then direct bonding is not feasible and bond straps must be used. Even at best, a bond strap is no more than a poor substitute for a direct bond.

b. Direct Bonding.—Direct Bonding is accomplished by direct metal-to-metal contact under high and uniform pressure, or by fusion of the joining surface layers. If properly constructed, a bond of this type has low d-c resistance as well as low r-f impedance. Permanent joining of metallic parts by welding, brazing, or sweating are the best direct bonds. Semi-permanent joints of machined metallic surfaces—rigidly held together—provide excellent direct bonds if the contact areas are clean and all protective coatings have been removed before assembly.

c. Semi-Permanent Bonds.

(1) Deterioration. — Semi-permanent bonds may deterioriate with time due to the chemical action of corrosion. While corrosion is a very complicated process, the most important factors are the amount of moisture present, and the relative position of the two metals in the so-called "electromotive-force series". The more moisture present, and the further apart the two metals in the electromotive-force series, the more severe is the corrosion. Figure 35-54 is the electromotive force series.

(2) RF Impedance.—Bonding straps are preferably solid flat strips in order to obtain large surface area for low r-f impedance—since r-f currents concentrate on the surfaces of conductors. The measured r-f impedance of typical flat bond straps at frequencies up to 30 mc increases almost linearly with frequency; hence, this impedance is due almost entirely to the inductance of the strap. An additional difficulty is introduced by the ever-present capacitance between the bonded members. This capacitance is in parallel with the inductance of the strap. The impedance of a parallel combination of inductance and capacitance is very high at certain frequencies, and in many applications these frequencies lie in the region between 50 and 500 mc, *i.e.,* well in the region of radio-interference considerations. These effects are reduced by keeping the inductance as low as possible, which in turn requires the use of straps of minimum length and high ratio of width to thickness. The most important considerations are to make the bonding straps as short as possible and to insure good contact between the straps and the members to be bonded.

(3) Typical Bonding Applications.

(a) Figure 35-55 shows a typical shock-mount bonding strap application. This type of bonding must be used with all shock-mounted equipment representing a potential source of interference and, even more important, with all shock-mounted receivers, for which a good bond to ground is especially important. Although not quite so effective as straps of sheet metal, braided straps are commonly used to secure the necessary mechanical flexibility.

(b) Other typical examples of the use of bond straps are the bonding of structural parts

Magnesium
Aluminum
Zinc
Chromium
Iron
Cadmium
Nickel
Tin
Lead
Copper
Silver

Figure 35-54.—*Electromotive-Force Series of Metals.*

of a vehicle which cannot be bonded directly for mechanical reasons, and bonding of a shock-mounted engine to its mounting frame.

(c) Because the best designed shielded enclosure, even without any discontinuities, is not a perfect shield, it is necessary to bond the enclosure to a common reference ground such as the aircraft structure. This contact is usually established through the mounting rack. A good bond will reduce the radiation leaking out of the shielded enclosure. Normally, this bond should not have an r-f impedance higher than 80 milliohms from 15 kc to 20 mc. A poorly designed bond will, in addition to increasing radiation from the case, permit undesired signals in the vicinity of the equipment to appear at the input of the receiver as shown in Figure 35-56, and thus cause undesired response or malfunctioning.

(d) A special problem arises when the two members to be bonded are in continuous relative motion. For example, to bond a generator shaft to the generator housing, obviously neither direct bonding nor bond straps are feasible. Recommended procedure for this case is the use of a shaft bond consisting of a brush which rides on a special slip ring or rides directly on the generator shaft.

d. Bonding Misapplications. — Several common misapplications of bonding techniques that can cause difficulties through excessively high impedance paths, or by incorrect interconnection of multiple paths, are noted here:

(1) *Screw Threads.* — Screw threads, including those of sheet-metal screws, are never considered adequate bonding surfaces. If two structural members are held together by means of screws, the impedance between them is usually comparatively high unless good direct contact is maintained. Where bonding is required, all efforts should be made to ensure good direct bonding; but, if for some reason this cannot be achieved, bond straps must be used.

(2) *Ground Loops.*—A ground loop is a closed conductive circuit which includes a multiplicity of paths intended for connection of equipment(s) to an r-f ground. Such an arrangement is explained in CED 3503.2c. Undesired effects may be avoided by the use of correct grounding techniques as illustrated by Figure 35-57. Where equipment is not interconnected, the single-point and multiple-point grounds of (A) and (B) may be satisfactory. Where equipment must be interconnected, only the system shown in (C) is acceptable. Even in (C), difficulty may be experienced when connecting leads are a significant fraction of a quarter wavelength, say $\lambda/40$ or greater; then lead ends are not at the same potential.

3506. ADDITIONAL INTERFERENCE - REDUCTION TECHNIQUES.

.1 Introduction. — In addition to good basic equipment design, and to the general suppression techniques which have broad application, certain

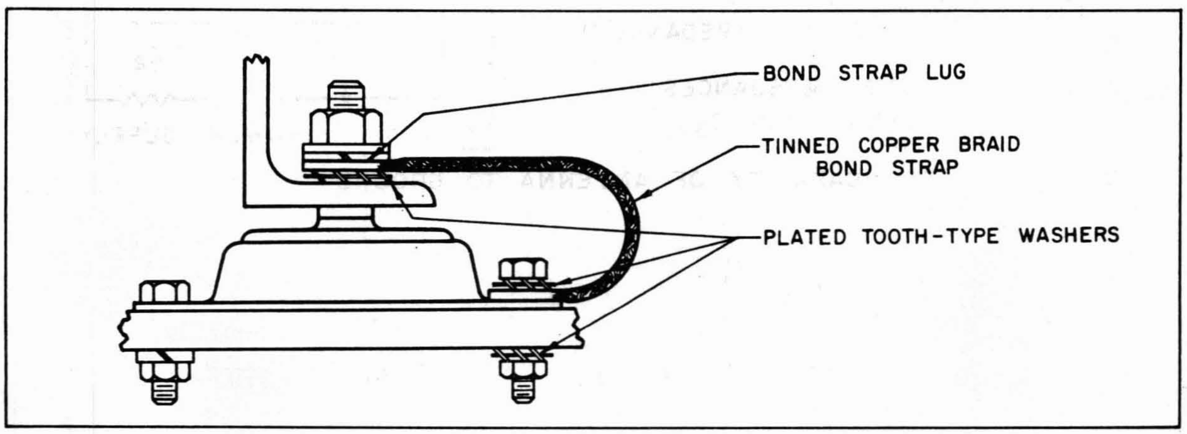
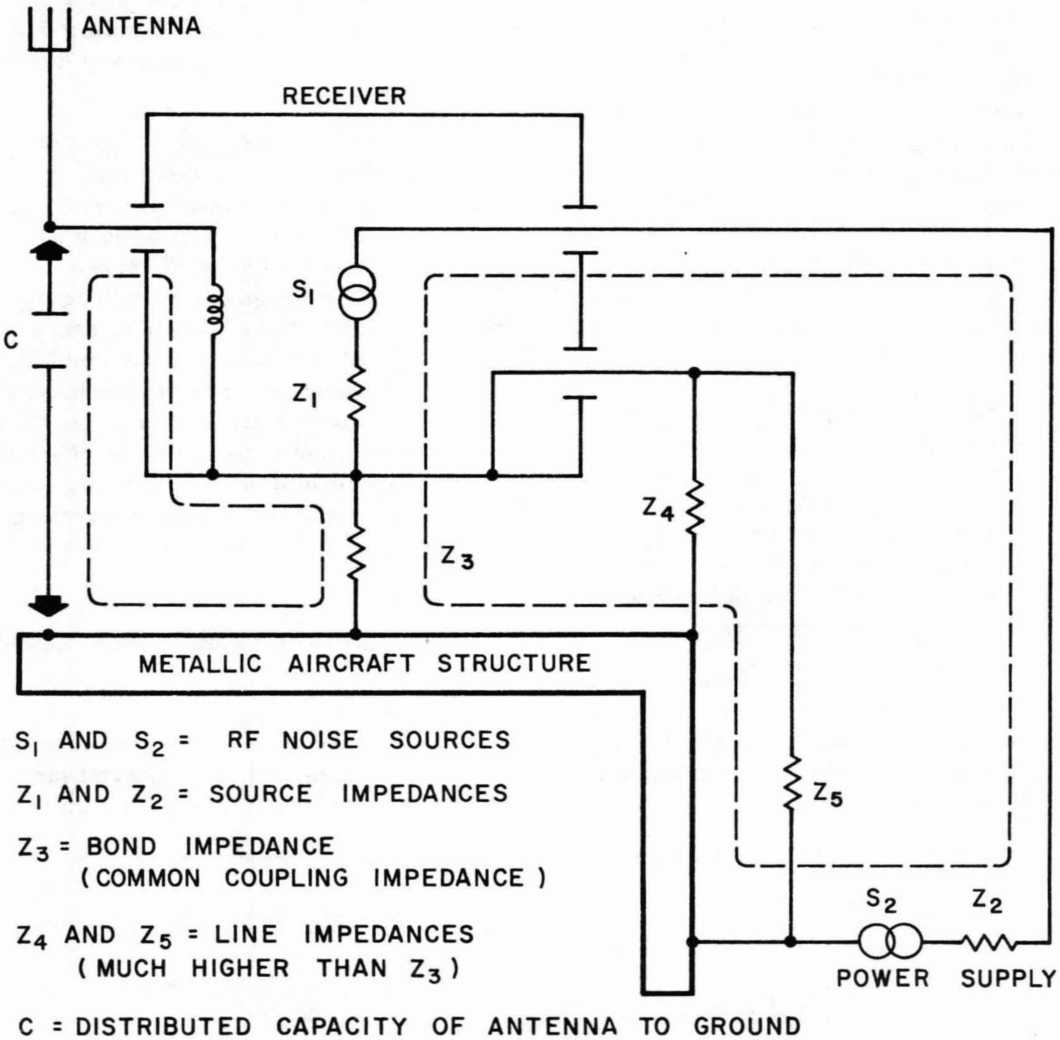


Figure 35-55.—*Typical Shock-Mount Bond.*


ANTENNA
RECEIVER
C
S_1
Z_1
Z_3
Z_4
Z_5
METALLIC AIRCRAFT STRUCTURE
S_2
Z_2
POWER SUPPLY
S_1 AND S_2 = RF NOISE SOURCES
Z_1 AND Z_2 = SOURCE IMPEDANCES
Z_3 = BOND IMPEDANCE
(COMMON COUPLING IMPEDANCE)
Z_4 AND Z_5 = LINE IMPEDANCES
(MUCH HIGHER THAN Z_3)
C = DISTRIBUTED CAPACITY OF ANTENNA TO GROUND

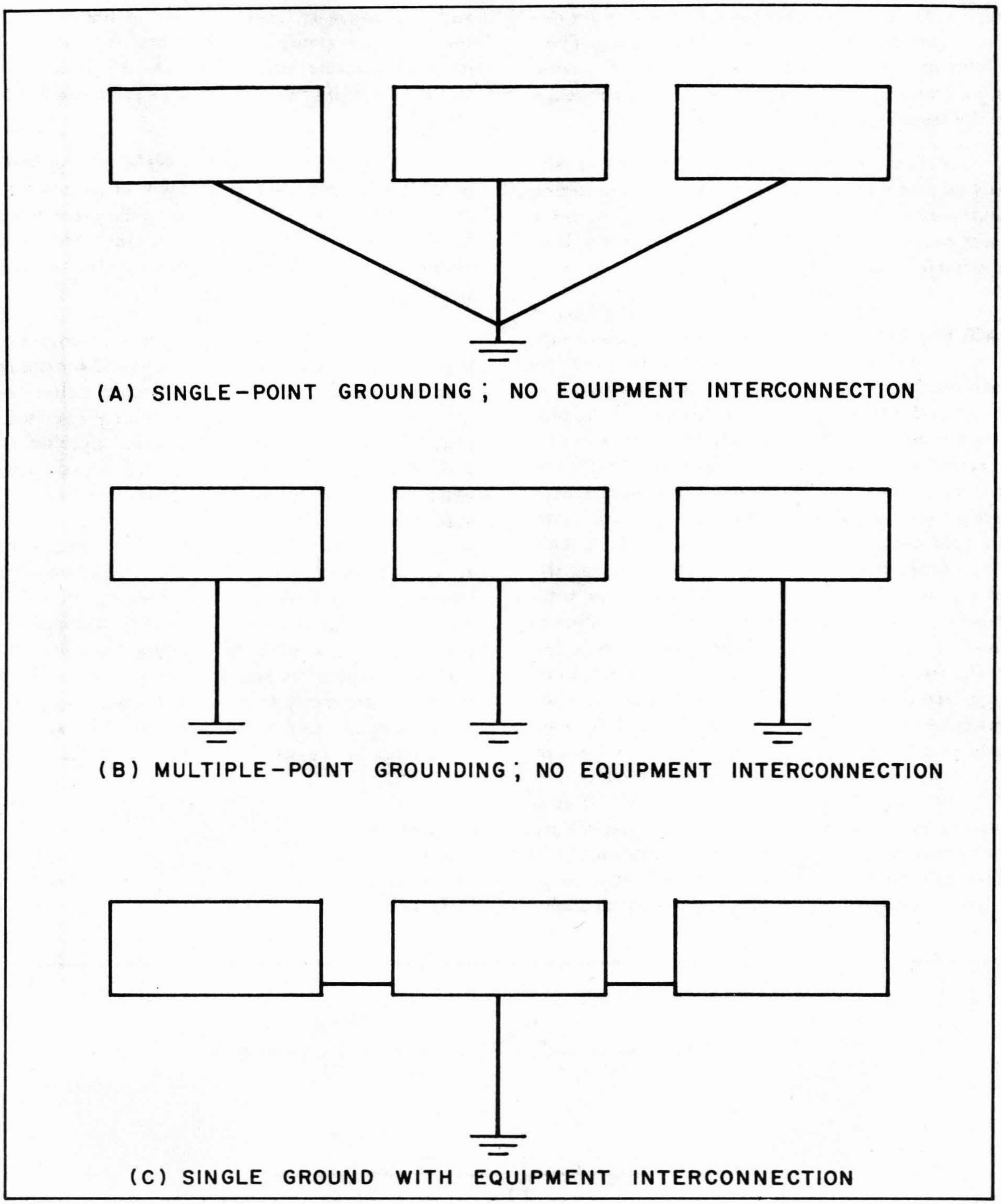


Figure 35-57.—*Preferred Equipment-Bonding Connections.*

other techniques more specialized in scope are useful to reduce electromagnetic interference. These additional approaches have been classified according to their application to sources of interference, to the transmission media, and to receivers.

.2 Sources of Generation. — Interference signals may be reduced in amplitude at the interfering source by various approaches, depending upon the exact nature of the source. Several methods will be presented below:

a. Employment of Dissipative Filters at Switching Contacts.—Approximately 40 db of suppression of both conducted and radiated interference can be obtained by the use of dissipative R-C filters at d-c and some a-c switching contacts, provided a voltage drop of about 10 percent can be tolerated across such filters. A dissipative R-C filter may consist of an equal resistance in series with each switch contact and a capacitor in parallel with the combination, as shown in Figure 35-58. This use of series resistance aids in slightly reducing the interference due to the small reduction in total switched current, but the major filtering effect is caused by a reduced rate of change of current due to the filter, combined with local dissipation of high-frequency energy. Practical experience with this circuitry indicates optimum suppression of interference when R is approximately 10 percent of the circuit resistance, and C is approximately 0.25 μfd., although these values are not critical. Of vital importance is the manner in which components are connected. As in similar filtering applications, it is absolutely necessary that all leads be kept as short as possible to minimize the circuit stray elements and radiating wire lengths. Capacitor leads to resistor elements should be less than 0.125-inch in length, if possible; resistor leads should also be kept short, although these lead lengths are not quite so critical.

b. Establishment of Well-Defined Equipotential Surfaces.—The problem of electrostatic discharge phenomena causing electromagnetic interference arises in high-voltage systems and in mechanically coupled systems which generate static electricity.

(1) High-Voltage Systems.—Examples of high-voltage systems which are potential sources of corona and associated radio interference include ionized gas display-signs, high-voltage power supplies (r-f or otherwise), electrostatic precipitators, and other high-voltage generators. Corona occurs when the voltage between two conductors becomes sufficiently high that the electric field intensity, which is greatest at a conductor surface, ionizes the air at such a surface and produces a faintly visible violet light. To decrease corona interference, it may be necessary to control contributory atmospheric conditions such as dust, dirt, fungus, humidity, and extreme temperature and pressure variations. Also, it may be necessary to round off sharp angles on conductors and solder joints, increase wire spacing or provide better insulation between wires.

(a) High-tension electrical lines near radio-sensitive areas which create interference by corona around, and leakage across, high-voltage insulation may frequently be improved as noted in CED 3502.4a.

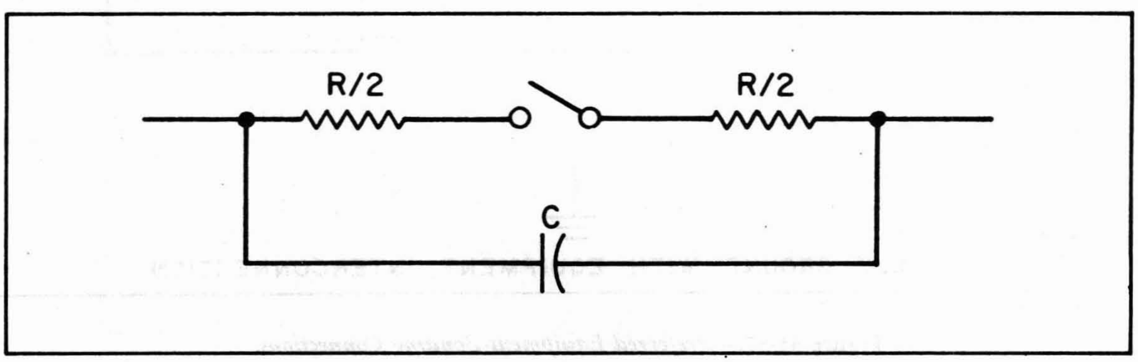


Figure 35-58.—*Dissipative R-C Filter.*

(2) Mechanically-Coupled Systems.—One example of a mechanically-coupled system is a belt drive feeding power to a lathe. In a dry atmosphere, static charges may accumulate on the belt, which is generally made of rubber or leather. The resulting electrical charge may then build up to a value sufficient for voltage breakdown, at which point an impulsive current generates interference signals as noted in CED 3502.4c. As an interference-reduction measure, the belt may be made sufficiently conductive by applying a specially-prepared coating so that charges are not generated so abundantly as before, and so that those which do accumulate can be more evenly distributed along the belt and be provided with a leakage path to ground. Such a coating, if used, should be renewed approximately every three months. The dressing must be re-applied periodically, or interference may again become prominent.

(a) Dressing for Rubber Belts.—To prepare a conductive coating for rubber belts, mix 18 parts of lamp-black to 82 parts of good spar varnish. The dressing must dry on the belt before using. A non-inflamable thinner for the varnish may be made by mixing equal volumes of carbon tetrachloride and printer's naphtha.

(b) Dressing for Leather Belts.—A nonstatic leather-belt dressing of merit is a mixture of 100-cc. liquid fish glue, 80-cc. glycerine, 100-cc. sulphonated castor oil, 170-cc. water, 82-grams lampblack, and 20-cc of 2 percent ammonium hydroxide. The glue and glycerine are heated 1.5 hours at 230°F. The 2 percent solution of ammonium hydroxide is added after the water has been mixed with the glue and glycerine. In some cases improved results may be obtained by increasing the quantities of fish glue and glycerine. This mixture is easily applied with a brush while the belt is in motion, since it is not necessary for the dressing to dry before running.

c. Use of Sector-Scan Radars.—Where operational requirements permit, a search radar might be operated to sector-scan as a means to prevent directing power into sensitive equipment. Although interfering power is eliminated in the sector not scanned, an operational penalty is implicit since performance capability in the non-scanned sector is deteriorated. Since other, more refined techniques are available to reject interfering signals, sector scanning devices should be used only to avoid the undesirable effects of physical objects, such as mountains or buildings.

.3 Means of Transmission.—During transmission from source to receiver, all efforts toward reducing interference are aimed at improving the ratio of coupling for the desired signal to coupling for the undesired signal. Some of the ways in which this objective can be accomplished are described in CED 3506.3a and b.

a. Space and Orientation Decoupling to Undesired Signals.—Increasing the distance between the receiver and the source of undesired signals is an obvious means of interference decoupling frequently used. If the desired signal source and undesired signal source lie in different directions from the receiving site, then optimum orientation of a directional receiving antenna will effectively reduce interference. Increased antenna directivity is usually beneficial, particularly against a plurality of undesired sources not in the same direction as the desired source. Furthermore, if desired and undesired signals have different polarizations, use of the optimum polarization for the receiving antenna will be helpful. Obviously, antenna orientation is determined by system operational requirements, and it may not always be possible to redirect an antenna, employ sector scanning, etc.

(1) Siting Effects.—A comparison of typical measured radarsite antenna patterns with those predicted theoretically from considerations of spillover and edge-current generation indicates that most of the measured back-radiation must come from reflections around the sites. For example, measured AN/CPS-6B patterns show far lobes attenuated 35 to 45 db below the main lobe, whereas theoretical free-space considerations indicate that these lobes should be 60 to 70 db below the main lobe.

(a) A typical AN / CPS-6B pattern taken at a site at which ground effects have been minimized is shown in Figure 35-59. The corresponding calculated far-side-lobe levels for representation feed and reflector geometries are shown in Figure 35-60. In the latter figure, n is a parameter related to the amount of primary spill-over.

(b) These considerations are also borne out experimentally in measurements made by the Air Force Special Weapons Center at Kirtland

Air Force Base. Signals returned to a radar are a measure of reflecting objects. Pulse counts at some sites were as high as 800, or even 1200, pulses per second at sensitive levels, although the radar pulse repetition frequency was only 400 pulses per second. These extra pulses could only be due to reflections.

(c) Proper siting can be employed to reduce side lobes by locating the antenna in as near a reflection-free area as possible. This means that there should be as few obstructions in the main beam as possible, such as building, hills, etc. Obviously, this requirement is limited by other considerations, such as logistics and real estate. Also, if the site is high and is relatively free and clear of reflecting objects in the immediate vicinity, the radar is usually more likely to receive interfering pulses from distant radars.

(2) Antenna-Pattern Characteristics. — Directional receiving and transmitting antennas may be employed to achieve improved interference rejection. Over-all power need not be increased, but appropriately-directed power with minimized side and back lobes can result in distinct performance advantages. In view of the importance of these techniques, they will be discussed in some detail.

(a) Side-Lobe Reduction.—Side-lobe reduction can be achieved by improving antenna design (not recommended as an alteration by the C-E officer), proper siting, and the use of absorbing or reflecting materials around the antenna itself. Additional reflectors on a parabolic antenna are

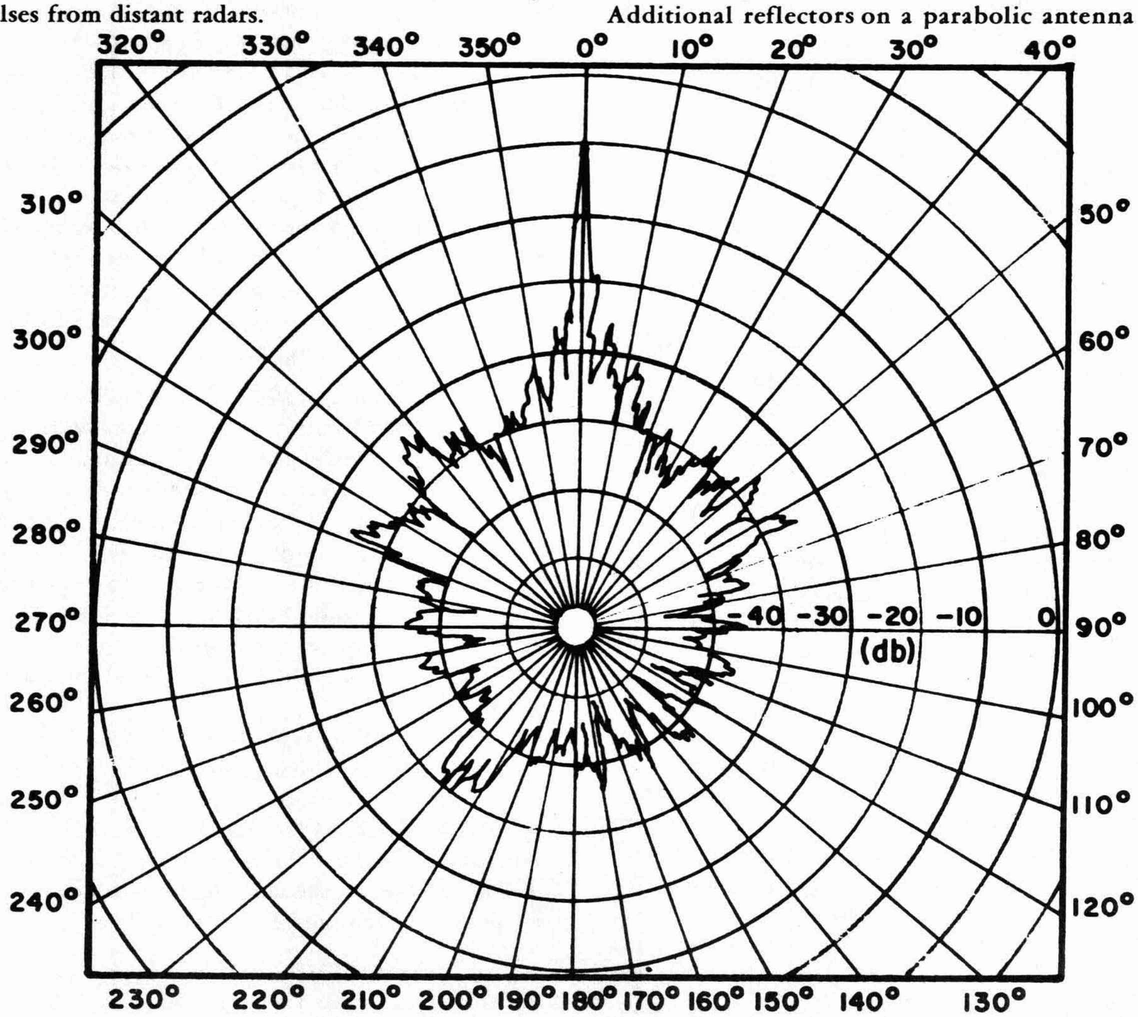


Figure 35-59.—*Typical AN/CPS-6B Antenna Pattern.*

occasionally used as field modifications to reduce specific lobes.

(b) Side-Lobe Subtraction. — Side-lobe subtraction is a method of utilizing both a main receiver with directional antenna and auxiliary receiver with omni-directional antenna. The auxiliary receiver gain is adjusted automatically by the output of a subtraction circuit. An interfering signal entering a side lobe is partly cancelled, depending on the precision of channel balance maintained between two receivers. This balance is hard to achieve; the method is more complicated than side-lobe blanking (or rejection), and it is useful against only one source.

(c) Side-Lobe Blanking.—As with side-lobe subtraction, side-lobe blanking (or rejection) also uses a separate omni-directional receiving antenna and associated receiver. As can be seen from Figure 35-61, if an interfering pulse arrives from an azimuth other than the one in which the main lobe is pointing, the reference channel response is stronger than the main channel contribution. In this case, the reference signal actuates the gain control amplifier so that the output voltage (e_0) is below the noise level. When a signal comes from the direction in which the main lobe is pointing, the main channel output is greater than the reference channel output, and maximum receiver gain is employed. Detailed theory and operation of this type of side-lobe rejection is discussed in CED 3514.41 in the bibliography. Other material concerning side-lobe blanking is included in CED 3514.42, .43, and .44. In addition to being a superior interference-reduction technique, side-lobe blanking has important applications in the field of counter-counter-measures and reconnaissance. However, it has two operating limitations. First, it does not prevent a radar from picking up an interfering radar in its own main lobe; second, echos from reflecting objects can cause interfering pulses to enter the main lobe as the antenna rotates. Also, since the radar side lobes are blanked, a small percentage of reception time, perhaps 0.1 percent, would be lost in dense signal areas; however, this time loss is negligible. Effects of side-lobe blanking as an interference-reduction technique for surveillance radars and IFF devices are shown in Figure 35-62.

b. Frequency Decoupling and Time Sharing.—Transmission systems operating at different frequencies for desired and undesired signals achieve interference reduction by best choice of these frequencies, relative to the receiver selectivity. Time-sharing is a technique whereby both desired and undesired transmissions may occupy the same channel for separate, non-overlapping periods of time. Since both approaches to interference reduction are elementary, they are often investigated before other measures.

4. Receivers. — Various specialized circuits may be used to suppress interference within the receiver. The most effective circuit depends on the nature of the desired and the undesired signals, as well as on the details of desired receiver design. It it not expected that the C-E officer will be concerned directly with selection of such circuits, but he should be cognizant of them since they constitute portions of electronic equipment under his jurisdiction, and since they are available for use against interference.

a. Bandwidth Control.—Use of an unnecessarily wide receiver bandwidth results in the

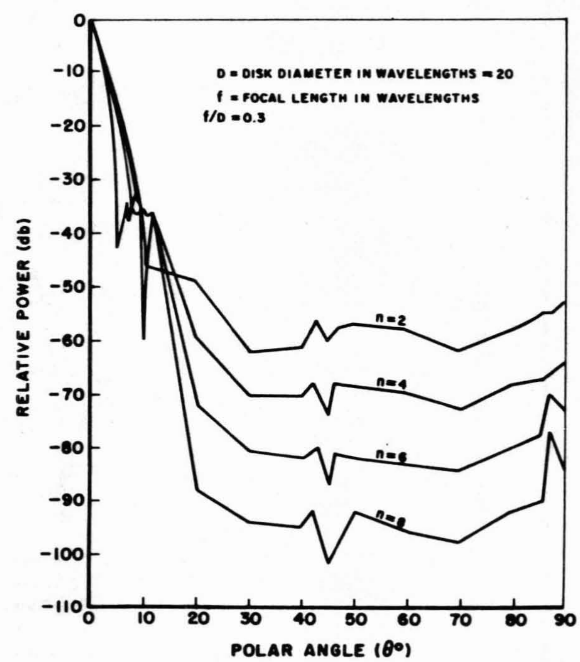


Figure 35-60.—*Representative Theoretical Far-Side-Lobe Radiation from a Parbolic Reflector.*

possibility of receiving undesired co-channel signals. When this type of interfering signal exists, the signal-to-noise ratio at the output of the receiver can be improved by use of a bandwidth no greater than necessary for the desired signal. For general communications use, control over the receiver bandwidth is a desirable feature, generally accomplished by control of the i-f bandwidth through either resistance loading of tuned i-f circuits, or by crystal or electro-mechanical filters.

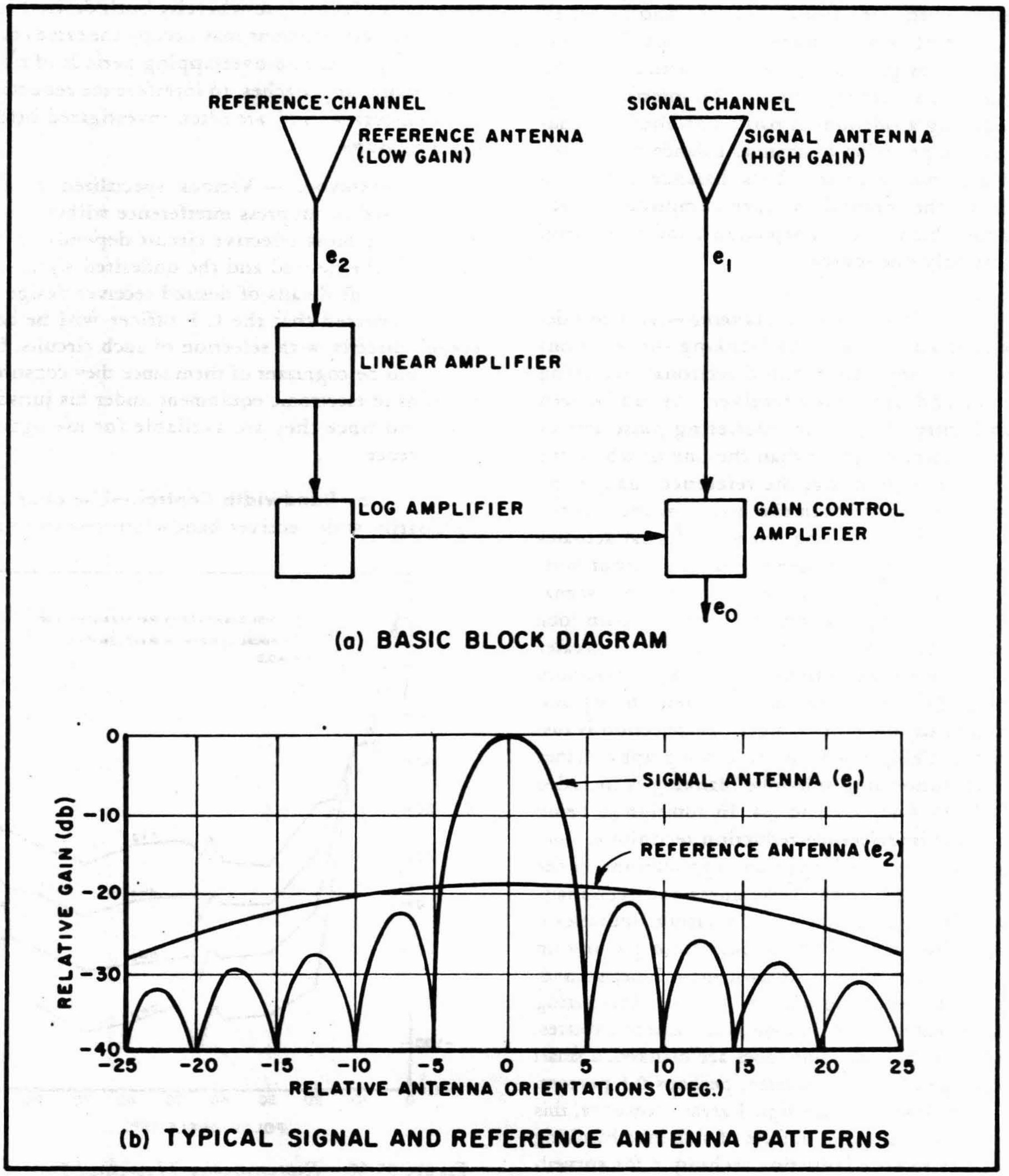


Figure 35-61.—*A Side-Lobe Blanking Technique.*

b. Interference Limiters.—Limiters, as the name implies, are restrictive devices. The limiter circuits discussed in this manual are designed to reduce the effects of undesired electrical disturbances of an impulsive nature—such as atmospheric noise, ignition noise, and radar signals—on the output of radio receivers designed particularly for amplitude-modulated communications use. The circuits described are the type located at or near the final detector in a receiver. For some specialized applications, preventive means have been developed that operate directly in the antenna circuit of a receiver.

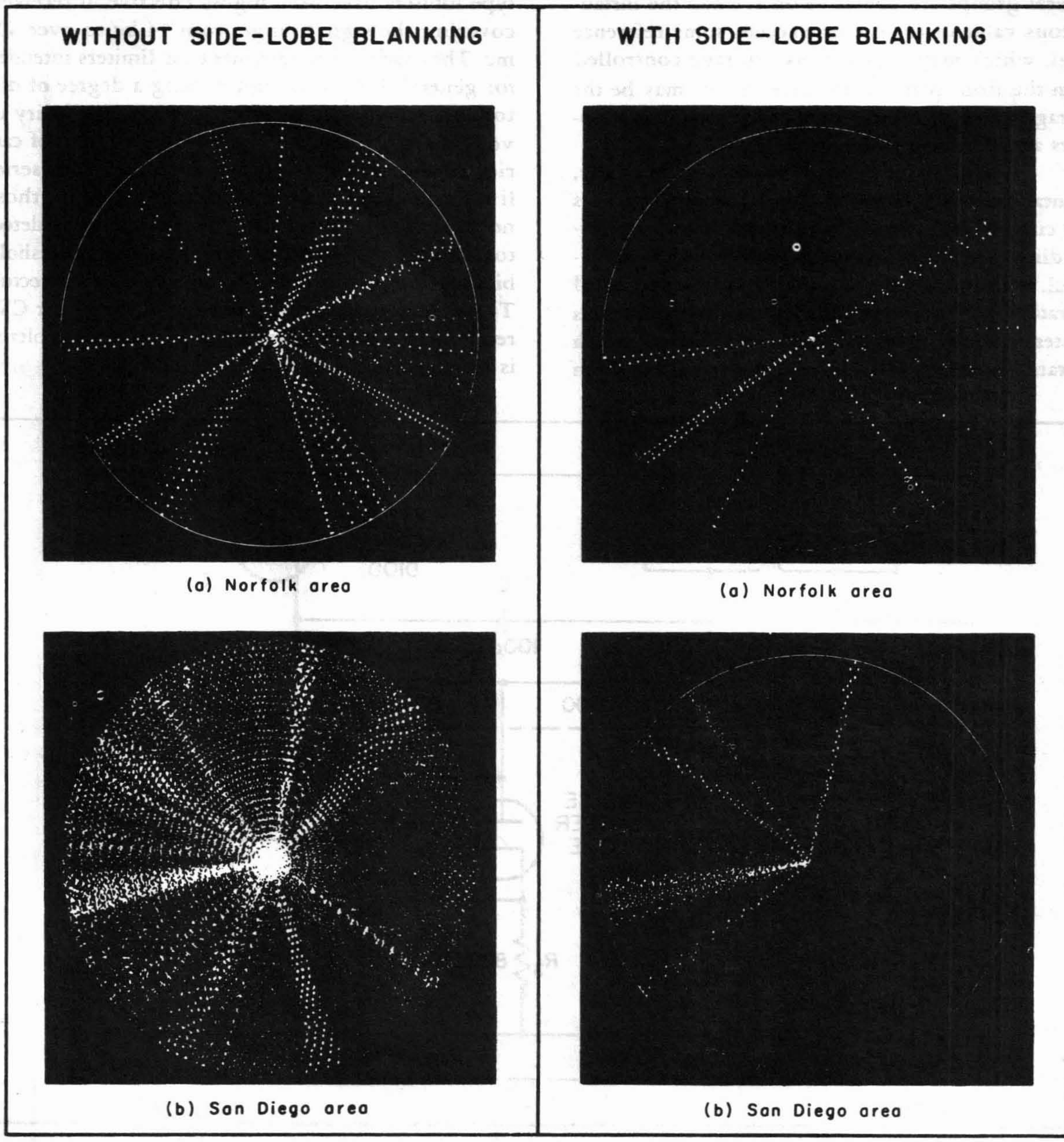


Figure 35-62.—*Typical L-Band Interference with and without Side-Lobe Blanking.*

(1) *Types of Limiters.*—Limiters may be divided into three groups: (1) instantaneous noise-peak limiters, whose primary usefulness is in amplitude-modulated-wave (AM) reception such as speech and music; (2) output limiters, useful mainly for pulsed carriers (CW) reception, such as telegraph signals; and (3) limiters for circuits not falling directly into the first two groups. Limiters of these general groups are operative only when the instantaneous value of the carrier exceeds some reference level, which may be a d-c bias voltage controlled from the front panel of the receiver, or may be the average value of the rectified carrier itself as it appears across the final detector load.

(2) *Principle of Operation.*—Essentially, an intantaneous noise-peak limiter usually involves two circuits; one, which has a time-constant corresponding to the usual detector load constant differential, is responsible in large part for the successful operation of the limiter. The selected instantaneous limiters to be described are half-wave devices which operate on the modulation envelope resulting from rectification of all positive (or all negative) half-cycles of r-f input to the detector. Full-wave limiters generally do not provide a substantial improvement when applied to detector circuits on AM operation, unless considerable clipping of the desired modulation is tolerable.

(3) *Series Noise-Peak Limiters.*—Series-type limiters have been highly effective in receivers covering the signal range from 14 kc to over 400 mc. They satisfy a requirement for limiters intended for general AM use by not causing a degree of distortion which would affect the intelligibility of voice signals when the usual average values of carrier modulation are employed. In addition, series limiters require very few components over those normally found in the usual half-wave diode detector, and are easily adaptable to automatic threshold biasing using the rectified voltage of such a detector. These limiters have also been found useful for CW reception if a stable beat-frequency oscillator voltage is provided to maintain a threshold bias.

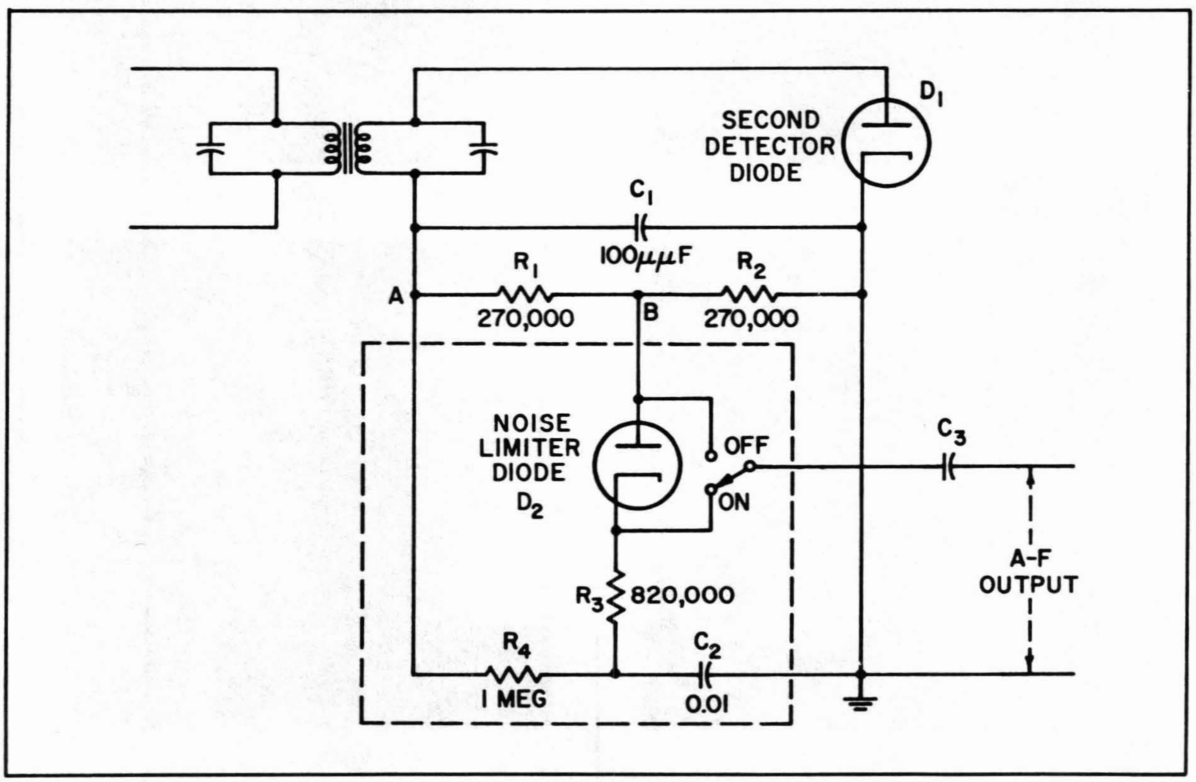


Figure 35-63.—*Simple Series Limiter, Requiring only the Four Additional Components inside the Dash-Dash Rectangle.*

(4) *Simple Series Limiter.*—Figure 35-63 shows the simplest form of series limiter, widely used in military receivers. It requires only one fixed capacitor, two fixed resistors, and a diode in addition to the normal components of a diode second detector. No front-panel control of threshold for varying carrier levels is required; threshold bias being automatic in the sense that it is directly derived from the rectified carrier. Its operation can be described briefly as follows:

(a) Assume that the limiter diode in Figure 35-63 is momentarily conductive, its resistance being fairly low compared to the other resistance values in the circuit, and that capacitor C_2 is charged through 1-megohm resistor R_4 to a potential of about -1.4 volts. Any appreciable change in this potential would require about 0.01 second, due to the time-constant of R_4 C_2. The time-constant of $(R_1 + R_2)$ C_1 is, however, only about 50 microseconds, so that the potential at the limiter diode plate can change in about 1/200th of the time required for its cathode to assume a new potential. Therefore, if a noise potential of perhaps 100 volts suddenly appears across $R_1 + R_2$ and brings the plate of the limiter to -50 volts from ground potential, the diode plate becomes about 48.6 volts more negative than its cathode and the diode stops conducting. This action, in effect, disconnects output capacitor C_3 from point B, and the a-f amplifier has no appreciable input for the duration of the noise modulation. By the time that the cathode of the limiter diode has assumed an effectively-more-negative potential, the noise pulse will usually have decayed and the limiter diode will have become conductive again, restoring the a-f input to the audio amplifier. With the circuit constants shown, the time-constant of recovery from surge input is ideal, for most applications.

(b) Oscilloscope tracking illustrating the operation of the simple series limiter on both AM and CW signals in a typical receiver appear in Figure 35-64. On CW, the beat-frequency oscillator causes operation of the limiter similar to that

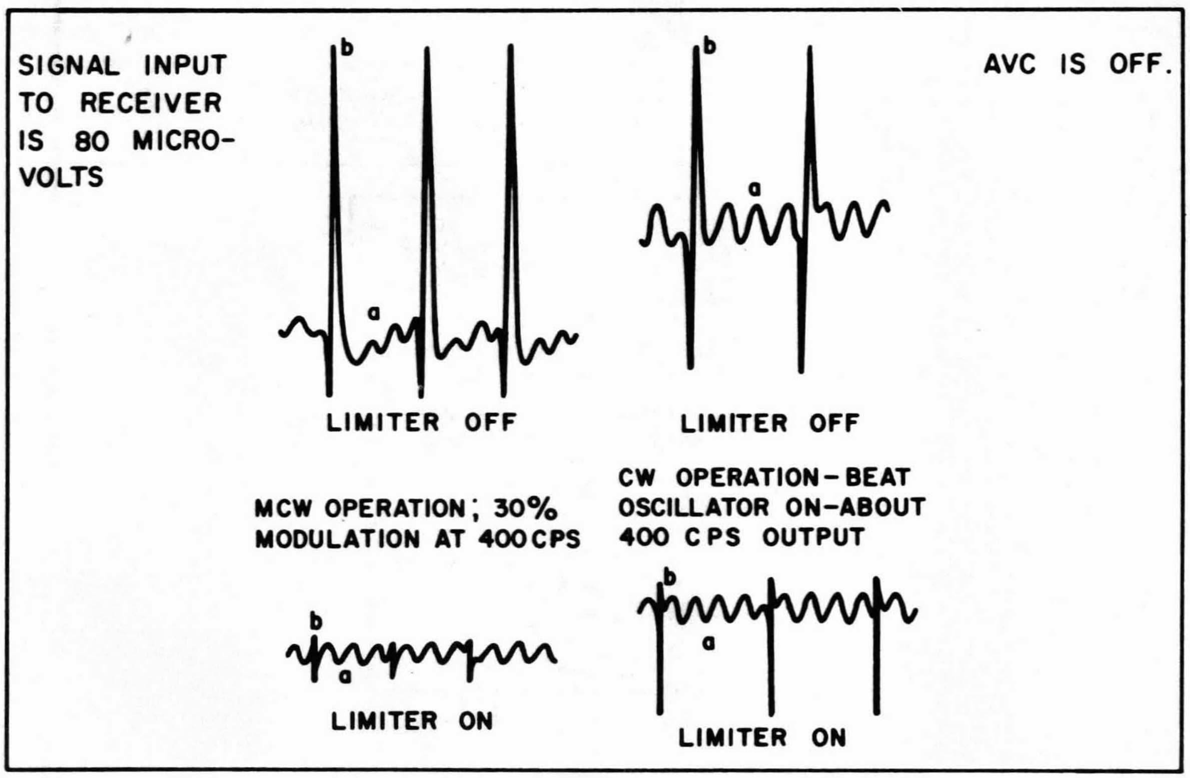


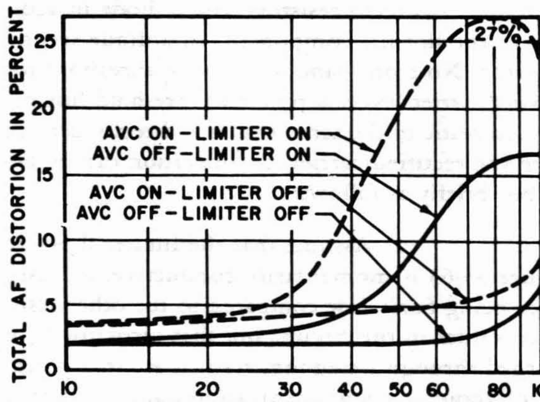
Figure 35-64.—*Oscilloscope Tracings of Audio-Output of Receiver, Illustrating Noise Suppression of Simple Series Limiter.*

obtained with a very low percentage of desired signal modulation at the detector.

(c) Modulation distortion under various conditions of AM operation is indicated by the curves of Figure 35-65. The change in threshold of limiter action between weak and strong signals is particularly evident.

(d) Operation of the series limiter on CW reception may be improved by the incorporation of additional r-f limiting in the i-f amplifier immediately preceding the final detector. This can take the form of an added grid leak and capacitor between the control grid and the input i-f transformer of this amplifier stage. The better i-f limiting, which results, will allow the use of a lower beat-frequency oscillator injection voltage to the detector, a condition favoring good operation of the limiter following the detector.

(5) *Modified Shunt-Type Noise Limiter.*—The limiter circuit in Figure 35-66 resembles the series-type limiter of Figure 35-63, except that the plate of the limiter diode and the low end of its cathode resistor are interchanged. As a result, the; limiter diode acts to shunt C, thereby reducing the a-f output voltage whenever a noise-peak makes the diode conductive. The arrangement shown permits grounding the low end of the i-f transformer secondary when necessary for amplifier stability.



THE AVC OFF CURVES ARE SUBSTANTIALLY THE SAME AS FOR WEAK-SIGNAL AVC ON OPERATION SIGNAL INPUT FREQUENCY IS 4,000 KC. AF OUTPUT FREQUENCY IS 1,000 CYCLES, AND SIGNAL INPUT LEVEL IS 1,000 MICROVOLTS.

Figure 35-65.—*Modulation-Distortion Curves as Measured at Output of Typical Communications Receiver Using Simple Series Limiter.*

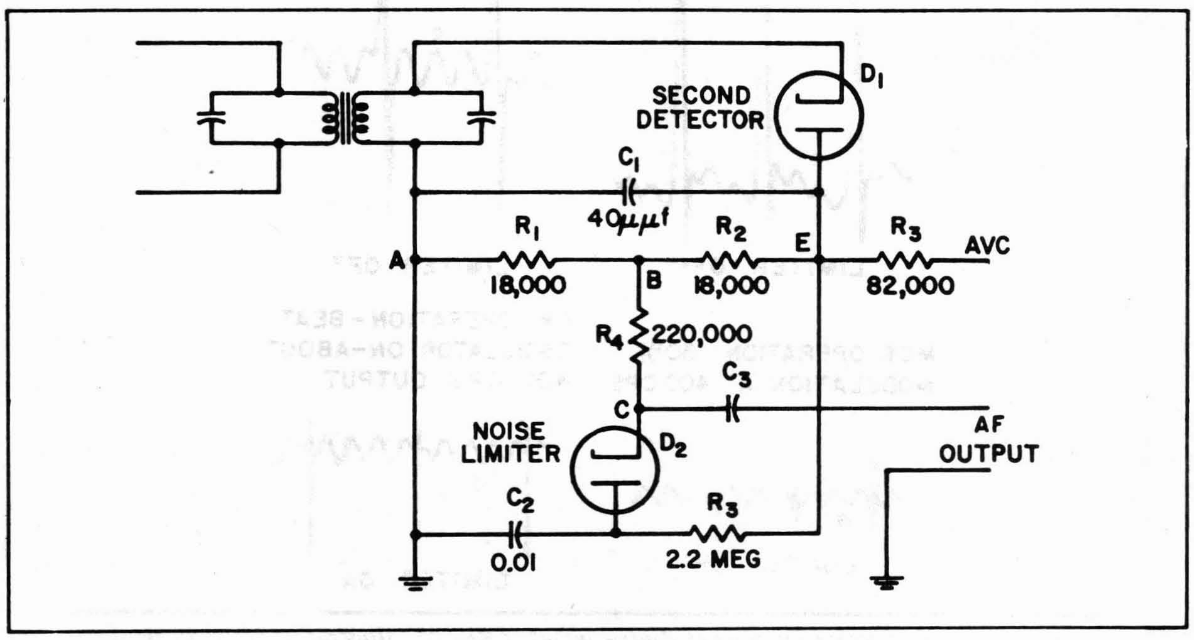


Figure 35-66.—*Modified Shunt Noise Limiter.*

(a) Assume a constant carrier making the limiter diode nonconducting, its plate being effectively at a -2 volt potential of point E. The plate circuit time-constant is much longer than that of the cathode circuit of the limiter, so that any noise surge in excess of 4 volt across the entire detector load drives the cathode of the limiter diode more than 2 volts negative with respect to ground and the diode conducts, shunting the input to the following a-f stage. This shunting action is made more effective by series cathode resistor R_4, which, with the limiter diode closed, acts as part of a voltage divider to attenuate detector-load voltage peaks. Limiting action ceases when C becomes positive with respect to D, due either to decay of the noise pulse or to charging of C_2. This limiter has been found to be much more effective than a simpler shunt limiter, although the simple series-type limiter is more effective at the lower carrier frequencies.

(6) Full-Wave Shunt AF Output Limiter.—Two diodes in a single 6H6 envelope, connected as in Figure 35-67, serve as a full-wave shunt type of audio output limiter. One diode shunts the plate load R_4 of the interstage a-f amplifier tube during the positive half of the audio cycle, and the other during the negative half. The diodes are biased in series with a d-c voltage obtained from R_7. This voltage controls the threshold level above which the diodes become conductive on audio peaks. The diode impedance—when conducting at the usual operating audio voltage levels involved—averages only a few thousand ohms, so that the plate load of the preceding amplifier drops from a value of about 250,000 ohms below limiting threshold to perhaps 5,000 ohms during limiting action.

(a) With a high plate-impedance, such a load change will produce about 30 db less gain above the limiting level than below it. This limiting system is considered to be among the best of the audio output limiters for CW reception.

(b) Figure 35-68 shows the resonant overload characteristics of this type of limiter as used in a typical receiver. The change in gain from LIMITER OFF to ON condition is caused by switching out a pad in the a-f amplifier system.

(7) Conclusions.—From the overall viewpoint of simplicity, effectiveness, and low distortion, the series-type noise-peak limiter appears to be the best choice for AM operation, while, from the standpoint of effective limiting, minimum change of gain below limiting threshold over a wide threshold range, and also relative simplicity, the fullwave a-f shunt output limiter appears best for CW operation. The former may be combined with the latter for even more effective operation on CW signals.

(a) No limiter is a cure-all. When noise-peaks do not substantially exceed the desired carrier peak values, and occur so frequently that they fill in the modulation, only some very elaborate limiter arrangements will afford any considable degree of relief. Within their inherent limitations, however, those limiters recommended above

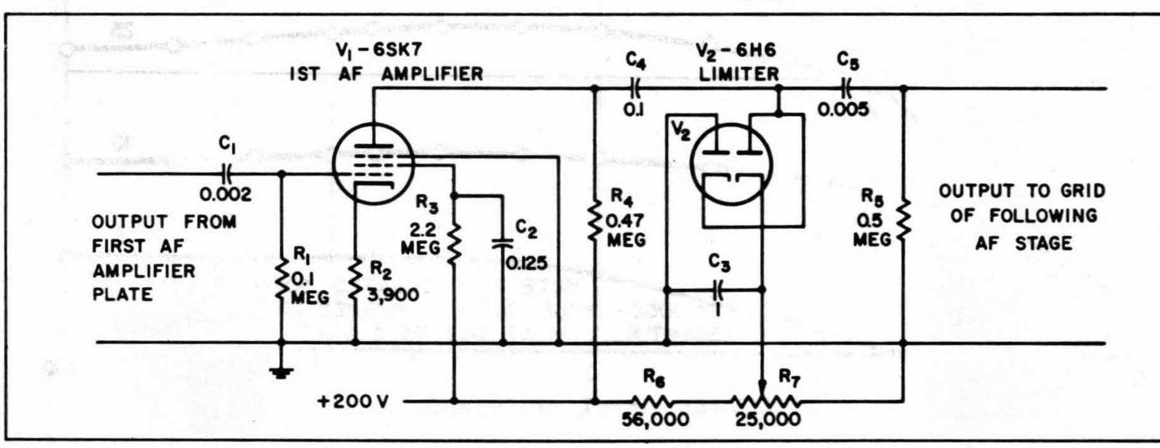


Figure 35-67.—*Full-Wave Shunt AF Output Limiter.*

can be a very useful addition to the communication receiver, which must work under conditions of high ambient static or similar disturbances.

c. Pulse Synchronization.—On-site interference to one radar equipment generated by other radars can be diminished by synchronization of pulses among the various radars concerned. In this way, the transmitters operate simultaneously or in fixed sequence, the radar gates are adjusted to ignore or reject the contributions of adjacent transmitters. Synchronization is a special application of a time-sharing technique. A major disadvantage of this approach is that the pulse repetition rates must be restricted to that of the slowest of the equipments concerned; this imposes a high degree of rigidity on the overall system.

d. Sector Blanking.—With radar, sector blanking is a standard method for eliminating reception capability in some given sector—usually azimuthal. An operational penalty is implicit in this technique. The method eliminates some extraneous energy, but reduces performance capability in the blanked sector as well. Since other, more refined techniques are available to reject interfering signals, sector blanking devices should be relied on only to avoid undesirable effects of fixed physical objects, such as mountains or buildings.

e. Blanking.—One solution to the on-site radar-to-radar interference problem lies in the use of blanking techniques to disable every receiver during the transmission of a pulse. For radar equipments, this technique results in a slight loss of information, and the deterioration in performance is consequently small. In addition, blanking techniques may also be applied to on-site communications receivers to decrease interference to their operations resulting from the reception of radar pulses. Electronic blanking has also been devised for aircraft communications receivers to diminish the effects of precipitation static.

(1) Master-Controlled Blanking. — In a fixed installation, a pulse generator in one of the radar equipments may be used as the common pulse source for all radars by means of interconnecting cables among the various equipments. The master pulse may also be used to initiate gating circuits in the various receivers, disabling reception during periods of pulse transmission.

(2) Individual Blanking.—An alternative approach, applicable to mobile and field installations as well as fixed installations, is to use self-contained interference blankers to protect each radar receiver on an individual basis. The self-contained

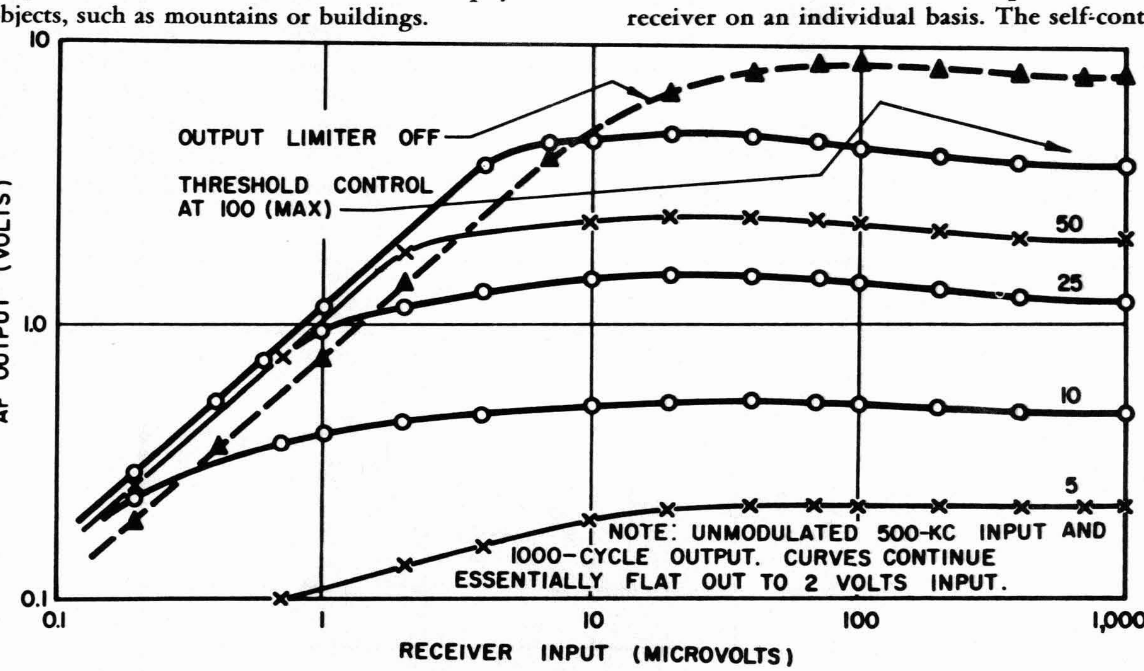


Figure 35-68.—*Resonant Overload Characteristics of Receiver Using Full-Wave Shunt AF Output Limiter on CW Operation (Unmodulated).*

interference blanker distinguishes between interference pulses and target returns, and generates a trigger from the interference. A blanking gate is derived from the trigger, and is used to deactivate the video amplifier for a pre-determined period of time following the reception of a trigger pulse. It accomplishes this result by utilizing, in addition to the basic radar receiver, a second guard-band receiver with passbands on both sides of the normal passband. This device is essentially an i-f receiver, making use of the antenna system, local oscillator, and mixer of the protected radar. Figure 35-69 shows a simplified block diagram of the limiter and double-passband circuits. The wide-band amplifier centered at 30 mc precedes the limiter. Following the limiter is the double-sideband amplifier whose output goes to the detector.

(a) Figure 35-70 illustrates three types of pulses that must be considered: (1) a target return at 30 mc that may be strong or weak; (2) an interference pulse whose center frequency lies within the passband of the limiter; the pulse may also be strong or weak; (3) an interference pulse whose center frequency lies outside the passband of the limiter; this pulse must be a strong pulse in order to produce an output in the offended radar receiver. In operation, the self-contained blanker produces an output trigger from the two types of interference, but no output from a target return.

(b) The block diagram of one version of a guard-band receiver is shown in Figure 35-71. A portion of the side-band amplifier is incorporated in a pre-amplifier coupler. With this arrangement, a high-impedance input is used in order not to degrade the signal of the protected radar at its mixer output. It also permits location of the main chassis of the guard-band receiver more conveniently away from the radar receiver. From the pre-amplifier coupler, the signals are fed to the rest of the wide-band amplifier, followed by the limiter. After the limiter is a double-sideband amplifier which has a video detector at its output. The video signals are amplified and used as a trigger for a video blanker.

(3) Electronic Blanker Against Precipitation (P) Static.—One electronic blanker against precipitation static has been used with communications receivers in the frequency range of 100 kc to 20 mc and higher. The unit functions as an electronic switch connected between the antenna and the input terminals of the receiver. Precipitation static or other types of pulse interference open the signal path from the antenna to the receiver for the duration of each pulse, and then closes the signal path until the next pulse occurs. The block diagram, Figure 35-72, shows the major units of the blanker.

(a) Operation.—In operation, the signal is delayed by approximately 0.7 microsecond through a conventional delay line, properly terminated. The delayed signal and noise is then amplified and applied to a gate circuit. Amplification is necessary to overcome the losses encountered in the delay line and in the gate circuitry. The coincidence gate, Figure 35-73, which is the heart of the blanker, should ideally be able to insert an attenuation to the signal and transients of approximately 100 db to remove them temporarily without generating any transient itself. It converts the signal to push-pull circuitry with the gating pulse introduced so that identical transients are generated in the output of each stage. Following the gate is a single tube arranged to revert back to single-ended operation. This tube cancels the parallel switching transients in the input, but the signal is preserved when the gate is "open". The last tube in the signal circuit

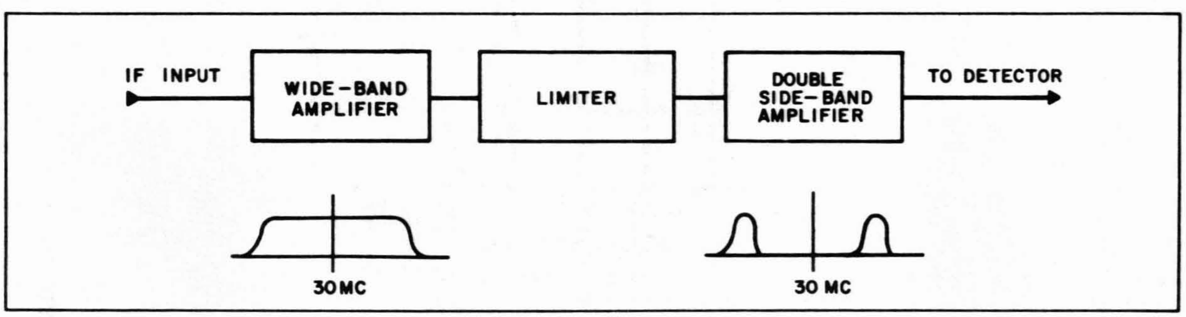


Figure 35-69.—*Block Diagram of Guard-Band Receiver IF System.*

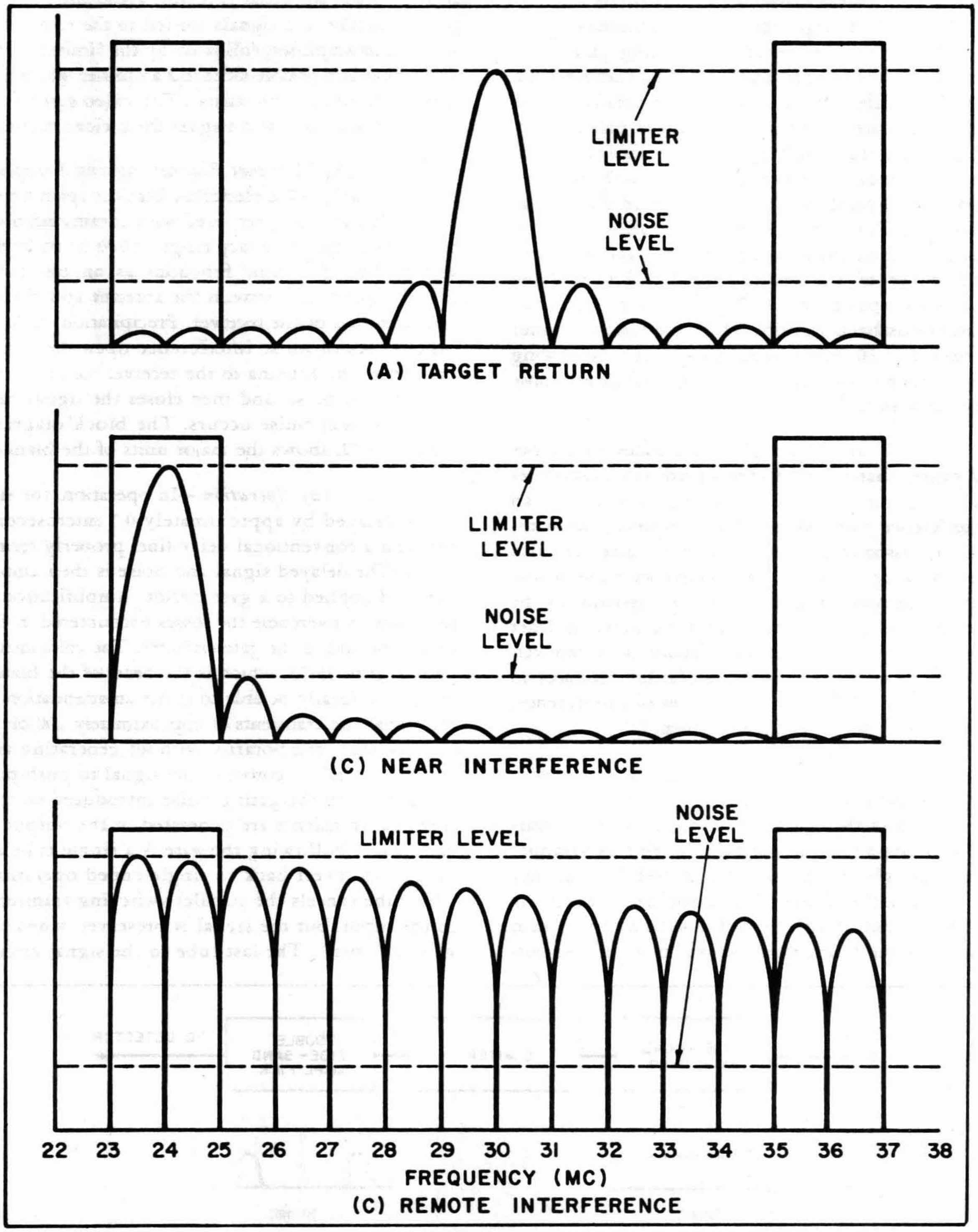


Figure 35-70.—*Interference Acceptance of Guard-Band Receiver under Various Conditions.*

is a cathode follower, used to obtain a low output impedance and to match the blanker to the receiver input. In operation, an interfering pulse generates a blanking pulse to close the gate before the delayed interference arrives 0.7 microsecond later. After the interfering pulse has disappeared, the gate is opened and the signal is re-applied to the receiver input. The blanked portions of the carrier are unnoticeable in the receiver output.

(b) Pulse Channel.—The pulse channel consists of an amplifier, which serves as a buffer stage, working into a polarizer circuit to convert bipolar pulses to unipolar pulses. They are fed through a slicer to prevent blanking in the presence of high amplitude carriers. The resulting pulse is coupled to a one-shot multivibrator which generates a blanking pulse. This is then stretched to approximately three microseconds to prevent the possibility of an interfering pulse occurring during the multivibrator recovery time and passing through the coincidence gate.

(c) Special Circuitry. — Units such as the signal amplifier, cathode follower, multivibrator, and the like, are conventional and do not merit

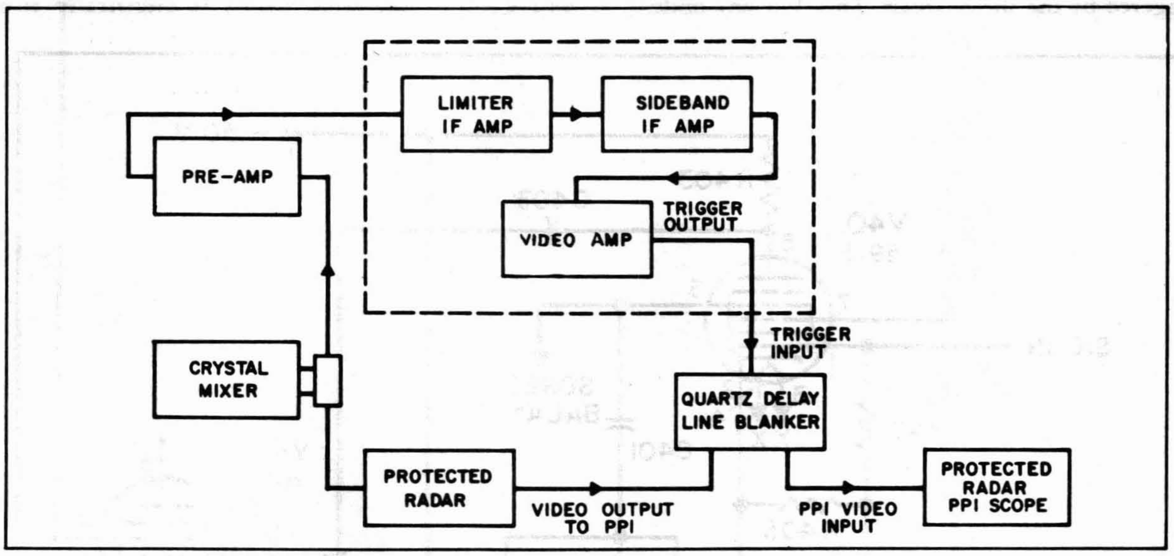


Figure 35-71.—*Block Diagram of Guard-Band Receiver.*

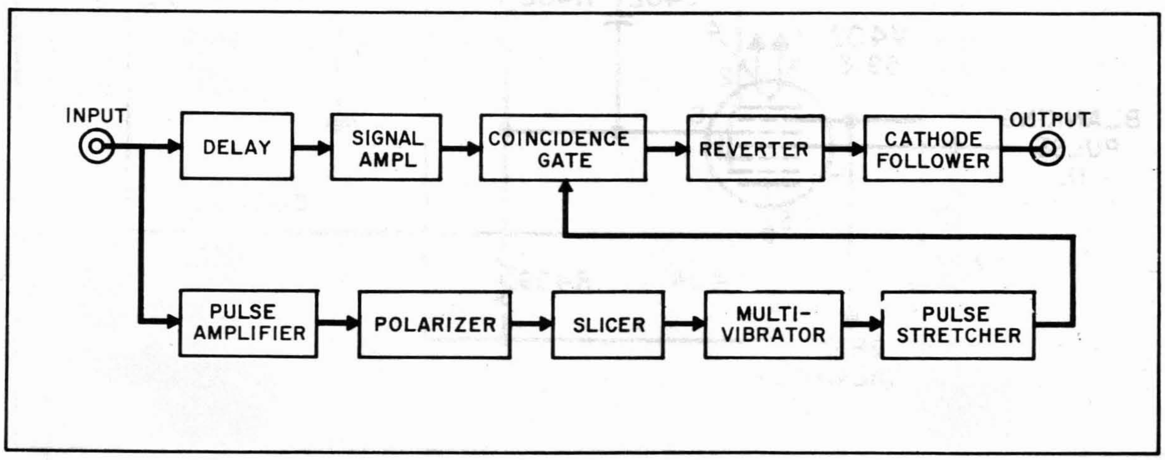


Figure 35-72.—*Block Diagram of an Electronic Interference Blanking System.*

any special attention. A schematic of the polarizer used in an MX-1077 (XA-B)/U is shown in Figure 35-74. The amplifier tube, V201, functions as a buffer between the antenna and the polarizer diodes, CR201 and CR202. The outputs of these diodes are coupled to V202 in such a fashion that the plate waveform is positive, regardless of the pulse polarity at J201. This positive pulse is then further amplified and applied to a slicer which removes all low-amplitude intelligence and allows only the pulses which exceed this threshold to pass to the multivibrator. The multivibrator is a conventional one-shot unit which generates a one-microsecond pulse when triggered by the slicer circuit. This, like any multivibrator, has a definite recovery time during which it cannot be retriggered. This action would allow an interfering pulse through the gate if it occurred during the recovery time of the multivibrator. For this reason, a pulse-stretching circuit is inserted after the multivibrator to stretch the blanking pulse to cover the multivibrator recovery time. The pulse-stretching circuit is shown in Figure 35-75 and its operation is as follows: The positive multivibrator output is coupled through V303 to the pulse stretching network, Z301. This consists of a delay line arranged to charge the entire line to the peak pulse amplitude through CR307, CR308, CR309, CR310, and CR311. The line, which is electrically two

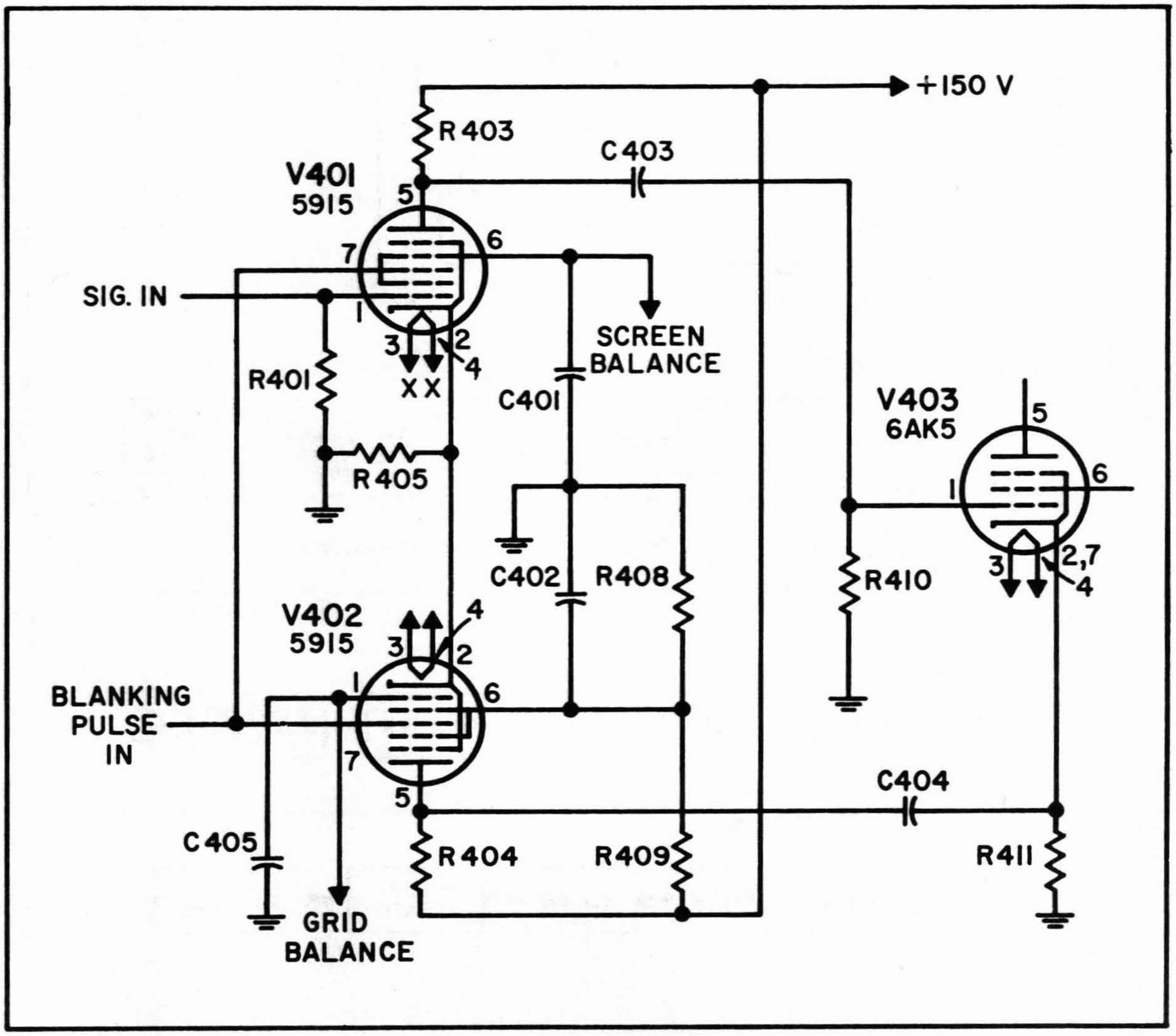


Figure 35-73.—*Coincidence Gate.*

microseconds long, discharges, across R325, which represents the characteristic impedance. This arrangement provides a three-microsecond blanking pulse which, after proper shaping in succeeding circuits, is coupled to the coincidence circuit.

f. Pulse-Repetition-Frequency Discrimination.—A promising way for a pulse radar to identify its own pulses is through PRF discrimination. For example, if a radar has a PRF of 500 pps, then the pulse period is 2000 μsec. If an interfering radar has a nominal PRF of 400 pps, differing from the first by 20 percent, then the interfering pulses will be advanced or retarded by about 400 μsec. per period. Microwave circuits can readily discriminate between delays of even less than this order of magnitude.

(1) The "double - threshold" (CED 3514.45 and .46) method of detection uses PRF discrimination. A specific number of target echoes is required to exceed the receiver threshold at the "precise" pulse repetition frequency before a target is declared present. For example, 16 echoes might be expected from a target as the main beam sweeps past, and the second threshold might be set at 8 pulses received at the precise transmitter PRF. "Precise" in the above statement can be taken to mean that the PRF of the accepted signals cannot deviate from that of the transmitter by more than 0.01 or 0.02 percent. Otherwise, the incoming pulses would "walk through" the acceptance time intervals before the criterion of filling the 8 gates was satisfied. The double threshold method can be said to be about 98 percent efficient in reducing pulse-type interference in acquisition radars.

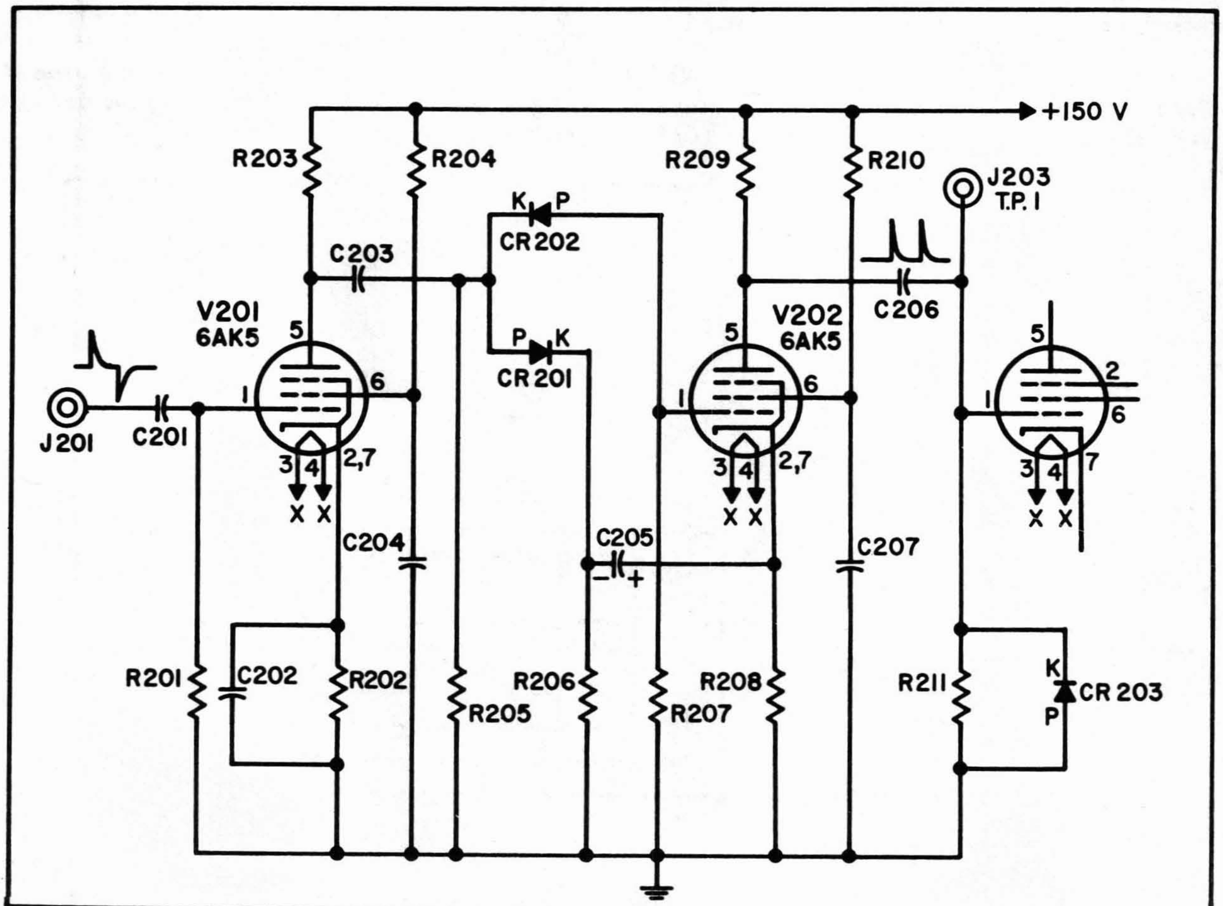


Figure 35-74.—*Polarizer.*

(2) As an example of one type of double-threshold detection, or PRF identification, the true target verification section of the AN/FST-2 data-processing system is shown in Figure 35-76.

(3) The Haller, Raymond, and Brown RAFAX System (CED 3514.47) accomplishes PRF discrimination by using a cathode-ray tube for storage and a flying spot scanner. The slowed-down video data-processing system used in the SAGE system operates in a similar manner.

(4) Deliberate PRF jitter, in conjunction with receiver gating, can aid in avoiding other emissions with relatively stable PRFs. In other words, if periods between pulses are staggered in a random or near-random fashion, and receiver gates are set to be open during these intervals, the probability of a stable PRF entering the gates often enough to cause degradation is extremely small.

(5) Other techniques that rely on PRF discrimination are video integration, the Least-Voltage Coincidence Detector (LVCD) (CED 3514.48), and the pulse interference seperator and blanker (CED 3514.49). In video- or post-detection integration, supersonic delay lines are used to store target-echo pulses. These pulses are fed back to the video input and added until a desired threshold is attained. If the time of arrival of successive pulses does not correspond to the interpulse period, no intergration takes place and a target is not declared to be present.

(6) The interference condition that PRF identification techniques are not designed to overcome is that of a nearly identical interfering PRF. For this case, it is more desirable to have a choice of operating PRFs available to the operator. Even then, it may not be possible to find a clear PRF in a dense signal environment. Also, the equipment for PRF discrimination techniques is usually bulky and expensive. The techniques usually result in 5-to 10-percent range deduction, and have negligible anti-jamming capability. Therefore, PRF discrimination is not a cure-all and should be used in conjunction with other detection methods in high-density environments.

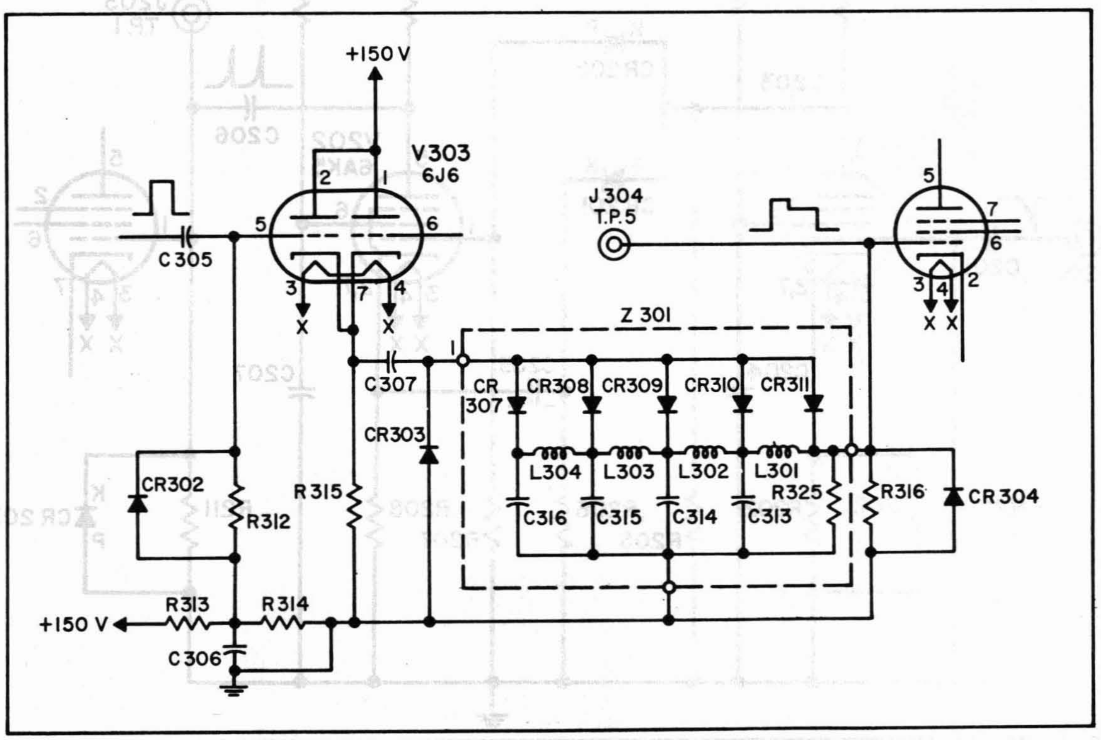


Figure 35-75.—*Pulse Stretch Circuit.*

3507. INSTRUMENTATION.

.1 Major Features of Radio-Interference Meters.—Specialized radio-interference measuring equipment is similar in many respects to superheterodyne types of communications receivers, except for differences required to provide quantitative measurments of various physical characteristics of both desired and undesired types of signals. The instrument may be regarded as a vacuum-tube voltmeter preceded by a tunable bandpass filter with a two terminal input. Various pickup accessories may be connected to the bandpass r-f voltmeter to convert it into a field-strength measuring unit. A representative instrument, as well as some of its accessories, is shown in Figure 35-77. Units are available for measurements over the frequency spectrum from 30 cps to 15 kmc.

a. Block Diagram.—A simplified block diagram of typical instrumentation is shown in Figure 35-78. It consists of much of the basic circuitry of a high-quality communications receiver, including a tuned r-f stage, local oscillator, mixer,

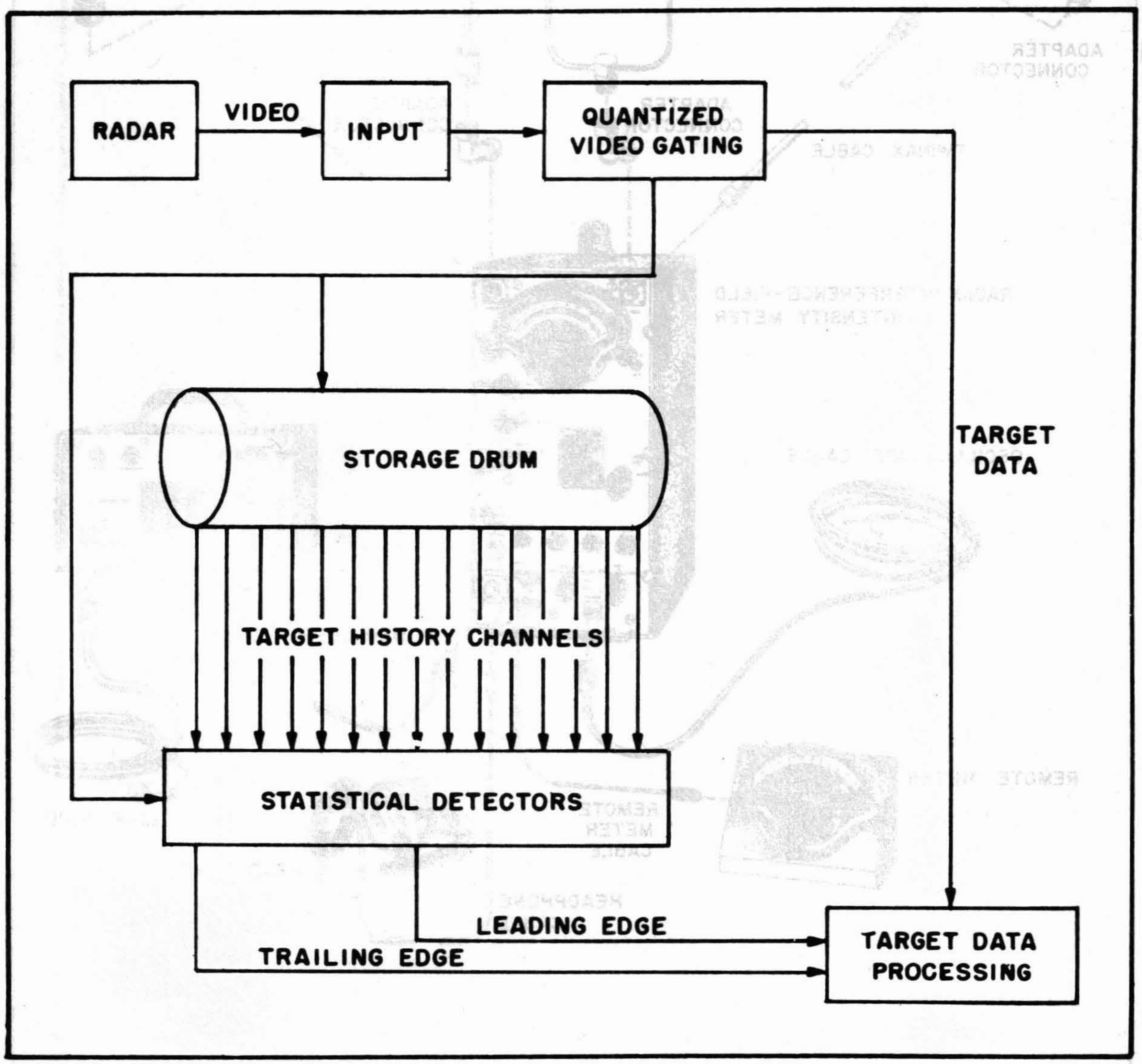


Figure 35-76.—*AN/FST-2 True Target Verification.*

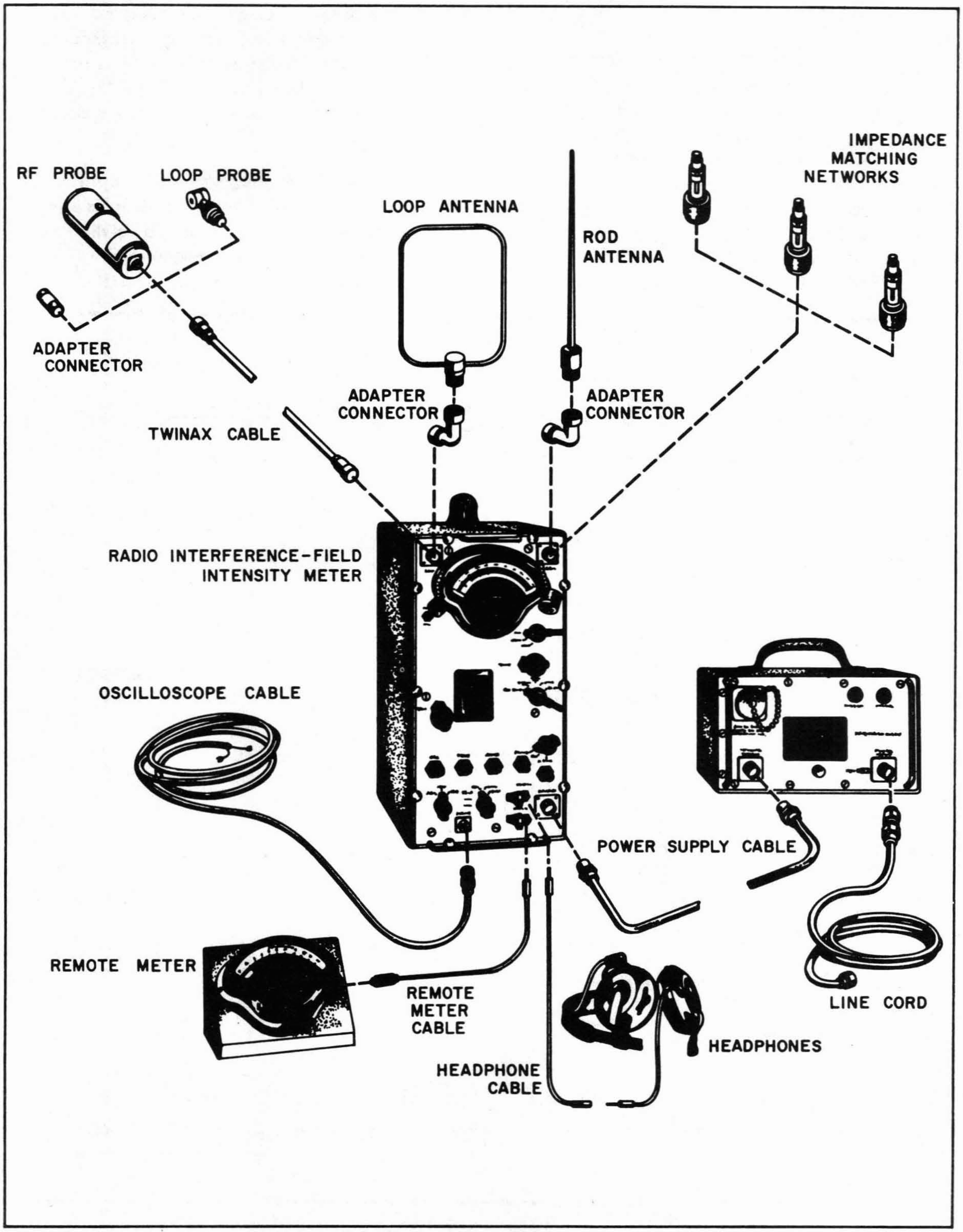


Figure 35-77.—*Typical Radio Test Set (AN/PRM-1A) Connection Diagram.*

i-f stages, BFO (optional), detector, and audio output, plus additional features including specialized pickup devices, step attenuators, an internal signal for amplitude calibration, and a vacuum-tube voltmeter for output measurement.

b. Tuned RF Stages.—The basic instrumentation circuitry requires special design considerations. Tuned r-f stages must be designed to operate in conjunction with an input attenuator for quanitative amplitude measurements. Consequently, they must possessa gain response fairly uniform with frequency. In other words, it is not possible to achieve optimum input signal-to-noise ratios over the entire band of the meter. The overall gain of the instrument must also be adjusted to some pre-selected value, usually by reducing the maximum available gain of the r-f stages. Another important consideration is that the r-f bandwidth must be wide enough to have little effect upon the overall bandwidth up to the second detector stage. In other words, it must not cause narrowing of the i-f bandwidth, an important design consideration at the low-frequency end of a tuning range.

c. Local Oscillator and Mixer.—Local oscillator design emphasis is on good frequency stability and low harmonic output. The mixer design follows conventional communications-receiver practice, with the additional provision that the mixer plate circuit must work into a step attenuator.

d. IF Stages.

(1) Under-Coupled Circuits.—Special precautions are taken in the design of i-f stages to avoid over-coupling of i-f transformers. Coupling below a value called "critical coupling" minimizes the generation of secondary, tertiary, and higher order lobes in response to input pulses. Typical responses are shown in Figure 35-79, where the upper curve is the response to a short-duration input pulse (or impulse) for i-f coupling below critical, and the lower curve is the response of an overcoupled circuit to the same input. If a second pulse should excite the input circuit a short time after the initial pulse, its output amplitude will be relatively unaffected by the first pulse in the under-coupled case, but may be either increased or decreased in the over-coupled case, depending upon phase relationships between the new pulse and the higher order lobes of the original pulse, as shown in Figure 35-79. Consequently, it is necessary to avoid overcoupled i-f stages in order to obtain quantative amplitude measurements of pulse trains.

(2) Dynamic Range.—Another i-f consideration results from the detector functions applied to the i-f output signal. In obtaining "average" measurements of pulse-type signals, the peak values of some pulses may become quite high, since the duty cycle of the pulses is very low. For quanitative amplitude measurement, the peak values of pulses must be handled without amplitude distortion by the i-f amplifier. Thus, the i-f amplifier must possess an exceptionally wide dynamic range. This range often extends 16 to 20 db above the sine wave peak value which causes full scale deflection on the output meter.

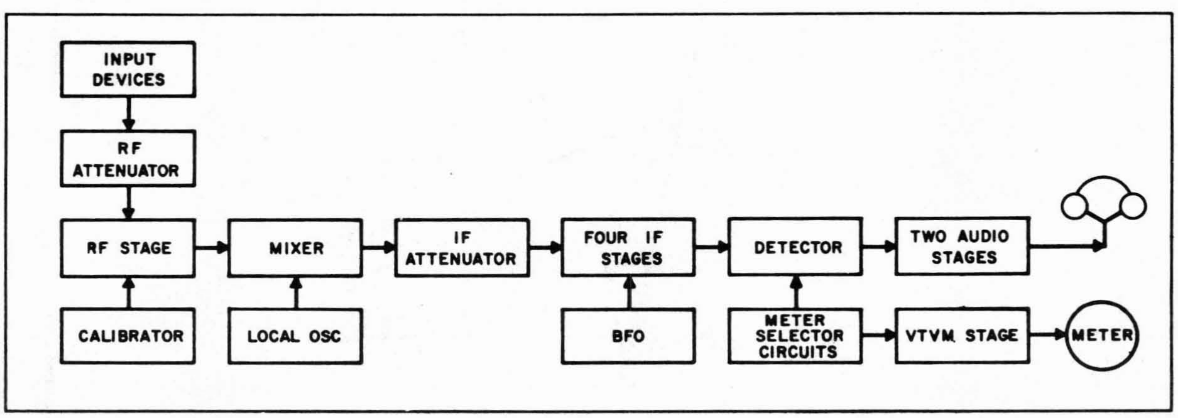


Figure 35-78.—*Simplified Block Diagram of RI Meter.*

(3) Output Impedance.—For quasi-peak types of measurement, the output stage of the i-f amplifier must present a very low impedance to the second detector, in order to permit its large load capacitor to charge rapidly.

(4) Logarithmic Response.—One additional characteristic is required of the i-f amplifier. Its desired output is a logarithmic function of the input signal. This performance permits the output indicating meter to give a logarithmic response of the input signal, a decided advantage in measuring widely varying signal amplitudes. In most instruments, two decades of logarithmic response are provided, although as few as one and as many as three are used in some instruments. Logarithmic response of the i-f amplifier is obtained by applying AGC voltage to grids of one or more variable-mu amplifier tubes.

e. Second Detector.—The heart of the radio frequency measurement instrument is the second detector, since it is here that the physical quantities to be measured are determined. It should be emphasized that the detector does not respond directly to the input signal, but only to that portion of it which is passed by the r-f and i-f channels; this fact is important to remember when analyzing wide-band signals.

(1) Average Detection.—In the conventional communications receiver, the detector load circuit is designed to follow the envelope of the i-f signal. This type of detection is also one of those made available in the radio-interference meter, and

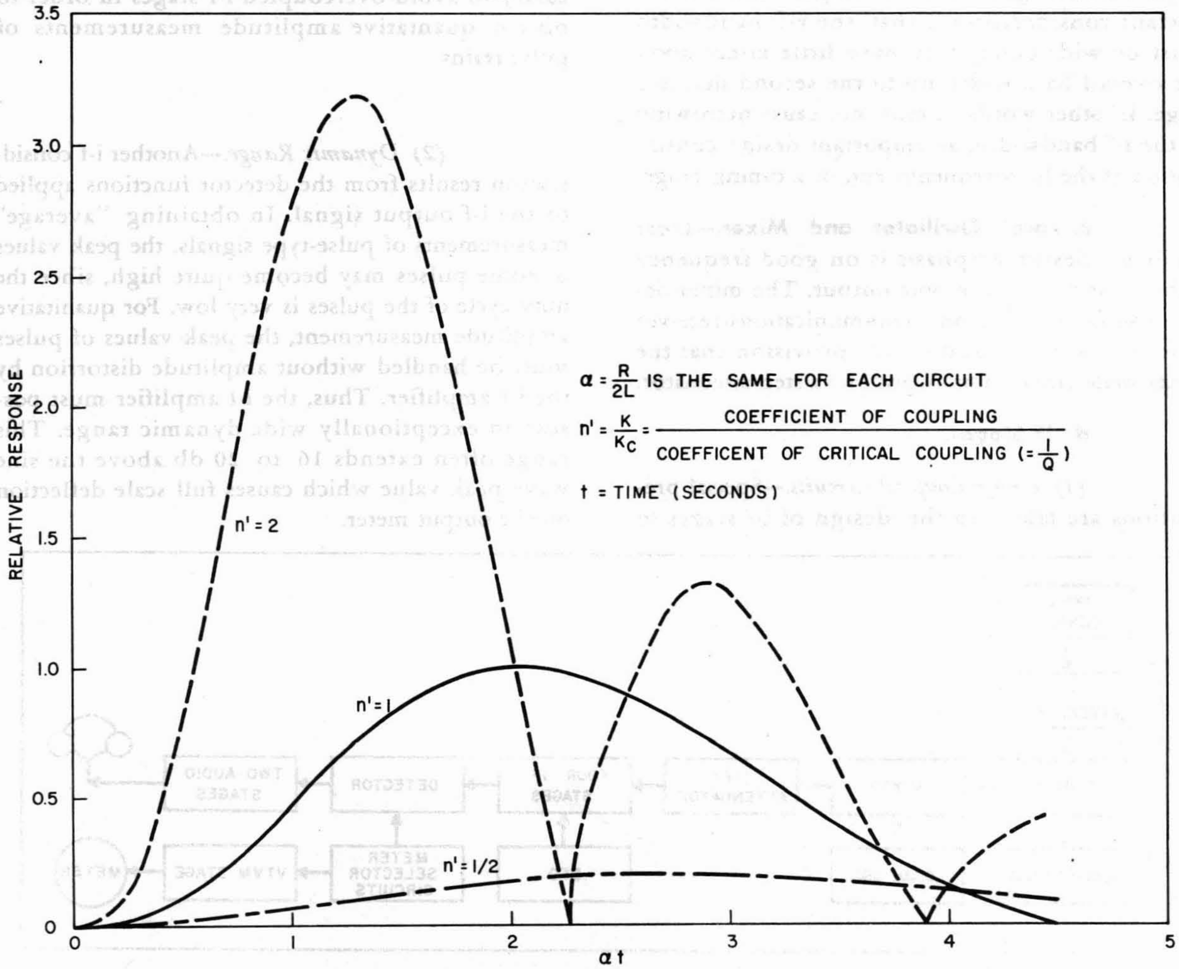


Figure 35-79.—*Effect of Coupling on Response of Two Coupled Tuned Circuits.*

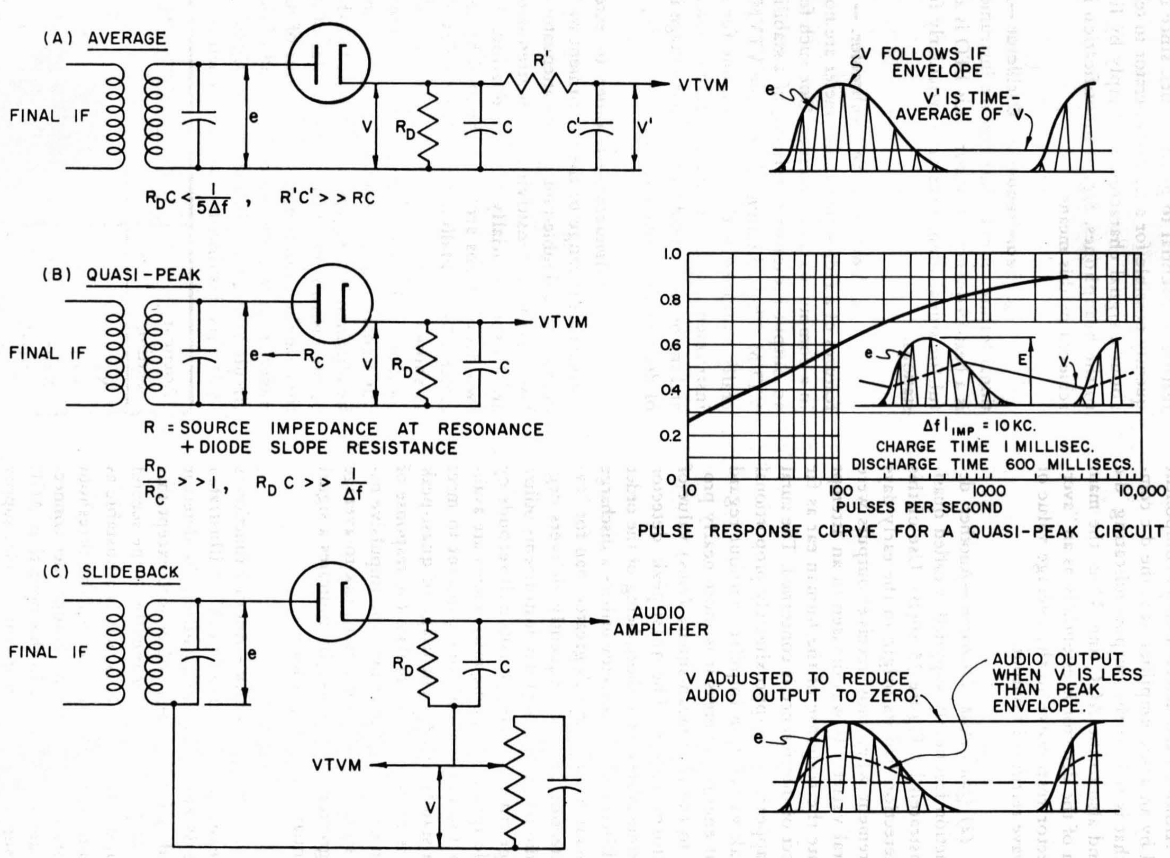


Figure 35-80.—*Detector Circuits.*

is usually designated as the "field-intensity" detector function. A repesentative circuit is shown in Figure 35-80(A). Although the detected audio component is utilized by an audio amplifier, it is the d-c component that is fed to the output-indicating d-c VTVM and also to the AGC line. Thus, the main utilization of the detector is essentially as an "average" detector responsive to the average value of the half-wave rectified i-f output.

(2) *Quasi-Peak Detection.*—Another detector function frequently supplied is called quasi-peak, illustrated by Figure 35-80(B). Use of this type of detection had its origin in the early days of measurement when most receiver outputs were of the aural variety. It was devised in an attempt to simulate the response of the human ear as far as the effect of interference is concerned. The aural response appears to be approximately proportional to the peak value of an impulse, without regard to its total energy, whereas it is more nearly proportional to the root-mean-square (rms) value of more uniform signals. The quasi-peak detector charging time is relatively short, being of the order of one millisecond. The detector utilizes a discharge time constant which is much greater than for "average" detection and, consequently, delivers negligible audio output. Present-day instruments utilize a discharge time constant of 600 milliseconds by nationwide agreement. Some instruments are available with 160-millisecond time constant to meet European standards. Present usage of quasi-peak detection is no longer to simulate the response of the human ear, but to determine the impulsive nature of a signal. A ratio of quasi-peak-to-average readings greater than 1.8 usually indicates a signal of an essentially impulsive nature.

(3) *Peak Detection.*—Another function is that of measuring slide-back "peak" as illustrated by Figure 35-80(C). In this position, the detector is operated as for "average" detection, except that a d-c bias may be applied manually to the second detector and AGC line. This bias is adjustable as a front-panel control and is set for the threshold of audibility as determined by headphones connected to the amplifier output. In this operation, AGC energy is supplied largely from the d-c bias supply rather than the low-energy signal. Consequently, the AGC and detected-output voltage can be set quite close to the peak value of the i-f output pulse.

f. Audio Amplifier.—An audio-amplifier provides gain adequate to operate headphones. This feature is essential to good results, since it is frequently possible for a trained operator to tell much about a signal characteristic simply by listening to the headphones. Signal identification is often achieved by this means.

g. Beat-Frequency Oscillator.—An optional feature on radio-interference instrumentation is a beat-frequency oscillator. This BFO is also useful for signal identification, particularly for code stations.

h. Vacuum-Tube Voltmeter. — Certain features of a radio-interference meter are not found in a communications receiver. One such feature is an output indicator consisting of a stabilized d-c VTVM. The indicating meter of the VTVM is generally equipped with two scales, one for reading instrument input terminal voltage in microvolts, and the other for reading the same voltage in terms of decibels above one microvolt.

i. Attenuator.—In order to extend the measurement range of the instrument to 100,000 microvolts, a double-unit ganged attenuator is used. For maximum sensitivity, both attenuator units are set for essentially zero attenuation. The first two decade steps are then obtained by inserting either a 20- or 40-db pad ahead of the first i-f stage, as shown in Figure 35-78. Use of the pad at this location in the system results in an instrument output signal-to-noise ratio that is higher than would be obtained if the pads were inserted at the input to the instrument. Additional decades of attenuation are then introduced at the input of the noise meter, as protection against overload of the input circuit by high amplitude impulse signals. Figure 35-81 lists this distribution of attenuators.

Attenuator Setting	Amount of attenuation in db	
	RF	IF
X1	0	0
X10	0	20
$X10^2$	0	40
$X10^3$	20	40
$X10^4$	40	40

Figure 35-81.—*Typical Attenuator Combinations.*

j. Signal Calibrator.—Another feature of radio-interference instrumentation results from the requirement of either adjusting the overall instrument gain to some standard value, or knowing the gain so that its value can be used in computing interference levels. Since those instruments must be suitable for both field and laboratory use, some means of amplitude calibration are usually built into them. The internal signal calibrator may take any one of various forms, including the following:

(1) Fixed tuned (single-freguency) sine wave oscillator.

(2) Tunable sine wave oscillator.

(3) Diode white-noise generator. (See Figure 35-88.)

(4) Gaseous random-noise generator.

(5) Impulse generator. (See Figure 35-89.)

Sine wave and impulse generators are most commonly employed. The various calibrators are used partly because each has a definite frequency range of maximum utility and partly because different designers disagree about the relative advantages of sine wave and broad-band calibration. A discussion of their relative merits is too detailed to be included here.

k. Pickup Devices.—Thus far the discussion on radio-interference instrumentation has described a special-purpose two-terminal band-pass r-f voltmeter. Use of the instrument is extended greatly by accessories employed as electric or magnetic field sensing devices, such as those illustrated in Figure 35-82. The useful frequency ranges of the major accessories are shown in Figure 35-83. Many of the antennas are supplied with calibration curves to relate indicated meter readings to field strength in microvolts per meter.

(1) Impedance Matching Networks.—Most radio-interference measuring equipment is supplied with coaxial impedance matching networks to increase the utility of the instruments. These networks are generally simple resistance, capacitance, or resistance-capacitance combinations, utilized to transform the input impedance to some desired fixed value, such as 50 ohms, or to compensate for the removal of antenna capacitance when the instrument is used as a two-terminal voltmeter.

(2) Power-Line Probe—For certain conducted measurements, a power-line probe may be useful to prevent the impedence level for voltage measurements from rising above some fixed value, generally either 600 to 150 ohms. It is more recent common practice to perform power line measurements across an impedance not over 60 ohms with the use of an auxiliary line-stabilization network, as described in interference specification MIL-I-26600.

(3) Clamp-On RF Ammeter.—It is sometimes desirable to measure r-f current flowing through a conductor without interrupting the conduction circuit. A clamp-on r-f ammeter has been developed for use from 14 kc to 25 mc for this purpose. It operates as an r-f transformer with the conductor acting as the primary and a coil on a clamp-on magnetic core acting as the secondary.

(4) Loop Antenna and Loop Probe.—At the lower frequencies, loop antennas and loop probes are supplied to pick up the magnetic field component of electromagnetic radiation. (See Figure 35-77.) The sizes of these devices and the number of turns employed vary for different portions of the frequency range. The more sensitive loop is usually several orders of magnitude less sensitive than a rod antenna for pickup of a plane-wave field. However, low frequency measurements are generally made not in a far field, but in the induction or near field, where the ratio of electric to magnetic fields is not constant. Consequently, a knowledge of the magnetic field requires measurement with a loop. The loop antenna is used chiefly to locate the area of a source of interference, and the loop probe to localize the source more closely.

(a) Use of Loop-Input Devices.—The loop antenna is used for field intensity and radio interference measurements; it determines the bearing of a signal source and then measures the strength of the signal. The directional characteristics of a loop are illustrated in Figure 35-84. When the signal being measured is properly tuned in, the loop is rotated to obtain an aural null. When a sharp null cannot be obtained because the signal is very strong, the attenuator should be adjusted as

necessary to reduce the signal. Sharpest nulls are obtained with the highest feasible attenuator setting. If desired, the magnetic bearing to the signal source can be determined by using a pocket compass, and the direction indicated by the aural null. Bilateral bearings are obtained with the loop, and the ambiguity must be resolved by triangulation. The loop should then be rotated ninety degrees away from the null point to make a measurement of the signal. This step is required to give maximum signal input to the RI (Radio-Interference) Meter.

(5) Rod.—Over the lower end of the spectrum, the rod antenna is used when measuring the intensity of the electric-field component of an incoming signal. In order to obtain the field intensity at a given point, the rod antenna is simply oriented in whatever direction yields a maximum meter reading. Since the rod antenna is a high-impedance device, it is quite sensitive to variations in soil conductivity and to the influence of nearby objects.

(6) Half-Wave Dipole.—In the HF and

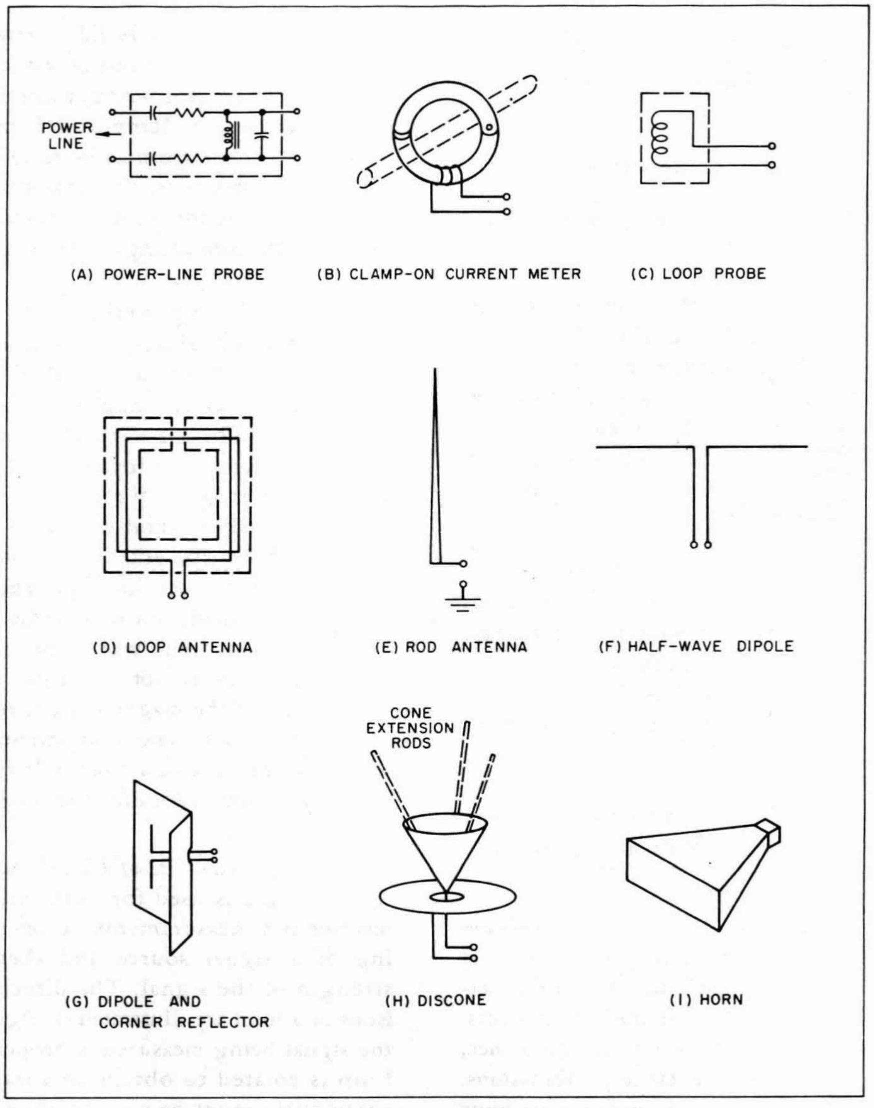


Figure 35-82.—*Typical Pickup Devices.*

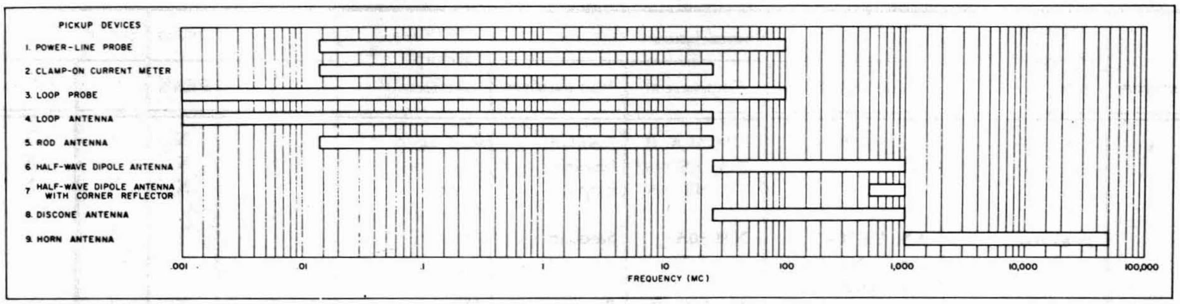


Figure 35-83.—*Useful Frequency Ranges of Pickup Devices.*

VHF portions of the spectrum, where the length of a resonant half-wave dipole is sufficiently short so that the antenna is convenient to handle, this type of field pickup may be used. In some instances, a corner reflector is employed with the dipole. For almost any dipole antenna, the length of the dipole must be adjusted for resonance at the frequency of reception if accurate readings are to be obtained, although for scanning operations the length may be set to the center of an octave band. Orientation instructions are similar to those for the rod antenna.

(7) *Discone.*—In order to avoid the adjustment of antenna length at each measurement frequency, a broad-band discone-type of antenna is used with some of the instruments. This antenna is frequently termed omni-directional because it is omni-directional in azimuth—with its ground plane horizontal. However, it has clearly defined elevation maxima whose displacement angles, with respect to the ground plane, vary as a function of frequency. Signals having mixed polarization can be received with the ground plane tilted to some angle between the vertical and horizontal.

(8) *Horn.*—For the microwave portion of the frequency range, one practical antenna in use is the directional horn antenna. It should be oriented for maximum pickup, the direction of the horn indicating the direction of the source.

l. Communications Receiver as Substitute RI Meter.—If a radio-interference meter is not available for making absolute conducted or radiated signal strength measurements, a good-quality communications receiver in conjunction with a calibrated signal generator may be used in a transfer technique. This method is subject to several limitations, including a limited ability to measure

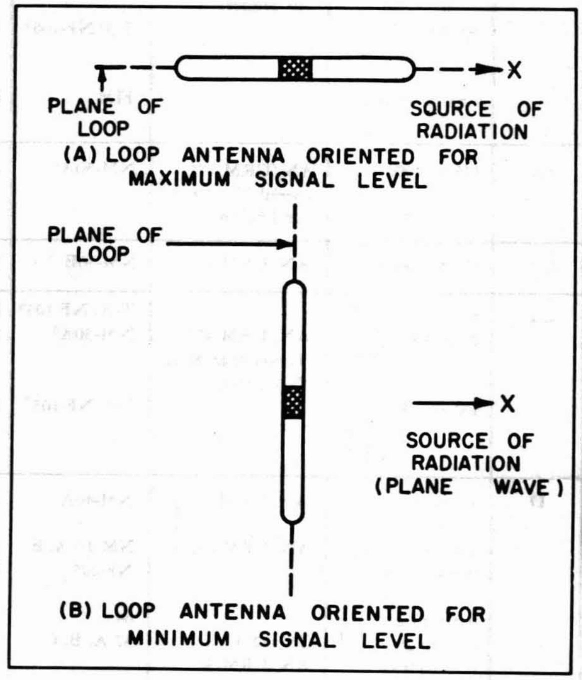


Figure 35-84.—*Loop Antenna Orientation for Maximum and Minimum Received (Plane-Wave) Signal.*

pulse-type signal characteristics. If interference location only is desired, a portable receiver for the given frequency range may be useful.

m. Spectrum Analyzers.—One difficulty with present-day radio-interference instrumentation is that its calibration procedure makes it ill-adapted to scanning the spectrum, an informative operation preliminary to actual measurements. For this reason, the spectrum analyzer is an auxiliary piece of equipment useful in radio-interference measurements. It is employed not only in obtaining

Category	Frequency Range (mc)	Nomenclature			Major Pickup Devices	Detecting Circuits			Power Source	
		Government	Commercial	Manufacturer		Avg.	QP	PEAK	AC	Battery
A	0.15 to 25	AN/PRM-1A	NM-20 A, B	Stoddart	Rod, Loop	X	X	X	X	X
	0.15 to 30		T-A/NF-105[2]	Empire	Rod, Loop	X		X	X	X
	20 to 200		T-1/NF-105	Empire	Dipole, Discone	X		X	X	X
	20 to 400	AN/URM-47[3] (Serial No. 191-1 or higher)	NM-30A[3]	Stoddart	Dipole	X	X	X	X	
	200 to 400		T-2/NF-105	Empire	Dipole, Discone	X		X	X	X
	375 to 1000	AN/URM-17[4] (Serial No. 222-1 or higher)	NM-50A[4]	Stoddart	Dipole	X	X	X	X	X
	400 to 1000		T-3/NF-105[5]	Empire	Dipole, Discone Corner Reflector	X		X	X	X
	1000 to 10,000		FIM	Polarad	Horn, Omni-directional	X	X	X	X	
B	375 to 1000	AN/URM-17[4] (Serial No. 190-50 and below)	NM-50A[4]	Stoddart	Dipole	X	X	X	X	X
C-1	375 to 1000	AN/URM-17	NM-50B	Stoddart	Dipole	X	X	X	X	X
C-2	0.15 to 30		T-A/NF-105[6]	Empire	Rod, Loop	X		X	X	X
	20 to 400	AN/URM-47[4] (Lower than Serial No. 191-1)	NM-30A[4]	Stoddart	Dipole	X	X	X	X	
	400 to 1000		T-3/NF-105[7]	Empire	Rod, Loop Dipole, Discone	X		X	X	X
D	30 cps to 0.15 mc	AN/URM-41	NM-40A	Stoddart	Rod, Loop	X (Also RMS)	X	X	X	
	0.014 to 0.25	AN/URM-6A, B	NM-10 A, B	Stoddart	Rod, Loop	X	X	X	X	X
	0.014 to 1000		NF-205	Empire	Rod, Loop Dipole, Discone	X		X	X	X
	0.015 to 2		64	Ferris	Rod, Loop	X	X	(?)	X	X
	0.15 to 25	TS-432/U	32 A, B, C	Ferris	Rod			X	X	X
	0.15 to 0.4, 1.6 to 40	AN/URM-3								
	0.15 to 80	AN/PRM-14	NF-114	Empire	Rod	X		X	X	X
	0.15 to 1000	AN/URM-85		Empire	Loop Dipole, Discone Corner Reflector	X		X	X	
	0.54 to 216		500[8]	Sprague	Rod, Loop Dipole		X		X	X
	15 to 150		58 AS	Measurement	Loop, Dipole	X	X	X	X	
	15 to 400	TS-587 A/U (Obsolete)	NMA-5A	Stoddart	Dipole	X	X	X	X	
	20 to 400	AN/URM-7		Empire	Loop, Dipole, Discone	X		X	X	X
	150 to 1000	AN/TRM-4		Empire						
	375 to 1000		NM52-A (Improved version of NM50-A)	Stoddart	Broadband	X	X	X	X	

Figure 35-85.—*Radio-Interference Measuring Equipment.*

Category	Frequency Range (mc)	Nomenclature			Major Pickup Devices	Detecting Circuits			Power Source	
		Government	Commercial	Manufacturer		Avg.	QP	PEAK	AC	Battery
	950 to 11,000	AN/TRM-6			Horn, Omni-					
	1000 to 10,000		FIM	Polarad	directional	X	X	X	X	
	1000 to 10,700	AN/URM-42	NM-60 A	Stoddart	Omni-directional	X	X	X	X	
	1000 to 15,000		NF-112 (Being devel.)	Empire	Horn	X		X	X	

[1] This table is subject to change to include new instruments having superior performance characteristics and to changing the category of older instruments which have become obsolete.
[2] This category applies only to tuning units purchased after 11 March 1957.
[3] This category applies only when power supply 91226-1 is used.
[4] These instruments can be modified to category A requirements by the manufacturer.
[5] This category applies to instruments purchased after 9 May 1956.
[6] This category applies to instruments purchased prior to 11 March 1957. The manufacturer can supply information on the changes necessary to modify the tuning units to category A requirements.
[7] This category applies to instruments purchased prior to 9 May 1956. These instruments can be modified to category A requirements by the instrument manufacturer.
[8] Used particularly by electric utilities.

Figure 35-85.—*Radio-Interference Measuring Equipment (Continued).*

the preliminary interference picture, but also in monitoring qualitatively the relative benefits to be obtained from the application of interference reduction techniques.

n. Available Radio Interference Instrumentation.—Interference-measuring instruments of both current and obsolete usage are listed in Figures 35-85 and 35-86. Categories, A, B, C-1, and C-2 include currently available commercial measuring instruments categorized according to their compliance with current Military Specifications MIL-I-26600 (USAF) and MIL-I-6181D—D is an additional category.

(1) *Category A.*—Category A instruments are those preferred interference measuring instruments which adequately measure the parameters of interference signals as required by this specification, and which are approved by the Air Force. Any combination of category A instruments may be used for the required measurements.

(2) *Category B.*—Category B instruments are those existing instruments which are in use, but which do not adequately measure the parameters of interference signals as required by this specification, but which are nevertheless also approved by the Air Force. Use of these instruments is permissible until conditions permit their replacement by category A instruments, if:

(a) the category B instrument was procured prior to 29 May 1953, and the instrument is listed in the table; or

(b) if a category A instrument is not commercially available in the same frequency range.

(3) *Category C.*—Category C instruments should not be used unless specifically authorized.

(a) *Category C-1.*—Category C-1 instruments are those which have recently been developed to meet category A requirements, but have not been evaluated by the Air Force.

(b) *Category C-2.*—Category C-2 instruments are those which have been recently developed and do not meet category A requirements, but which can presumably be modified by the manufacturer to attain a category A rating.

(4) *Category D.*—Category D instruments are not authorized for use under Specifications MIL-I-26600 (USAF) and MIL-J-6181D, but are included in the table for possible utility in other applications. This category includes instruments approved for use under other radio-interference specifications by

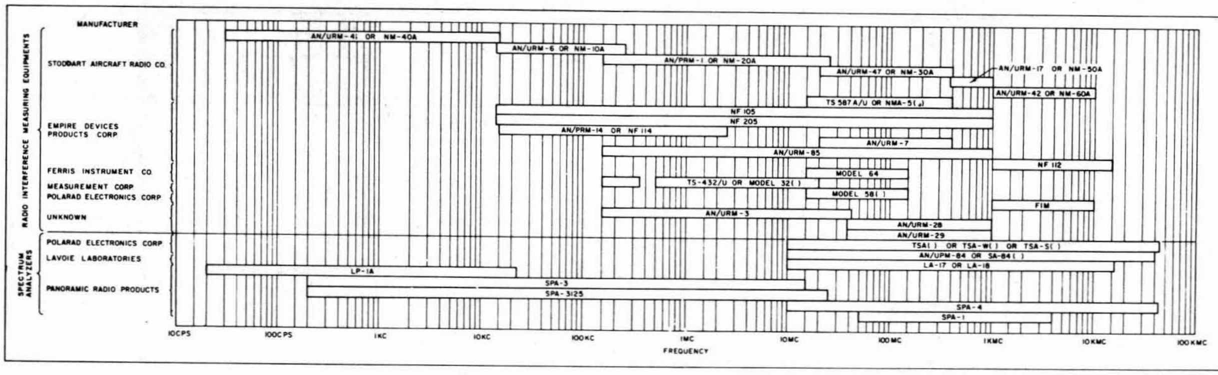


Figure 35-86.—*Spectrum Covered by RI Instrumentation.*

CHARACTERISTIC		SIGNAL GENERATOR	IMPULSE GENERATOR	WHITE-NOISE GENERATOR
FREQUENCY RANGE		Commercially available from dc to 40 kmc.	Commercially available 10 kc to 1 kmc. Advertised for future delivery in frequency range 1 to 10 kmc.	Commercially available from d-c to 28 kmc.
MAXIMUM AVAILABLE POWER	Broad band	107 db above 1μw/mc.	Experimental equipment 67 db above 1μw/mc above 1 kmc. Advertised specifications 79 db above 1μw/mc.	9 db above 1μw/mc.
	Continuous wave	1 milliwatt.	0.002 milliwatt.	0.2 micromicrowatt.
CALIBRATION	Error	High output level results in negligible error caused by noise.	Low level results in calibration error.	Level much too low for practical use.
	Measurement	CW and pulsed-CW levels determined directly. Broad-band level determination requires calibration of impulse bandwidth.	CW, pulsed CW-levels require determination of impulse bandwidth with signal generator. Broad-band level determined directly.	CW, pulsed-CW levels require knowledge of noise bandwidth. Broad-band level determined directly.
ACCURACY	Broad band	Absolute power ±2.5 db.	Relative power ±2 db. Absolute (calibrated by external generator) ±4.5 db.	Absolute power ±0.25 db.
	Continuous wave and pulse	Absolute power ±2 db (referred to internal power monitor). Continuous monitoring of output level.	Absolute power ±4.5 db (calibrated by external generator). No means of checking output.	Absolute power ±1.0 db.
SELECTIVITY	Source	Essentially monotonic. Produces signal at one frequency (plus harmonic).	Broad band.	Broad band.
	Effect	Harmonic signals can cause response at image and spurious frequencies; but probability is low.	Overloading of receiver and receiver spurious responses and image frequencies caused by broad-band impulse signal can result in calibration error.	Broad-band noise can cause calibration error due to image and spurious responses.
RELIABILITY		Noncontacting short; long cavity life.	Contacts result in erratic operation, limited life.	Long life.

Figure 35-87.—*Characteristics of Typical Calibration Sources.*

other military services, and commercial instruments. In addition to current instrumentation, some obsolete units still in use are listed in the table.

.2 Calibration of Radio-Interference Instrumentation.—Radio-interference field-intensity meters can be calibrated either directly, by means of a power measuring element, or by signal substitution. Three different instruments, the signal generator, the impulse generator, and the white-noise generator are commonly used to produce a standard signal for the signal substitution method. Of these three, each has its frequency range of maximum utility. Figure 35-87 provides a comparison of characteristics.

a. White-Noise Generators.—One-frequently employed signal source is a conventional diode white-noise source shown in Figure 35-88. White-noise is so-called because its output is uniformly distributed over its operating frequency range from the lowest frequencies up to approximately 1000 mc, where electron transit time effects become a limiting factor. Such a source utilizes a diode in a temperature-limited condition to produce random white noise as a result of the shot effect. This output voltage is proportional to the square root of the diode plate current. Because of their simplicity, diode noise sources are used as internal secondary calibrators in some radio-interference meters operating through the VHF range. One common difficutly in using white-noise sources for calibration purposes is their relatively low output. Furthermore, they may introduce error caused by image and spurious responses of the instrument being calibrated.

b. Impulse Generators.—An impulse generator can provide a noise output which is uniform over a frequency range from 15 kc to 1000 mc, and even higher. Many principles of impulse generation have been employed. The most commonly used unit, illustrated in Figure 35-89, employs an electromechanical switch to send on each operation a unit-step current pulse down a delay line open-circuited at the far end. At this end, a reflected current pulse of equal magnitude and opposite polarity is produced. At some appropriate output point along the line (usually at the switching control), the net pulse is the algebraic sum of incident and reflected pulses, or a very narrow rectangular pulse, the frequency components of which are uniformly distributed over a wide spectrum. The output of such a device is quite high, and is generally useful up to 1000 mc. Additional errors may be introduced by spurious and intermodulation responses of the instrument being calibrated.

c. Sine Wave Generators.—An instrument useful throughout the entire range of frequencies is a standard signal generator, which provides a single-frequency sine wave signal of known, adjustable amplitude that is tunable throughout the spectrum. Simplified sine wave genetrators, both fixed-frequency and variable-frequency, are utilized as internal calibrators for some radio-interference instrumentation. Calibration by means of

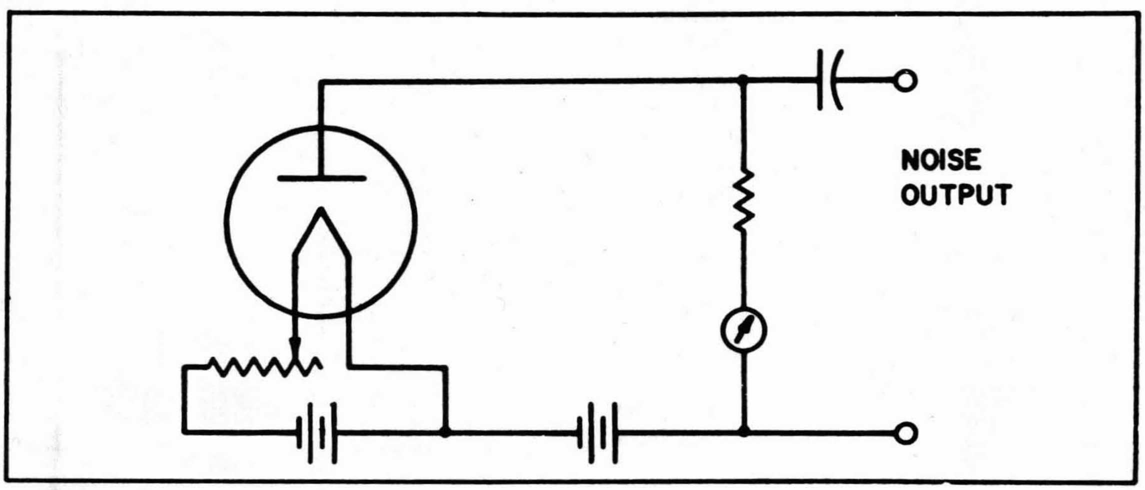


Figure 35-88.—*Diode White-Noise Generator.*

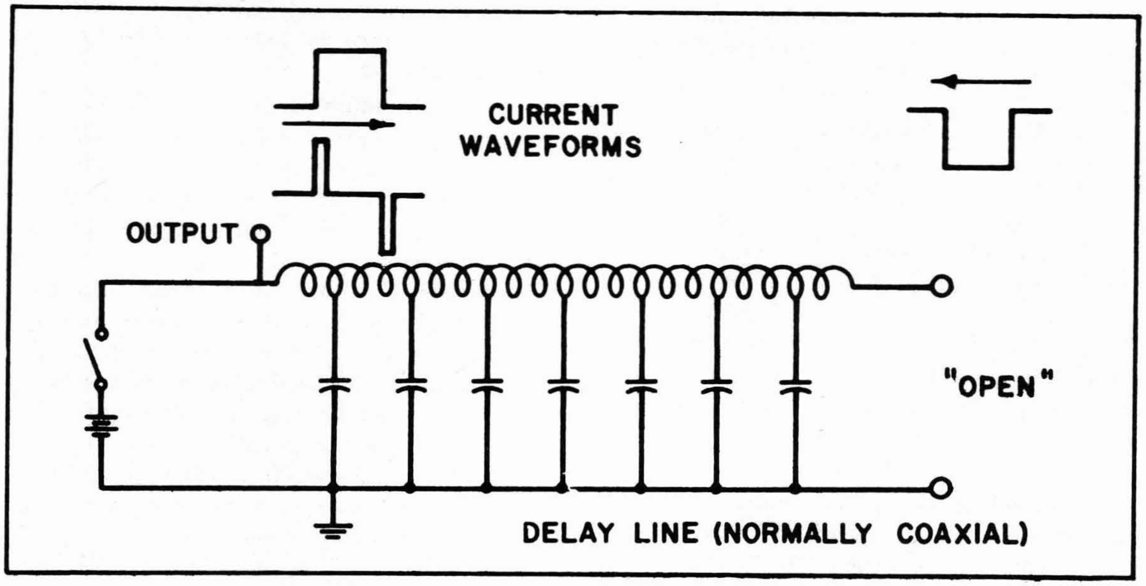


Figure 35-89.—*Simplified Diagram of Impulse Generator.*

standard signal generators involves complex equipment and requires a knowledge (or measurement) of bandwidth and also considerable time to perform the calibration. However, it is the basic laboratory method used at all frequencies.

.3 Interpretation of Instrument Readings.— Radio-interference meters incorporate design features that render them suitable for quantitative measurements of not only conventional radio signals, but also measurements of more irregular emanations, such as impulsive interference created by ignition systems, commutation, and similar recurring signals. The detected quantity is not the signal applied at the input terminals as it may be greatly modified by passage through the band-pass characteristics of the instrument. Consequently, the detected signal results from that modified signal which appears at the output of the last i-f stage. This signal has some relationship to the input signal, but this relationship is different for different types of input signals. The instrument reading is affected, not only by the bandwidth, but also by the particular detection operation performed upon the i-f output signal. The characteristics of both i-f bandwidth and these detector functions result in false readings for certain types of input pulses. These effects will be described in this section, in order to permit an intelligent appraisal of meter readings.

a. Bandwidth and Detection Effects.— The effects of bandwidth upon the signal to be measured are dependent upon the nature of the signal itself and upon the shape of the overall selectivity curve of the instrument. This shape depends upon the number and types of tuned stages, but is relatively insensitive to these stages as they are used in radio-interference instrumentation. Bandwidth relationships for radio-interference instrumentation are given in Figure 35-90, as defined by Figure 35-91.

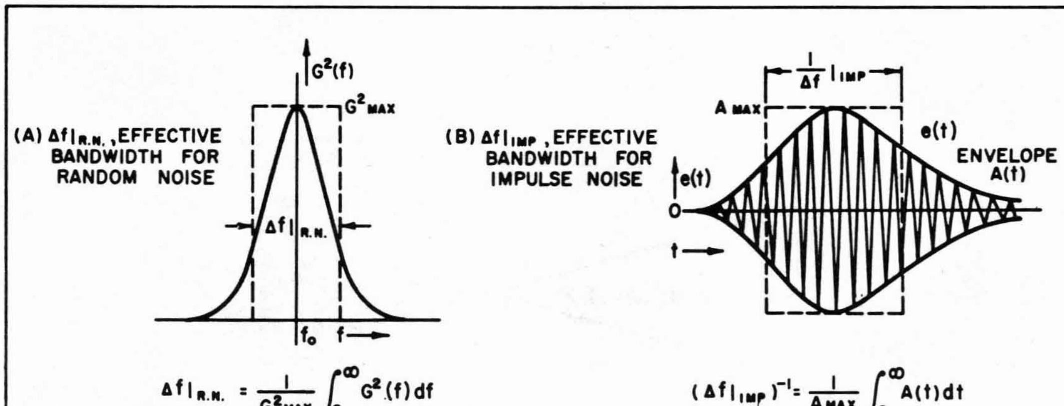
To obtain this bandwidth→ / Multiply this bandwidth by↓	Random Noise	Impulse	6-db	3-db
Random Noise	1.	1.41	1.30	1.25
Impulse	0.707	1.	0.922	0.886
6-db	0.770	1.08	1.	0.962
3-db	0.801	1.12	1.04	1.

Figure 35-90.—*Bandwidth Relationships for Radio-Interference Instrumentation.*

(1) Sine Wave Carrier Input.—The bandwidths of interference meters are generally expressed in terms of effective random-noise bandwidth; to obtain the sine wave, 6-db bandwidth, simply multiply the random-noise bandwidth by 1.3; for the 3-db sine-wave bandwidth multiply by 1.25. A relatively pure sine wave i-f input signal results in an output that is independent of the i-f bandwidth, as in Figure 35-92. Consequently, all detector functions, average (field intensity), quasi-peak, and peak, provide readings which are independent of bandwidth. Readings are expressed in microvolts (μv) for conducted interference and microvolts per meter ($\mu v/m$) for radiated interference.

(2) White-Noise Input.—The power in a white-noise signal modified by limited bandwidth is directly proportional to the bandwidth. In other words, the rms voltage of the i-f output signal is proportional to the square root of this bandwidth ($e=\sqrt{4kTR\Delta f}$). Since the statistical signal characteristics of white noise have not been altered by passage through the i-f amplifier (illustrated in Figure 35-92), average quasi-peak, and peak-detector outputs must also be proportional to the square root of bandwidth. It is because of this property that the white-noise type of signal is measured in units involving the square root of bandwidth; microvolts per square root of kilocycles ($\mu v/\sqrt{kc}$) and microvolts per meter per square root of kilocycles ($\mu v/m/\sqrt{kc}$). When white noise is expressed in such terms, the results of measurement should be independent of the bandwidth of the instrument making the measurement.

(3) Impulsive Interference Input. — The equivalent impulse noise bandwidth equals the random noise bandwidth multiplied by 1.41. When the input noise signal is primarily inpulsive, the effect of instrument bandwidth is to change completely the signal characteristics as determined at the i-f output. When a pulse of duration γ is applied, if this pulse is short compared with the reciprocal of twice the i-f bandwidth ($\tau \ll \frac{1}{2\Delta f}$) the energy in such a pulse shock excites the tuned circuits and the output pulse shape depends only on these circuits and not on the shape of the input pulse, as illustrated by Figure 35-92. Since the duration of the output pulse is a fixed quantity, an increase of input signal energy (area under the input pulse, Figure 35-92) results only in an increase of output-pulse height—the output-pulse energy must increase in a manner similar to the input. Thus, peak readings will be proportional



$$\Delta f|_{R.N.} = \frac{1}{G^2_{MAX}} \int_0^{\infty} G^2(f)\,df$$

RECTANGLE HAS AREA EQUAL TO THAT UNDER SELECTIVITY CURVE EXPRESSED IN POWER RATIO.

$$(\Delta f|_{IMP})^{-1} = \frac{1}{A_{MAX}} \int_0^{\infty} A(t)\,dt$$

RECTANGLE HAS AREA EQUAL TO THAT UNDER ENVELOPE OF IMPULSE RESPONSE OF BAND-PASS AMPLIFIER.

Figure 35-91.—*Effective-Bandwidth Definitions.*

to the total energy in the input impulse, and will also increase proportional to the i-f bandwidth. Peak readings are stated in terms of per-unit-bandwidth; microvolts per kilocycle (μv/kc) for radiated interference. On the other hand, the average reading does not change, provided successive i-f output pulses do not overlap; average readings are specified in terms of microvolts (μv) or microvolts per meter (μv/m). Quasi-peak readings are also influenced by pulse repetition rate, charge-time-constants of detector circuits and the i-f overload factor—as well as pulse width, if the i-f input pulse is not short compared with the reciprocal of twice the i-f frequency. Despite these variables, it is conventional practice to express quasi-peak readings in the same units as peak readings. It is preferred practice to specify the pulse repetition rate with such readings (CED 3507.3c).

b. Identification of Nature of Signal.— The operator of a radio-interference measuring instrument should bear in mind that impulse-type interference of a high repetition rate assumes some of the characteristics of random type interference. Under such conditions, he must carefully evaluate his readings to determine the nature of the interference. It is convenient to make this determination on the basis of the ratio of quasi-peak-to-average readings for those instruments employing both types of detection circuits, although the ratio of peak-to-average readings may also be used for other instruments. A quasi-peak-to-average ratio above 1.8 indicates predominantly impulsive interference and a ratio 1.8 or less indicates predominantly random interference. The nomograph of Figure 35-187 is an aid in this determination.

c. Pulse Repetition Rate.— If the interference has been identified as impulsive, the pulse rate may be determined approximately with the aid of Figure 35-188. A quasi-peak-to-average ratio greater than 10 generally indicates the possibility of erroneous readings due to overload of the final i-f stage on pulse peaks. This condition may be encountered most often in the case of low-duty-cycle signals. A more accurate measure of the threshold of overload can be taken as the ratio of quasi-peak-to-average readings multiplied by the linear percent-of-full-scale deflection of the meter. This result should be no greater than the permissible overload factor of the instrument (generally about 10), and can be expressed as:

$$\frac{QP}{Avg} \times (\%\ \text{Scale Deflection on QP}) \leq 10. \quad (25)$$

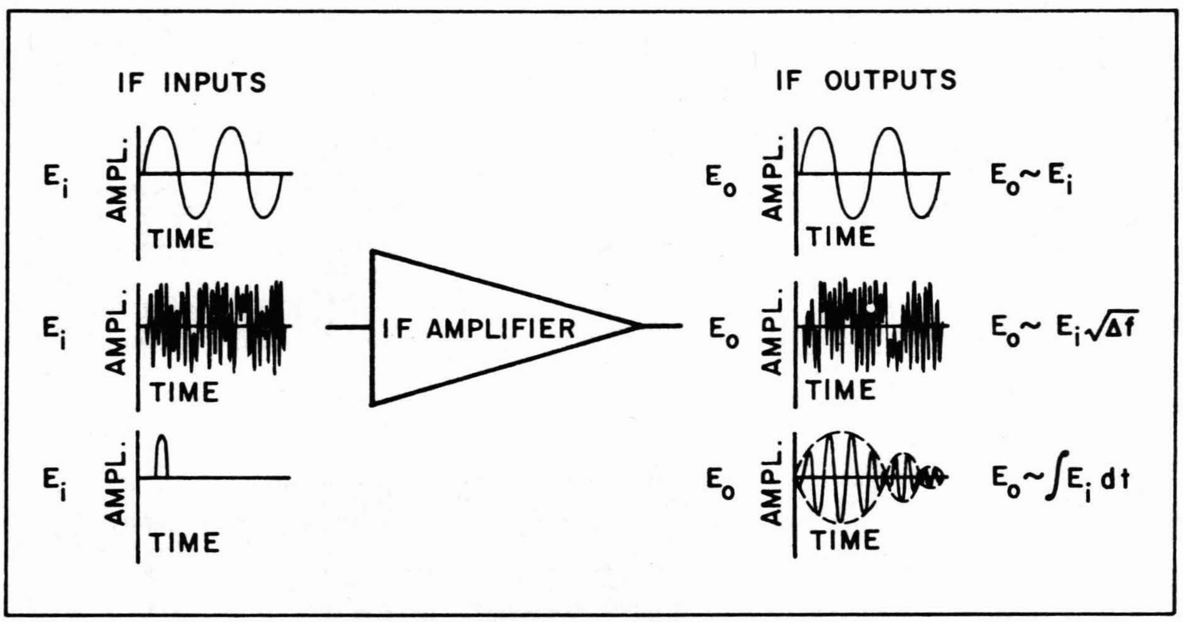


Figure 35-92.—*IF-Output Waveforms.*

Internal Noise (Reading = A)	Type of Signal (Reading in Internal Noise = B)	Detector Function	Direct Subtraction $R = B - A$	RMS Subtraction $R = \sqrt{B^2 - A^2}$
Random	Sine Wave	Average		X
		Quasi-Peak	X	
		Peak	X	
Random	Random	Average		X
		Quasi-Peak		X
		Peak		X
Random	Non-Overlapping Impulse of High PRF	Average		X
		Quasi-Peak	X	
		Peak	X	

Figure 35-93.—*Correction Operations to Remove Reading Error Due to Internal Noise.*

d. Low-Level Signals.—Actual signals received, combine with input random noise—internal to the measuring instrument—to produce an uncorrected reading B. When the signals to be measured are weak, meter readings must be corrected for the error introduced by internal noise. In addition to the signal measurement, a reading A should be obtained represesting internal noise in the absence of a signal. This result is usually accomplished by disconnecting the input cable and noting the meter reading. Then the corrected reading R will be indicated in Figure 35-93, the correction operation depending upon the nature of the signal and the detection function employed.

.4 Spectrum Analyzers.—Since spectrum analyzers are useful complementary equipment in certain phases of radio-interference measurements, a (partial) list of available spectrum analyzers is provided in Figure 35-94.

3508. INTERFERENCE PREDICTION PROBLEMS.

.1 Introduction.—Interference prediction is the technique which attempts an estimate of severity of interference and of possible frequencies at which interference is likely to be experienced by a communications-electronics system, due to undesired signals orginating outside the system. Such a technique is useful to determine in advance: to what extent mutual radio-frequency interference is likely to be experienced by communications-electronics equipment in a proposed installation; to what extent local radio-frequency interference is likely to be generated due to the installation of additional equipment in an existing equipment complex; to what extent radio-frequency interference is likely to be experienced by communications-electronic equipment at a site due to the incidence of off-site signals; and the optimum utilization of available r-f channels for various communications links. It is convenient to consider applying an interference-prediction technique to three classes of problems: the intra-site problem; the inter-site problem; and the operational problem, since the method of handling each is different.

a. The Intra-Site Problem.—As part of a typical intra-site problem, it may be necessary to estimate how much interference will result due to the simultaneous operation of a number of electronic equipments located relatively close to one another, such as in an aircraft or at an air station. Examples of interference which might be amenable to such prediction are communications interference to airborne navigational systems, and potential radar modulation interference to nearby communication receivers. A reasonably reliable estimate of these and similar types of interference will aid in spotlighting those equipments which will respond to interfering signals, and those equipments that can cause the interference. It will also be helpful in determining what effect system improvements such as equipment modifications, relocation, or time-sharing will have on mutual electromagnetic interference.

Frequency Range	Maximum Frequency Dispersion (mc)	Nomenclature		Manufacturer
		Government	Commercial	
20 cps - 25 kc	5 kc		LP-1A	Panoramic
200 cps - 15 mc	3 mc		SPA-3	Panoramic
200 cps - 25 mc	3 mc		SPA-3/25	Panoramic
10 - 16,000 mc	25 mc	AN/UPM-17	LA-17, 18	Lavoie
10 - 40,880 mc	5 and 25[1] mc	AN/UPM-84	SA-84 ( )	Polarad
10 - 44,000 mc	5 and 25[1] mc		TSA-S ( )	Polarad
10 - 44,000 mc	5 and 70[1] mc		SPA-4	Panoramic
10 - 44,000 mc	5, 25 and 70 mc		TSA-W ( )	Polarad
50- - 4000 mc	10 mc		SPA-1	Panoramic
8,970 - 9,630 mc		AN/UPM-33 (formerly TS148/UP)		

1 Depending upon frequency.

Figure 35-94.—*Spectrum Analyzers.*

b. The Inter-Site Problem.—As part of a typical inter-site problem, it may be necessary to estimate how much interference will result from the reception of electromagnetic signals orginating several miles from the site and coupled into the site equipment by means of a line-of-site propagation path and antenna pickup. Consider two low-power, mobile communication nets at locations remote from each other, but sharing the same or an adjacent channel. It may be necessary to estimate a physical separation distance that is adequate to avoid interference under "normal" operating conditions, but is not over-generous in separation so that a large number of nets may share the same channel.

c. The Operational Problem.—It is possible for interference to occur under some conditions and not occur under others. Consequently, another problem is that which requires an estimate of interference between two nets under varying propagation conditions, with scanning antennas, and with other factors which contribute to a changing environment. Such an estimate would be useful to the C-E officer in appraising the reliability of a given communications link. The knowledge of impending interference may also be used to establish time-sharing procedures for the interfering nets. A typical problem would be to determine what channel, and what periods of time, should be allocated to each specific communication link.

.2 Discussion.

a. The Intra-Site Problem.—The intra-site problem is characterized by the fact that all equipments involved in the interference problem under consideration exist locally, and may frequently come under the jurisdiction of a single C-E officer. Consequently, the concerned equipments and their characteristics pertinent to interference predictions are either known or can be determined, and the coupling between equipments can be estimated fairly easily. Since the number of equipments involved is fairly restricted, it becomes feasible to consider prediction of the over-all interference situation from a number of sub-problems, each involving relatively few equipments.

b. The Inter-Site Problem.—For the inter-site problem, the potentially available data are less complete, since a single C-E officer will not have jurisdiction over all of the electronic equipment involved. In most cases, jurisdiction will even fall outside of the realm of a group of C-E officers, and may involve responsibilities of other military and civil authorities. Consequently, the on-site electronic equipment characteristics may be known, but off-site signal source characteristics may or may not be known. The degree of inter-site coupling between equipments can seldom be estimated with the accuracy of the intra-site case. In specialized cases, a limited number of known sources may be involved and coupling may be reasonably well estimated. Under such conditions, the prediction technique to be used for the intra-site situation may also be employed. However, the majority of inter-site problems involve one or more of the following factors: multiple interference sources, ill-defined locations of such sources, incompletely known operating schedules, poorly defined equipment operating characteristics, or variable propagation conditions. If so, the most promising analytical approach may be a statistical one. Statistical approaches to interference evaluation are being investigated, but have not yet been developed into a useful, practical tool for the C-E officer.

c. The Operational Problem.—The operational interference-prediction problem involves both intra-site and inter-site situations. It is potentially solvable for the intra-site and many of the inter-site situations, but cannot be analyzed in detail for inter-site situations where pertinent performance data is lacking. The most significant data needed for the operational case includes such factors as frequency, operating times, power and sensitivities of equipments, time-varying parameters and general location.

d. Apporach to the Problems.—Present-day interference prediction techniques are essentially methods for estimating receiver effective input signals (true input signal corrected for reduced response caused by different type modulation) due to sources of desired and undesired energy. Such techniques may vary in complexity, depending on the accuracy and amount of system information available, the desired prediction accuracy, and the analytical effort (in both time and cost) that can be expended realistically to achieve the desired results. The remainder of this chapter will discuss the application of prediction methods to various interference problems, starting with a relatively simple approach requiring comparatively little information about the components of the system under consideration.

.3 Simplified Interference Prediction.—Simplified interference prediction considers only the major direct transmitter-receiver inter-actions and purposely neglects harmonic and spurious effects of all kinds. Such over-simplification of the prediction problem limits its usefulness to those cases where transmitter harmonics and receiver i-f image, and other responses are unimportant. Thus, it is employed only to obtain preliminary evaluation of equipment compatibility. It also neglects the effects of impedance mismatches among antennas, transmission lines, and transmitters or receivers, and it neglects any adjustment of effective signal level to account for differences between transmitter modulation and that which the receiver detection circuitry is designed to handle. In the elementary interference problem, it is assumed that information is available on interference source powers and frequencies, on gain and directivity of both the interfering transmitter antenna and the receiving antenna, on transmission line losses, and on pertinent on-channel and adjacent-channel receiver characteristics. It is also assumed that the super-position principle applies when multiple interference sources exist, so that the total interference from several causes will be simply the sum of the effects of the individual cases.

a. The Prediction Method.—For each transmitter-receiver pair, the relation between the desired-or-interfering-transmiter output power and the receiver input signal is illustrated graphically by Figure 35-95. The solid line represents co-channel considerations, while the dashed line is an additional effect that must be taken into account for any off-channel interference. To effect simplified interference prediction, it is necessary first to assemble all required data as indicated by check marks on the sample work sheet, Figure 35-96. Where information is not available, a reasonable estimate of these characteristics must be made. The remainder of the information is derived from known data. The factors which must be known to make the prediction of receiver performance listed on the sample work sheet, Figure 35-96, include:

(1) *For the transmitter*—carrier frequency, type of modulation (required later to determine a correction for any difference between the type of modulation and that which the eventual receiver is designed to handle), rated out-put power, loss in the transmission line, and antenna gain in the direction of the receiver concerned.

(a) Under "Transmitter," item 6 is simply the algebraic sum of items 4 and 5. Item 7 is derived from items 3 and 6 since the effective radiated power $P_{t\,eff}$ is the algebraic sum of true output power and net gain.

(2) *For the propagation path*—distance of separation between transmitter and receiver, attenuation of the propagation path.

(a) The section on "Propagation" requires the use of propagation-loss curves to account for losses over the propagation path (refer to CED 3503.6 and Figures 35-178 through 35-184) once the separation distance and frequency are known. The difference between the effective radiated power of the transmitter and propagation loss determines the power level at the receiving antenna, item 10.

(3) *For the receiver*—tuned frequency, input impedance, antenna gain in transmitter direction, loss in the transmission line, correction for reduced sensitivity due to off-channel response (obtained from overall selectivity curve), acceptance ratio (correction for reduced receiver response when transmitter modulation differs from that for which the receiver is designed).

(a) Item 16, the net gain g_r, is derived from item 14 minus item 15. This information,

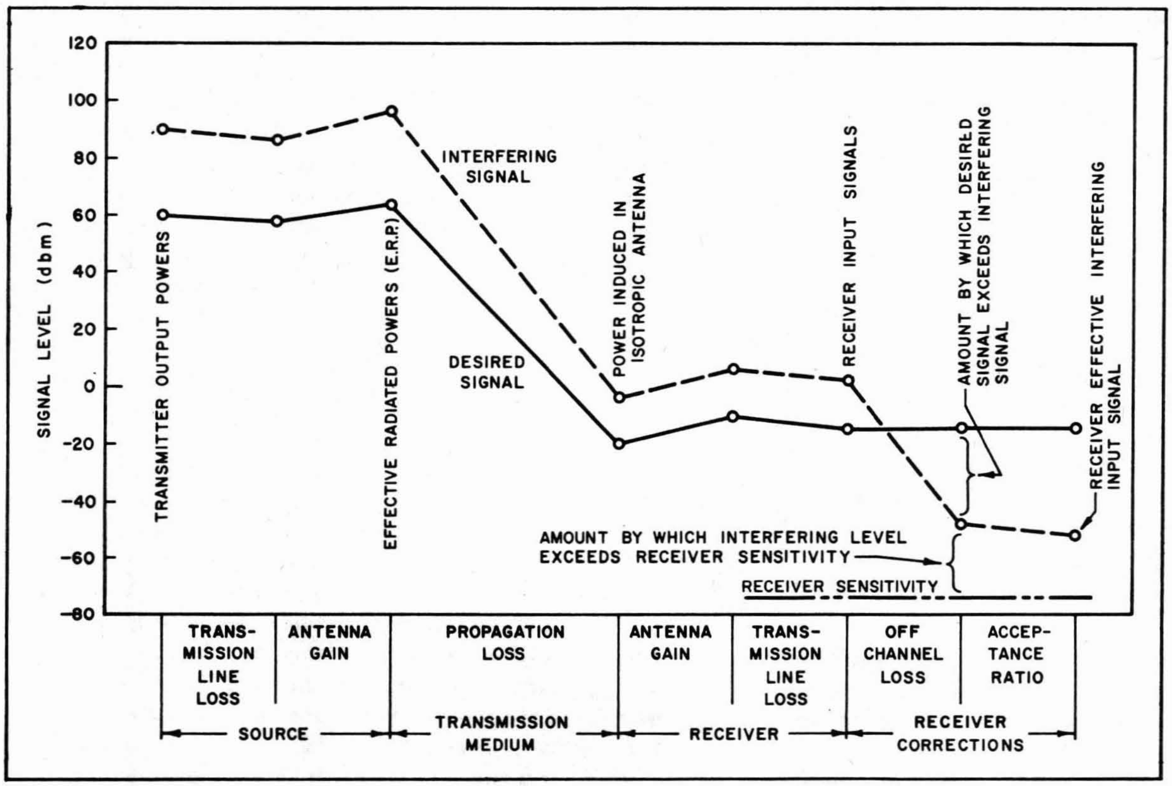


Figure 35-95.—*Signal Levels Involved in Simplified Interference Prediction.*

SAMPLE SIMPLIFIED—PREDICTION WORK SHEET

DATE

TRANSMITTER

1. CARRIER FREQUENCY	mc	2. MODULATION ☐ AM ☐ FM ☐ PPM ________ OTHER		3. RATED OUTPUT POWER [1]	kw / dbm
4. TRANSMISSION LINE LOSS	db	5. ANTENNA GAIN IN RECEIVER DIRECTION	db	6. NET GAIN *(item 5 minus item 4)*	db
7. EFFECTIVE RADIATED POWER IN DIRECTION OF RECEIVER, $P_{t\ eff}$, *(item 3 plus item 6)*					dbm

PROPAGATION

8. SEPARATION BETWEEN TRANSMITTER AND RECEIVER	miles or feet	9. PATH ATTENUATION	db
10. POWER LEVEL *(out of an isotropic antenna)* AT RECEIVING LOCATION, P_r, *(item 7 minus item 9)*			dbm

RECEIVER

11. TUNED FREQUENCY	mc	12. DEMODULATION *(AM, FM, PM, etc)*		
13. INPUT IMPEDANCE R_{in}	ohms	14. ANTENNA GAIN IN TRANSMITTER DIRECTION	db	
		15. TRANSMISSION LINE LOSS	db	
16. NET GAIN BEFORE RECEIVER INPUT *(item 14 minus item 15)*				db
17. POWER LEVEL AT RECEIVER INPUT TERMINALS, P_i, *(item 10 plus item 15)*				dbm
18. CORRECTIONS:				
		18a ACCEPTANCE RATIO	db	
		18b OFF-CHANNEL RESPONSE	db	
		18c NET CORRECTIONS [2]		db
19. EFFECTIVE POWER LEVEL $P_{i\ eff}$ AT RECEIVER INPUT TERMINALS *(item 17 plus item 18)*				dbm
20. EFFECTIVE RECEIVED SIGNAL LEVEL [3]	uv	21. RECEIVER SENSITIVITY	uv	

[1] $1\ kw = 60\ dbm$ [2] $a + b = c$ [3] $P_{i\,eff}R_{in}$

Figure 35-96.—Simplified-Prediction Work Sheet.

combined with the power level p_r at the receiving antenna, will establish the received interfering signal power P_i or voltage level V_i at the receiver input terminals across input impedance R_{in} (assumed resistive).

$$P_i \text{ (dbm)} = p_r \text{ (dbm)} + g_r \text{ (db)}, \quad (26)$$

and

$$V_i \ (\mu v) = \sqrt{10^9 \ P_i \text{ (mw)} \ \ R_{in} \text{ (ohms)}}, \quad (27).$$

where

$$P \text{ (mw)} = \text{antilog} \frac{p_i \text{ (dbm)}}{10} \quad (28)$$

In order to determine the effect of V_i at the receiver output in terms of an equivalent input signal $V_{i\,eq}$ having modulation characteristics similar to those for which the receiver was designed, and operating at a carrier frequency in the center of the passband, two corrections need be made to V_i.

(b) The correction for modulation is commonly known as an acceptance ratio, and specifies the amount, in decibels, by which the desired signal voltage or power must exceed the interfering voltage or power to achieve satisfactory intelligence transmission. It is a measured quantity whose value is dependent on complex relationships involving the desired and interfering signal modulations, the receiver response characteristics, and the abilities of the receiver operator. Representative values for the acceptance ratio are shown in Figure 35-97. If specific acceptance-ratio information is not known, a 0-db ratio can be assumed when desired and interfering modulations, a ratio of -10 db might be arbitrarily employed. A correction for modulation may be omitted if desired and a comparison can be made at the completion of the analysis between the effective received signal level and the receiver sensitivity.

(c) The correction for decreased receiver sensitivity to off-channel signals can be obtained directly from the overall time selectivity curve of the receiver when such data are available from actual measurement of the receiver time selectivity at the specific frequency in question, or from an estimate of the receiver off-frequency response.

(d) The sum of these corrections is applied to the received signal level to determine the equivalent input-signal power level $P_{i\,eq}$ and voltage level $V_{i\,eq}$.

$$P_{i\,eq} \text{ (dbm)} = p_i \text{ (dbm)} + \alpha \text{ (db)} \quad (29)$$

where α is normally a negativequantity. Then, the equivalent input voltage $V_{i\,eq}$ is

$$V_{i\,eq} \ (\mu v) = 10^6 \sqrt{10^{-3} \ \ P_{ieq} \text{ (mw)} \ R_i \text{ (ohms)}}, \quad (30)$$

where

$$P_{i\,eq} \text{ (mw)} = \text{antilog} \frac{P_{i\,eq} \text{ (dbm)}}{10} \quad (31)$$

If the undesired $V_{i\,eq}$ is below the receiver sensitivity level, satisfactory signal reception will always occur. If the undesired $V_{i\,eq}$ is above the receiver sensitivity level, the former should be compared with the level of the desired signal input V_d to determine if interference can be expected.

b. Sample Calculation of Simplified Interference Prediction.—An example will now be given relative to the use of the prediction method just discussed.

(1) *Available Data.*—Assume the following information is available from operating manuals and other sources:

(a) *Transmitter.*

Carrier frequency,	236.6 mc
Modulation,	AM
Rated output power,	0.5 kw
Transmission-line loss (line type and frequency of operation obtainable from instruction manual; length from installation records, and corresponding loss from manufacturer's information),	1 db

Antenna gain in direction of receiver (obtainable from transmitter antenna pattern), 3 db

(*b*) *Propagation.*

Separation between transimtter and receiver, 10 miles

(*c*) *Receiver.*

Tuned frequency,	236.613 mc
Demodulation,	FM
Input impedance, R_{in},	50 ohms
Antenna gain in transmiter direction,	−18 db
Transmission line loss,	2 db
Receiver sensitivity,	7 μv

(2) *Calculations.*—The remaining information is determined in the following manner:

(*a*) *Transmitter.*—Express the power output in decibels above 1 milliwatt (dbm). Since 1 kw is the same as 60 dbm, the rated output power of 0.5 kw is a ratio of one-half or logarithmically 3 db less. Thus, the rated output power is 57 dbm. The net gain is item 5 minus item 4 on the sample work sheet, which in this case is 3 −1 =2 db. Effective radiated power in the direction of the receiver is then 57 +2 =59 dbm.

(*b*) *Propagation.*—At a frequency of 236.6 mc, sky-wave reflection will not be present

RECEIVER → / SOURCE ↓		AM			FM	
		CW ($A_1 + A_2$)	DSB (A_3)	SSB_{sc} (A_3a)	F_3	FSK
AM	CW (A_1 and A_2)	0 db			2 db	
	DSB (A_3)		0 db (5 db for beat note conditions.)			
	SSB_{sc} (A_3a)		5 db (Beat note conditions; more for carrier coincidence.)	(Same as at left)		
FM	F_3		Depends on bandwidth-to-deviation ratio.		0 db (Nearly equal frequency deviations.)	
	FSK				2 db	

Notes: 1. Values are given tentative only for 70% sentence intelligibility.

2. Add 6 db for 80% sentence intelligibility.

10 db for 95% sentence intelligibility,

15 db for 99% sentence intelligibility.

Figure 35-97.—*Table of Acceptance Ratios.*

and, at a distance of 10 miles, the ground wave will be negligible. Hence, line-of-sight propagation should be assumed, provided there are no natural or man-made barriers between transmitter and receiver. Under these conditions, the path attenuation may be determined from a nomogram, Figure 35-178, for path attenuation between isotropic antennas. For given frequency and distance, the path attenuation is 99 db. Thus, the power level at the receiving antenna is the effective radiated power less the path attenuation, or 59 −99 =40 dbm.

(c) Receiver.—The net gain before the receiver input is the difference between items 14 and 15, or −18 −2 =−20 db. This gain added to the power level at the receiving antenna results in a power level at the receiving input terminals or −20 −40 =−60 dbm. In terms of an equivalent on-channel signal of the same modulation as a desired signal, several corrections have to be made to this figure. The correction for modulation is the acceptance ratio obtained from Figure 35-97. For an AM signal in an FM receiver, it is −2 db. Since the transmitter is not directly on-channel, but differs by 236.618 −236.600 =0.018 mc, or 18 kc, the receiver selectivity curve indicates the correction to be made, here assumed to be −3 db. The net correction is then −2 −3 =−5 db. Hence, the effective power level at the receiver input terminal is −60 −5 =−65 dbm, or 0.316 x 10^{-6} milliwatts. Thus, the effective receiver signal level across the 50-ohm receiver input impedance is $\sqrt{10^9 \times 0.136\ 10^{-6} \times 50} = 126\ \mu v$. If this level had been below the receiver sensitivity figure of 7 μv, it could have been neglected. Since it is above, it indicates that it will interfere with any desired signal of less than 126 μv input. The estimated level of a desired signal can be computed in a similar manner except that the corrections, item 18, will be zero.

.4 Intra-Site Interference Prediction.—Intra-site prediction, the next step in prediction complexity, is put on a sound basis by the procedure to be given under section b, below. In order that the technique may be better understood, the procedure is preceded by a discussion of the basic principles involved.

a. Basic Principles of Intra-Site Prediction.—Intra-site prediction deals with known signal sources, estimated couplings to receivers, and known receiver susceptibilities to these sources, acting either singly or in combination. The degree of coupling between signal sources and receivers is generally estimated on the basis of equipment location and position with respect to known coupling paths. For a communications-electronics site, sources and receivers may be arranged in some complex for which certain important interactions between equipment must be considered in the prediction process. This prediction process will normally include first, second, and third order interactions, and will neglect higher orders unless some special circumstances indicates more should be included.

(1) First Order Interaction.—Direct, or first order, interactions involve a single undesired source affecting the output of a single receiver, and include all cases of interfering-source output power occurring at a receiver response frequency. Under this definition, the following interactions on any transmitter output (1) through (3) with any receiver response (a) through (d) must be considered.

Transmitter Outputs	Receiver Responses
(1) Fundamental output	(a) Desired response
(2) All harmonics	(b) Image response(s)
(3) All other suprious radiations	(c) IF response(s)
	(d) Spurious responses (including those due to harmonics of the local oscillator)

(a) Mutual Interference Chart.—The spectrum of direct interactions can be illustrated by a mutual interference chart (MIC) of the type shown in Figure 35-98. This chart has as its ordinate the tuned frequency of the interfering transmitter, and as its abscissa the receiver tuned frequency. The outlined regions of the chart represent those frequencies at which interference to the receiver can occure.

[1] The transmitter fundamental or any harmonic may be received when the receiver is tuned directly to the frequency concerned. This condition is represented by the diagonal bands extending across the figure and labeled fundamental, second harmonics, third harmonic, etc. For the undesired receiver responses of the equipment of Figure 35-98, it has been established on the basis of more complete measurements that the receiver possesses sufficient off-channel rejection so that only the transmitter fundamental and first two harmonics are strong enough to cause a deleterious response.

[2] The remaining interactions shown on Figure 35-98 are primarily those which occur when the transmitter fundamental or first two harmonic frequencies coincide with the image, i-f, or

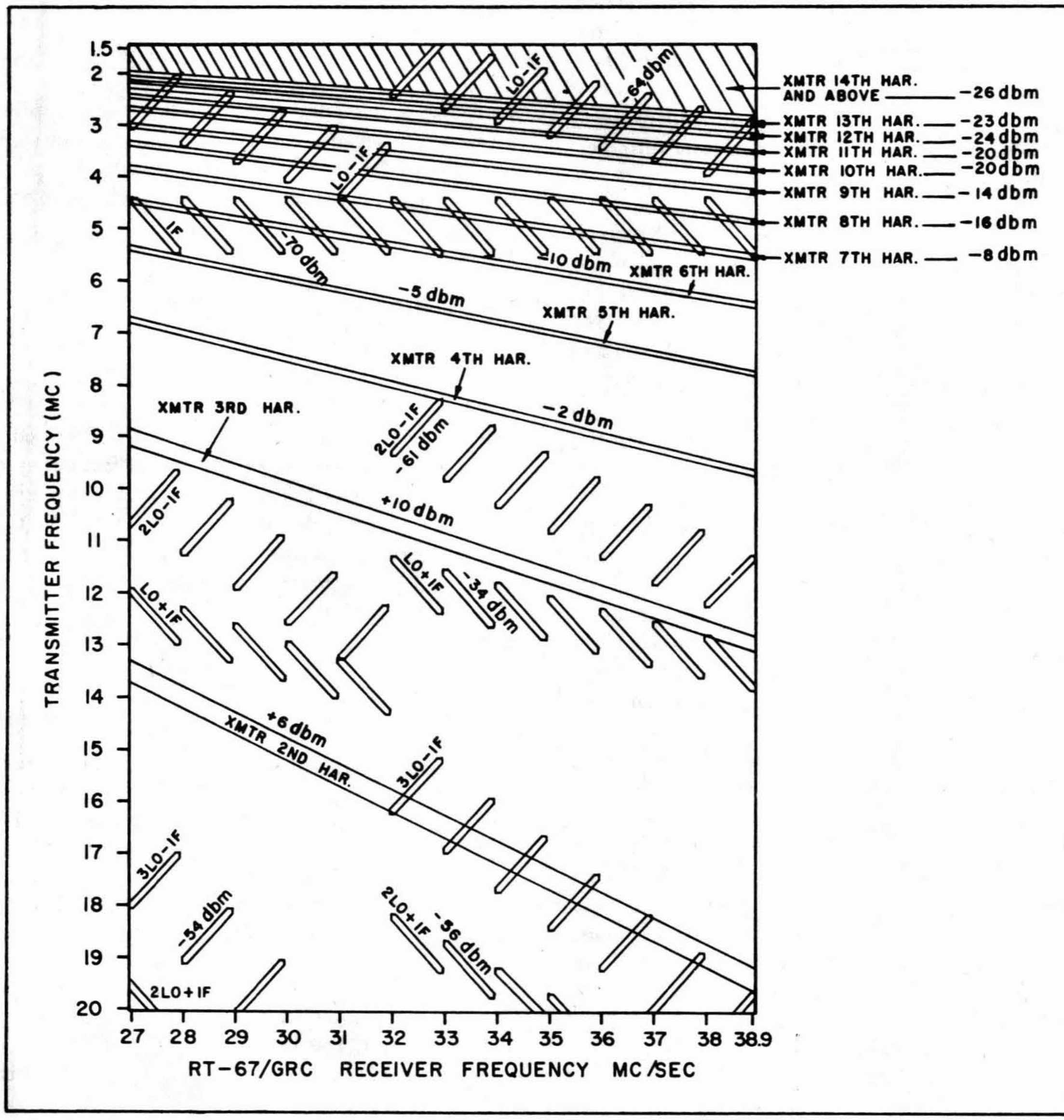


Figure 35-98.—*Example of Theoretical MIC.*

some multiple of the local oscillator frequency plus or minus the i-f. Again, in the case of the particular equipment represented by Figure 35-98, only harmonics of the receiver local oscillator below the third are considered important from the standpoint of first-order interference effects.

(2) Second- and Third-Order Interactions.—Second-and third-order interactions occur only as the result of non-linearities in either receiving or transmitting systems. These forms of interference include intermodulation, cross-modulation, and receiver desensitization. Although the fundamentals of intermodulation and cross-modulation are essentially the same for both receivers and transmitters, the methods for evaluating them are quite different and will be presented separately.

(a) Receiver Intermodulation.—Receiver intermodulation may occur whenever two or more undesired signals enter a receiver. The r-f amplifiers and/or the first mixer generate additional frequency components from these signals, which are known as intermodulation products. This generation of intermodulation products results from nonlinear action of vacuum tubes, transistors and semiconductor diodes. In the plate current expansion of a tube, the intermodulation products are those sub-terms whose arguments include both the original frequencies or their harmonics; i.e., subterms with arguments in the form $(mw_a t \pm bw_a t)$, where m, n =1, 2, 3, etc. The order of any particular intermodulation product is the sum of the coefficients (m +n). In the prediction process, only the second- and third-order intermodulation products are normally used, since these are generally the strongest. The number and strength of significant intermodulation products are limited not only by the tendency for reduction in strength with increased order, but also by the finite levels of interfering signals that enter the receiver, and the selective attenuation of signals outside the passband by the input circuits of the receiver. When this happens, the intermodulation product is treated by all of the receiver stages in exactly the same manner as a cochannel signal of external origin.

[1] The most serious form of second-order intermodulation occurs at a frequency

$$f_o = f_b - f_a, \qquad (32)$$

where f_o is the receiver tuned frequency, f_a and f_b are the frequencies of the interference signals, and f_b is greater that f_a. Second-order intermodulation is inherently the worst type because it is due mainly to the square-law nonlinearity in a tube, transistor, or diode characteristics, and this is usually more pronounced than any of the higher-order nonlinearities. The amplitude of the second-order intermodulation product voltage E_2 is proportional to the product of the interfering signal voltages E_a and E_b:

$$E_2 \propto E_a E_b . \qquad (33)$$

The effects of second-order products are suppressed somewhat, because one or both interfering signals are always far from the receiver tuned frequency, and are thus considerably attenuated before reaching the mixing device.

[2] Only one form of third-order intermodulation is of serious consequence. This effect occurs at a frequency

$$f_o = 2f_a - f_b , \qquad (34)$$

where the frequencies are as previously defined, except that f_b is the interfering signal frequency that is farther removed from the tuned frequency and is not necessarily the higher of the two. The third-order intermodulation-product voltage E_3 is proportional to the product of the square of the interfering-signal voltage E_a (the signal closer to the tuned frequency) and the interfering-signal voltage E_b,

$$E_3 \propto E^2{}_a E_b . \qquad (35)$$

Although third-order intermodulation is not inherently so strong as second-order, the total effect may be worse under some circumstances because both f_a and f_n may be quite near f_o for third-order intermodulation, with the possible result that neither signal is appreciably attenuated before reaching the first nonlinear circuit element.

[3] The conventional laboratory test for receiver intermodulation measurement is described in CED 3512.3e. Measurements typical of second- and third-order intermodulation performed on receiver R-392/URR are presented in Figure 35-99 for purposes of illustration. This basic information was determined approximately by utilizing

equal-level interfering signals. For any other level, equal or unequal signals, the corresponding intermodulation signals may be obtained from use of equations (33) and (35) or, more conveniently, by use of nomographs. Figure 35-185. Receiver intermodulation curves may be approximated by straight-line segments (Figure 35-100) representing three specific pieces of information: the minimum intermodulation rejection for small Δf, given in db; the approximate close-in slope, given in db/octave of Δf; and the asymptotic intermodulation rejection for large Δf, given in db. These characteristics for a number of receivers have been measured and are given in Figure 35-101 for both second-order and third-order intermodulation characteristics.

(b) Receiver Cross-Modulation.—Cross-modulation in a radio receiver is the name given to unwanted signals in the output which are caused by the interaction between one or more undesired r-f signals, and the r-f signal to which the receiver is tuned. It occurs when a receiver is tuned to a strong signal and another strong signal is also present at a close-in frequency. Furthermore, it usually occurs when the r-f gain is set low to cause tubes or transistors to operate close to cut-off. Cross-modulation manifests itself by the fact that, during intervals when there is no modulation on the desired carrier, one hears the modulation of the undesired signal. If the desired carrier is absent, however, the undesired signal is no longer heard. Such cross-modulation is the result of third-order curvature in the plate-current or collector current characteristics of the first tube or transistor of a receiver. It is a special case of the third-order intermodulation discussed in the previous section, wherein one of the signals, E_a of equation (35) is the desired one.

(c) Receiver Desensitization.—Desensitization occurs primarily when an undesired signal is sufficiently strong either to cause grid rectification with consequent increase in the bias of one or more amplifier stages, or an increase in AVC voltage and a resulting decrease in receiver sensitivity. This effect usually results from a local source which is sufficiently close, in frequency, to the desired channel that input-circuit rejection is inadequate. Desensitization can be determined from measured data, a two-signal selectivity curve (similar to Figure 35-22), where one signal is now a moderate-strength, on-channel, desired signal, and the other is at a higher threshold level just great enough to decrease the desired-signal receiver output.

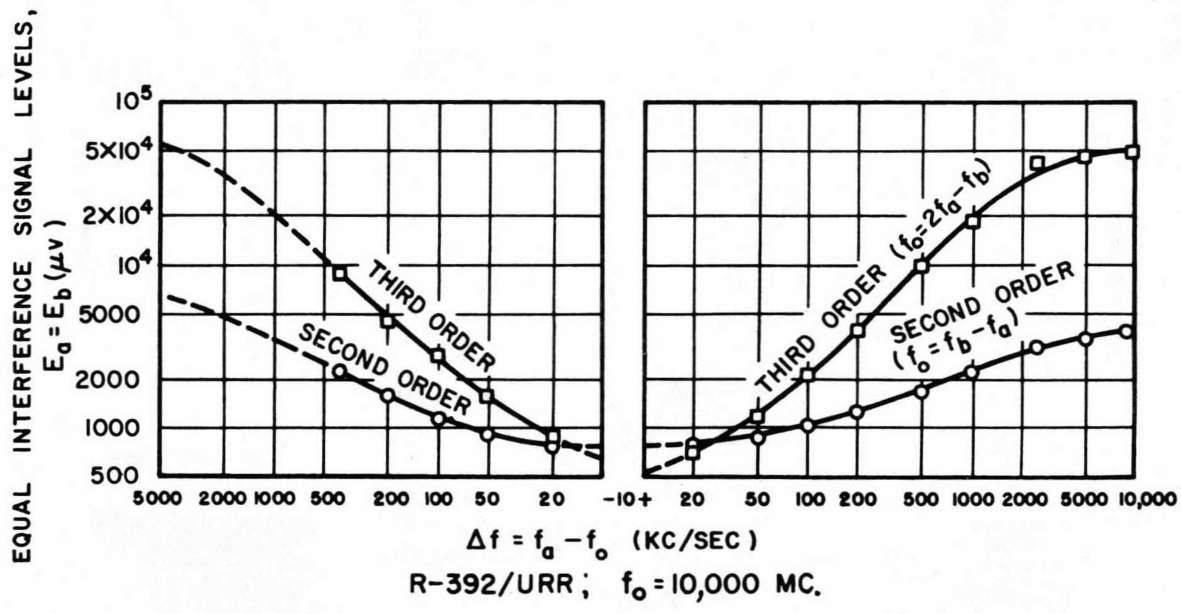


Figure 35-99.—*Receiver Intermodulation for 6-DB (S+N)/N Ratio, R-392/URR;* f_o *= 10,000mc.*

(d) Transmitter Cross-Modulation.—Transmitter cross-modulation (frequency called intermodulation), by contrast to receiver cross-modulation, is produced primarily by signals which enter the plate circuit of a stage rather than those entering the grid circuit, although both contribute to the final modulation products. Only one external signal is required for transmitter cross-modulation-product generation. A signal differing in frequency from the desired signal frequency by only a few hundred kilocycles may be passed by the transmitter output circuitry at an amplitude sufficient to produce serious modulation products when mixed with the desired-signal fundamental, or harmonics thereof. Because of the variation of circuit parameters of each transmitter type, the amplitudes of the products produced in different transmitters will vary; however, the cross-modulation-product frequency for any given desired and interfering signal frequency will be the same. Since the even-order products fall outside the transmitter passband and are attenuated considerably, they need not be considered.

[1] Cross-modulation products may be generated in the output stage of a transmitter by two methods. Each method involves the mixing of two signals in the transmitter plate circuit in the following combinations:

Signal No. 1	Signal No. 2
Primary Mixing	
Any desired signal fundamental or harmonic present before introducing undesired signal into plate circuit.	Undesired signal fundamental or harmonic externally generated and introduced into plate circuit.
Secondary Mixing	
Any signal listed under primary mixing (either from column 1 or 2).	Harmonics generated within transmitter due to introduction of undesired signal.

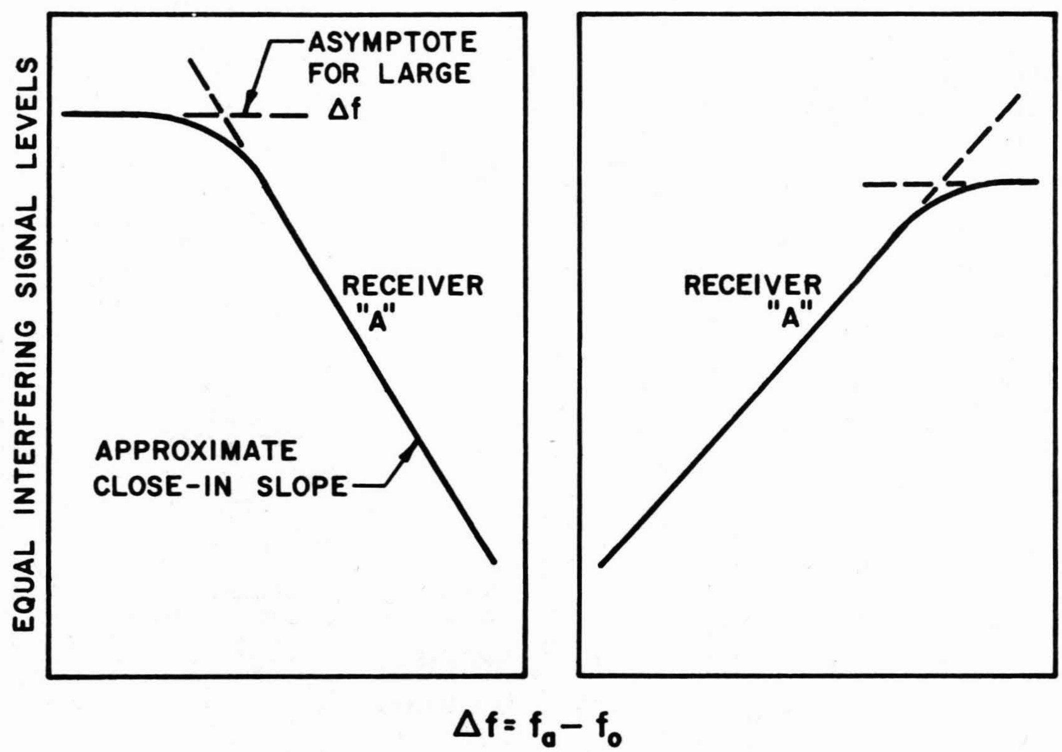


Figure 35-100.—*Approximate Intermodulation Characteristics of a Receiver.*

SECOND ORDER INTERMODULATION				
Receiver Type, Serial Number	f_o (mc)	Min. Intermod. Rej. for Small Δf (db)	Approximate Close-In Slope (db/octave of Δf)	Asymptotic Intermod. Rej., for Large Δf (db)
R 390A/URR				
821	10.0	63	2.0	73
2970	10.0	73	2.0	87
	20.0	75	2.0	86
BC-342D				
116	15.0	82	3.0	. . .
BC-342N				
1432	15.0	80	3.5	. . .
RT-77A/GRC-9				
7336	12.0	84	2.0	106
7340	12.0	85	2.0	106
R-274A/FRR				
1470	10.0	73	3.0	94
R-274C/FRR				
2170	10.0	79	3.0	102
R-388/URR				
43	10.0	74	2.5	. . .
	20.0	76	2.5	. . .
61	10.0	80	2.0	. . .
	20.0	79	2.0	. . .
R-392/URR				
3949M1	10.0	87	2.0	100
	20.0	69	1.5	. . .
4964	10.0	65	2.0	79
	20.0	65	1.5	. . .
4967R	20.0	68	1.5	. . .
5912R	20.0	65	1.5	. . .
R-257/U				
893	45.0	83	. .	101
1218	30.0	81	. .	108
	45.0	73	. .	94

Figure 35-101.—*Comparison of Intermodulation Characteristics of Receivers.*

SECOND ORDER INTERMODULATION				
Receiver Type, Serial Number	f_o (mc)	Min. Intermod. Rej. for Small Δf (db)	Approximate Close-In Slope (db/octave of Δf)	Asymptotic Intermod. Rej., for Large Δf (db)
R-394/U				
386	156.0	96	. .	. . .
399	156.0	96	. .	. . .
	165.0	97	. .	. . .
R-108/GRC				
4850	24.0	80	2.5	108
7766	24.0	79	2.5	108
RT-66/GRC				
21743	24.0	77	3.0	110
23449	24.0	77	3.0	104
RT-70/GRC				
13688	55.0	82	2.0	98
16238	55.0	80	2.0	. . .
R-125/GRC				
660	60.0	76	1.5	99
	70.0	75	1.5	96
825	60.0	71	1.5	92
	70.0	76	1.5	95
R-417/TRC-24				
234	161.75	84[1]	. .	. . .
		94[2]	. .	. . .
	309.5	70[1]	. .	. . .
		>98[2]	. .	. . .
	161.75	87[1]	. .	. . .
		95[2]	. .	. . .
	309.5	68[1]	. .	. . .
		>96[2]	. .	. . .

1 Dummy filter used on input.
2 Bandpass filter used on input.

Figure 35-101.—*Comparison of Intermodulation Characteristics of Receivers (Continued).*

THIRD ORDER MODULATION				
Receiver Type, Serial Number	f_o (mc)	Min. Intermod. Rej. for Small Δf (db)	Approximate Close-In Slope (db/octave of Δf)	Asymptotic Intermod. Rej. for Large Δf (db)
R-390A/URR				
821	10.0	60	6.0	101
2970	10.0	64	7.5	110
	20.0	61	7.5	109
BC-342D				
116	15.0	75	6.0	...
BC-342N				
1432	15.0	73	7.0	...
RT-77/GRC-9				
7336	12.0	65	7.0	108
7340	12.0	63	7.0	107
R-274A/FRR				
1470	10.0	54	10.0	111
	20.0	67	5.0	...
R-388/URR				
43	10.0	61	10.0	...
	20.0	62	7.5	...
61	10.0	62	10.0	...
	20.0	63	6.0	...
R-392/URR				
3949M1	10.0	61	8.0	110
	20.0	63	6.0	...
4964	10.0	64	6.0	97
	20.0	59	6.0	...
4967R	20.0	65	6.0	...
5921R	20.0	58	9.0	...
R-257/U				
893	45.0	68	6.0	110
1218	30.0	65	6.0	102
	45.0	56	6.0	102

Figure 35-101.—*Comparison of Intermodulation Characteristics of Receivers (Continued).*

THIRD ORDER INTERMODULATION				
Receiver Type, Serial Number	f_o (mc)	Min. Intermod. Rej. for Small Δf (db)	Approximate Close-In Slope (db/octave of Δf)	Asymptotic Intermod. Rej. for Large Δf (db)
R-394/U				
386	156.0	67	5.0	...
	165.0	65	5.0	...
399	156.0	67	5.0	...
	165.0	65	5.0	...
R-108/GRC				
4850	24.0	76	7.0	111
7766	24.0	73	6.5	109
RT-66/GRC				
21743	24.0	78	5.0	108
23449	24.0	73	5.0	107
RT-70/GRC				
13688	55.0	62	7.0	100
16238	55.0	54	8.0	102
R-125/GRC				
660	60.0	55	8.5	...
	70.0	53	8.0	...
825	60.0	54	9.5	...
	70.0	64	9.0	...
R-417/TRC-24				
234	161.75	69[1]	10.5	...
		78[2]	10.0	...
	309.5	66[1]	8.0	...
		68[2]	13.0	...
	161.75	84[1]	5.0	...
		91[2]	3.0	...
	309.5	63[1]	9.5	...
		68[2]	14.0	...

1 Dummy filter used on input.
2 Bandpass filter used on input.

Figure 35-101.—*Comparison of Intermodulation Characteristics of Receivers (Continued).*

The frequency of either or both of these products may be identified by the expressions

$$f_I = f_d + \left(\frac{N+1}{2}\right)\Delta f \qquad (36)$$

or

$$f_I = f_d - \left(\frac{N-1}{2}\right)\Delta f, \qquad (37)$$

where

f_I = cross-modulation-product frequency,

f_d = desired or carrier frequency,

f_i = interfering-signal frequency,

$\Delta f = f_i - f_d$,

N = product order.

These equations yield two products for each other, one being greater in frequency than the desired signal and one which is lower in frequency than the desired signal.

[2] A comparison of the experimentally-determined cross-modulation characteristics of various types of transmitters has shown relatively good correlation for transmitters of the same type. Furthermore, the experimental results have shown that the amplitudes of odd-order modulation products bear a linear relationship with the interfering signal when plotted on a log-log scale. However, they do not bear exactly the same relationship for each transmitter type, or for different signal spacings. Fifth, seventh, and higher-order products are not so systematic as third-order products but they can usually be neglected for the prediction process since their levels are generally 60 db or more below the desired signal.

[3] Experimental data show that the third-order products on the low side (where $f_I < f_d$ and $f_i > f_d$) have essentially the same slope for all transmitter types tested; and the third-order product

Transmitter Type Serial Number 10 mc/sec	P_d (dbm)	P_i (dbm)	Spacing	Third Order Low		Third Order High	
				C_I (db)	k	C_I (db)	k
BC-339							
47	59.5	26.5	500 kc	− 7	1.0	−49.3	1.5
"	59.5	19.5	500 kc	− 7	1.0	−49.3	1.5
53	59.5	29.0	1000 kc	− 6.5	1.0	−73.1	2.16
"	59.5	19.5	1000 kc	− 6.5	1.0	−73.1	2.16
T-368							
34	56.6	34.5	100 kc	−15.2	1.03	−70.0	2.13
"	57.9	18.9	100 kc	−15.2	1.03	−70.0	2.13
"	59.0	39.3	500 kc	−31.1	0.965	−90.4	2.08
"	57.8	22.5	500 kc	−31.1	0.965	−90.4	2.08
"	56.8	39.5	1000 kc	−43.5	1.0	.....	....
"	57.8	22.7	1000 kc	−43.5	1.0	.....	....
161 mc/sec							
T-278							
399	43.7	23.9	2.25 mc	−18.2	0.955	−59.0	1.77
"	43.7	12.9	2.25 mc	−18.2	0.955	−59.0	1.77
386	43.5	25.9	2.25 mc	−22.5	1.22	−83.9	2.1
"	43.5	14.6	2.25 mc	−22.5	1.22	−83.9	2.1

Average k for 3rd Order Low = 1.02
Average k for 3rd Order High = 1.96

Third Order Low = Third Order on Carrier Side
Third Order High = Third Order on Interfering Signal Side

Figure 35-102.—*Typical Values of Transmitter Cross-Modulation Constants.*

curves on the high side (where $f_I > f_d$ and $f_i > f_d$) have essentially the same slope for all transmitter types tested; however, the slope of the low third-order product curve is different from the slope of the high third-order product curve. These slope constants (k) are usually equal to one for the third-order product on the carrier side and equal to two for the third-order product on the interfering signal side. The amplitude of odd-order intermodulation products may be described by the expression

$$P_I = C_I + k\,P_i\,, \qquad (38)$$

where

P_I = intermodulation product level (dbm),

C_I = intermodulation constant (db),

k = slope constant, usually 1 for carrier-side product or 2 for interfering-signal side,

P_i = interfering power level (dbm).

Calculated values of constants associated with a small number of different transmitter types for various signal spacings are shown in Figure 35-102. It can be seen from this figure that a vast difference in C_I exists between low-side and high-side third-order signals.

b. Procedure for Intra-Site Interference Prediction.—A considerable amount of effort is required to utilize the procedure to be given. Even so, it does not appear possible at this time to predict the existence of intra-site interference with a high degree of precision due to the randomness of the relevant variables with respect to different units of similar type equipment. The calculation of amplitude of the resulting interference is an even more difficult problem due to the influence of antenna and propagation uncertainties, as well as equipment variations. However, difficulties in intra-site prediction will be minimized by following the procedure given below.

(1) List all equipments to be considered in the prediction process. This list will normally include all radio and radar transmitters and receivers. Where applicable, it may also include sources such as induction heaters, diathermy, r-f-stabilized welding equipment, electro-surgical apparatus, electronic computers, etc.; plus susceptible electronic equipment such as high gain electra-medical amplifiers, intercommunication equipment, etc.

(2) Obtain instruction booklets, maintenance manuals, or other sources of information on each piece of equipment considered. If the required information is not available, estimates may be used with corresponding reduced confidence in the results of the prediction process. The information required is that necessary to complete the forms of Figures 35-103 and 35-104 (sample forms).

(3) The basic procedure given below involves an assumption of surface-wave drop-off of radiation with distance from the source; that is, the power varies as the inverse square of this distance. The received power P_r in kilowatts at the receiving antenna may be estimated from the following simplified expression:

$$P_r = G_r G_t P_t \left(\frac{\lambda}{4\pi d}\right)^2, \qquad (39)$$

where

P_t = Power into the transmitting antenna (kw),

G_t = Gain of the transmitting antenna over isotropic radiator in the direction of the receiver.

G_r = Gain of receiving antenna over isotropic radiator in the direction of the transmitter,

d = Antenna separation (meters),

λ = Wavelength (meters).

The power into the antenna is determined by the transmiter output power P_o modified by losses of the transmission line T, that is, $P_t = P_o - T$. Thus, the path attenuation α is

$$\alpha = 10 \log_{10} \frac{P_r}{G_r G_t P_t} = 20 \log_{10} \frac{\lambda}{4\pi d}\,, \qquad (40)$$

which also may have been obtained from the nomograph, Figure 35-178.

(4) To determine direct or first-order interaction frequencies at which interference can be expected, construct a two-dimensional mutual interference chart (in the manner of Figure 35-98) for each transmitter-receiver combination in the following manner:

(a) Lay out the axis with the ordinate (vertical axis) representing the tuning range of the

SAMPLE RECEIVER DATA

SAMPLE RECEIVER DATA						DATE
RECEIVER NR	MODEL NR	SERIAL NR	2-SIGNAL SELECTIVITY	DETECTION	ACCEPTANCE RATIO (*db*)	ANTENNA LOCATION

NATURE OF RESPONSE	FREQUENCY (*mc*)	INPUT TERMINAL SENSITIVITY (*uv*)	TRANS-MISSION LINE LOSS (*db*)	ANTENNA				
				MAJOR LOBE				MINOR LOBE
				POLARI-ZATION	AZIMUTHAL ORIENTATION	GAIN (*db*)	3-*db* BEAMWIDTH (*degrees*)	DEPRESSION
TUNING (f_d)								
SPURIOUS:								
IF IMAGE (f_d + 2IF)								
$2f_d$ + IF								
$2f_a$ + 3IF								
$3f_d$ + 2IF								
$3f_a$ + 4IF								

Figure 35-103.—*Sample Receiver Data Form.*

	SAMPLE TRANSMITTER DATA							DATE
TRANSMITTER NR	MODEL NR	SERIAL NR	BANDWIDTH		MODULATION	ANTENNA LOCATION		
				ANTENNA				
				MAJOR LOBE				MINOR LOBE
NATURE OF OUTPUT	FREQUENCY (*mc*)	OUTPUT POWER (*kw*)	TRANSMISSION LINE LOSS (*db*)	POLARIZATION	AZIMUTHAL ORIENTATION	GAIN (*db*)	*3-db* BEAMWIDTH (*degrees*)	DEPRESSION (*db*)
FUNDAMENTAL (f_1)								
2D HARMONIC ($2 f_1$)								
3D HARMONIC ($3 f_1$)								

Figure 35-104.—*Sample Transmitter Data Form.*

transmitter and the abscissa (horizontal axis) representing the tuning range of the receiver.

(b) The points where a transmitter harmonic would become a co-channel signal at the low and high ends of the receiver tuning range should be noted from the transmitter data sheet, marked on the graph, and a straight line drawn between these points for each transmitter harmonic. The width of each harmonic line represents the band over which serious interference is expected to occur. This width is a function of the receiver selectivity, the transmitter modulator bandwidth, and splatter.

(c) From the receiver data sheet, Figure 35-103, note spurious responses in the tuning range of the fundamental and first few harmonics of the transmitter. Plot on the chart straight, sloping, continuous lines for a tunable local oscillator, or short, broken, sloping lines if the first local oscillator of a multiple conversion receiver is fixed-tuned for each band.

(d) Plot the i-f feed-through as a horizontal line at the i-f frequency if fixed, or as a series of short, broken, sloping lines if the first i-f is variable due to use of a fixed-frequency local oscillator.

(e) Similarly plot the 1/2-and 1/3-i-f lines due to i-f feed-through of the second and third harmonics of the transmitter.

(5) The magnitude of direct interaction interference is a third dimension which should be added to the mutual interference chart. For each receiver frequency at which the possibility of interference is indicated, the received interfering signal level must be compared with the receiver susceptibility (sensitivity decreased by acceptance ratio) level. The difference in decibels between these two levels is a measure of the interference to be expected. These levels should be noted on the MIC in the manner of Figure 35-98.

(6) Nonlinear second and third-order intermodulation effects must also be considered in receivers. These involve the mixing of two or more different transmitter signals in the receiver, although only two signals will be treated in the prediction process since this is the most common case. The frequency of secondary intermodulation occurs at the receiver tuned frequency f_o where f_o is the difference between the frequencies f_b and f_a of the interfering signals,

$$f_o = f_b - f_a. \tag{41}$$

The range of frequencies over which interference of this nature is possible may be plotted on a Receiver Intermodulation Chart (RIC) such as Figure 35-105.

(a) Lay out the axis with the ordinate representing the tuning range of the high-frequency transmitter B and the abscissa representing the tuning range of the receiver.

(b) For maximum and minimum frequencies of the lower frequency transmitter A, plot the positive-slope, 45-degree, solid lines which denote the boundaries of possible second-order intermodulation.

(7) Third-order intermodulation occurs as the result of receiver mixing of two interfering signals f_b and f_a such that the received frequency f_o becomes

$$f_o = 2f_a - f_b, \tag{42}$$

where

$$f_b > f_a.$$

Again, the range of intermodulation frequencies may be plotted on the RIC such as Figure 35-105. For maximum and minimum frequencies of transmitter A, plot the negative-slope, 45-degree, dashed lines which denote the boundaries of possible third-order intermodulation. In the illustration given, the lower frequency line is missing, since the resulting intermodulation frequency does not fall within the tuning range of the receiver.

(8) The magnitudes of the receiver intermodulation effects must also be added to the RIC. For each interfering transmitter, calculate the electric field intensities at the receiving antenna in accordance with the method of CED 3508.4b(3) above. Multiply by the effective antenna heights or aperatures at the two frequencies for the relative antenna orientations to obtain the received input

signals in microvolts. For second-order intermodulation, compare the square root of the product of these two signals with the microvolt value of minimum-second-order-intermodulation-rejection-for-small-Δf for the particular receiver concerned, some typical values of which are already tabulated in Figure 35-101. For third-order intermodulation, compare the product of the lower-frequency signal level times the square root of the higher-frequency signal level with the value of minimum third-order intermodulation threshold; some of these typical values are also tabulated in Figure 35-101.

(9) If these values have not been tabulated, they may be measured in accordance with CED3512.3e, or estimates may be made on the basis of previous experience. When the calculated intermodulation signals are below the tabulated minimum-intermodulation-rejection-levels-for-small-Δf, then they should cause no receiver response and may be neglected. On the other hand, if a signal is above this value, it may cause a response. The corresponding second-order intermodulation interference N will be considered as the logarithmic ratio

$$N = 20 \log_{10} \frac{V_I}{V_o}, \qquad (43)$$

V_I =second-or third-order intermodulation input voltage,

V_O =minimum intermodulation rejection threshold for small Δf.

The predicted interference N should be marked on the RIC as in Figure 35-105.

(10) Next, consider transmitter-cross-modulation or intermodulation effects due to mixing of one strong interference signal at frequency f_i with a desired signal at frequency f_d in the output tank circuit of the latter. For the prediction technique only one intermodulation product need be considered, the third-order product on the low side. The frequency f_I of this signal is

$$f_I = 2f_d - f_i. \qquad (44)$$

The range of frequencies over which interference of this type is possible may be plotted on a Transmitter Intermodulation Chart (TIC), such as Figure 35-106. This intermodulation signal power p_i may be treated as a separate transmitter source of output power

$$p_i = C_I + kP_i, \qquad (45)$$

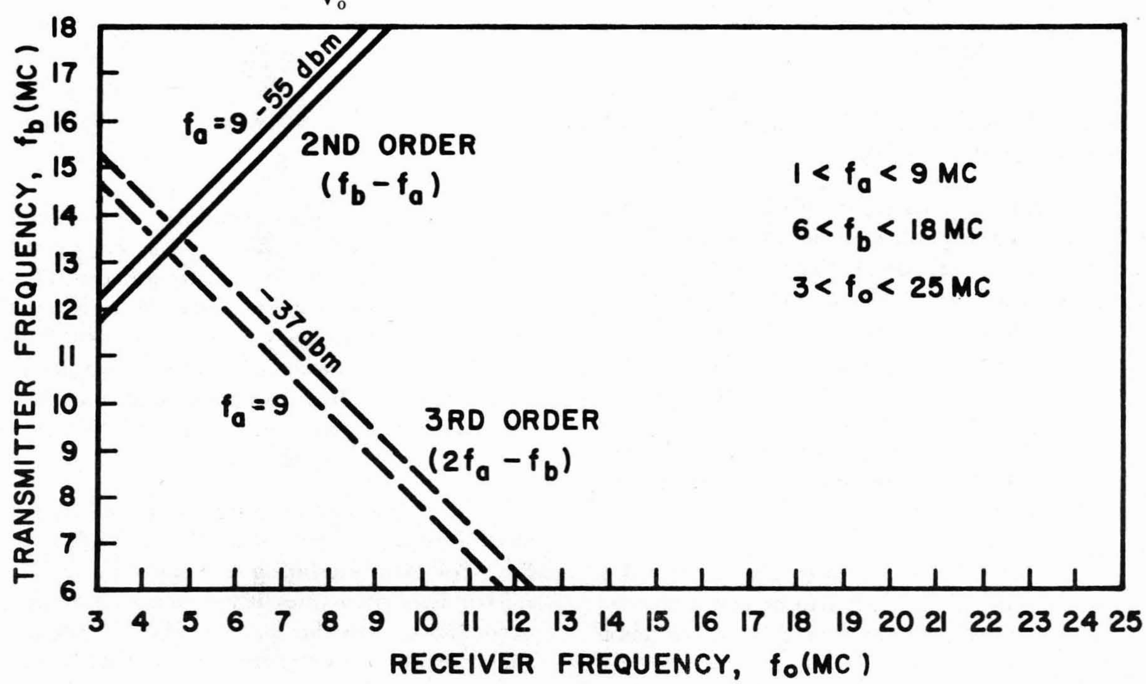


Figure 35-105.—*Simplified Receiver Intermodulation Chart.*

where

p_i =the interfering signal level (dbm), to be calculated,

C_I =intermodulation constant (db) typical of the particular transmitter, to be obtained from Figure 35-102,

k =constant for particular transmitter, to be obtained from Figure 35-102, but usually equal to one.

(11) The interfering signal may be calculated from its power p_i at the antenna of the desired transmitter, the latter to be obtained in accordance with CED 3508.4b(3). The interfering power p_i will be assumed to be

$$P_i = 20 \log P_n + G_B - T_B, \qquad (46)$$

where

G_B =Gain of transmitting antenna B in direction of arrival of interfering signal,

T_B =Loss of transmission line from this antenna to transmitter B.

Once the transmitter intermodulation power has been determined, it is then necessary to relate this signal to power at the receiver by reapplication of CED 3508.4b(3). The received electric field intensity E_e is to be multiplied by the antenna effective height in the direction of reception to obtain the transmitter intermodulation level at the receiver. If this value is in excess of the receiver susceptibility threshold, it should be entered on the TIC.

(12) For any receiver tuned frequency f_o, the total interference will be the sum of separate values for that frequency as obtained from the various charts; MIC, RIC, TIC.

.5 Inter-Site Prediction.—Two cases of radio-frequency interference due to off-site signals must be distinguished, since the required data and techniques used in the prediction process are quite different.

a. Case I.—One case involves a relatively small number of such off-site signals about which pertinent technical information is obtainable, such as output power, carrier power, type of modulation

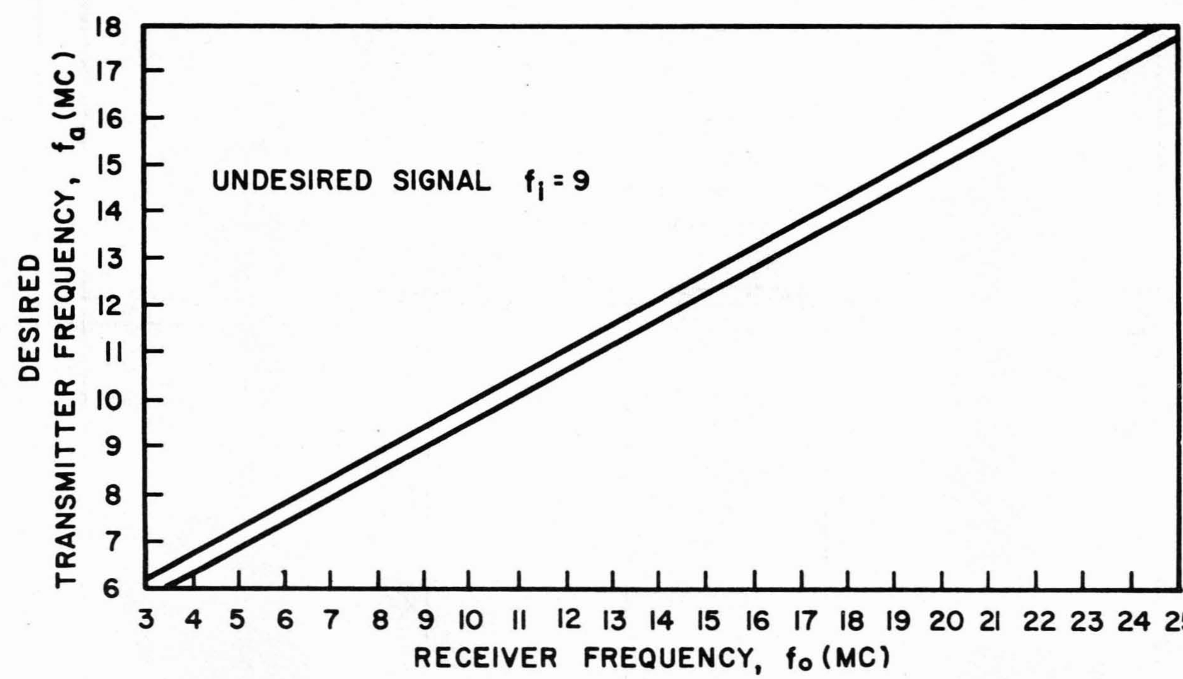


Figure 35-106.—*Transmitter Cross-Modulation Chart.*

SAMPLE OPERATIONAL PREDICTION WORK SHEET — DATE

I CHANNEL[1]	PREDICTED LEVEL				
		INTERFERENCE			
a. TIME	b. DESIRED SIGNAL (*dbm*)	c. INTRA-SITE (*dbm*)	d. INTER-SITE (*dbm*)	e. TOTAL (*dbm*) (*c plus d*)	f. SNR (*db*) (*b minus e*)

[1] PART I IS APPLICABLE FOR ONLY ONE CHANNEL. ADDITIONAL CHANNELS REQUIRE COMPLETION OF PART I FOR EACH INDIVIDUAL CHANNEL.

II	SIGNAL-TO-NOISE RATIO (*SNR*) (*db*)				
TIME	CHANNEL A	CHANNEL B	CHANNEL C	CHANNEL D	CHANNEL E

III	ORDER OF CHANNEL RELIABILITY AND SIGNAL-TO-NOISE RATIO (*db*)				
TIME	1	2	3	4	5

Figure 35-107.—*Sample Work Sheets for Operational Prediction.*

and other characteristics required by Figure 35-104. The entire prediction procedure for this case is the same as has already been described, except for the calculation of the degree of coupling between the interference source and the receiver. In this case, the coupling is no longer calculated on the basis of free-space propagation alone, as in CED 3503.6b, but is also calculated for certain frequencies and source-to-site distances, on the basis of sky-wave propagation. In order to estimate the degree of coupling, standard propagation estimation techniques exist, such as those found in TO. 31-3-28, *Basic Radio Propagation Predictions* (published monthly for a period of three months in advance) which is supplement to TO. 31-3-27, *Radio Propagation.*

b. Case II.—The second inter-site-prediction case includes off-site signals about which relatively little is known, or those which are so numerous that the gross amount of real-time information would be impractical to handle. Under those circumstances, the best promise for inter-site prediction is to handle the problem on a statistical basis. However, detailed statistical techniques have not yet been developed sufficiently for use by the C-E officer.

.6 Operational Interference Prediction.—Operational interference prediction is an aid to the C-E officer in determining channel assignments to various messages for various intervals of time. The problem is to predict desired-signal and undesired-interference levels for the various available channels and to estimate the signal-to-noise ratio for each available channel. For this purpose, use sample work sheets similar to those of Figure 35-107. In Part I, identify each available channel and date at the head of the sheet. Note the time of day in the first column. For each time in column a, estimate the level of desired signal in column b in accordance with standard techniques utilizing the propagation information appropriate for the day and times concerned. Utilize the techniques of this chapter to estimate the interference levels from both intra-site and inter-site sources. These levels are entered in the next two columns c and d and their totals in the succeding column e. The signal-to-interference ratio in decibels then is equal to the value in column b, less that in column e, and is entered in column f. The prediction resulting from column f may (optionally) be re-entered in another table like Part II, for a comparative listing of predicted performance of the various channels. In order to make easy the comparison of channel performance in decreasing order, Part III may be constructed to show at any given time the channels in their order of predicted reliability. The decibel signal-to-interference ratio may be associated—in parenthesis—with the channel designation.

3509. A PLAN FOR INTERFERENCE REDUCTION.

.1 Responsibility for Reduction of Interference.—Responsibility for reduction of an electromagnetic interference situation is not always well defined. The agencies and individuals assigned to a particular area of operational responsibility may conflict in their capabilities and requirements relative to solution of a mutual interference problem.

a. Air Force Equipment Only.—When all of the equipment involved in an interference situation is under the control of the Air Force, there is no question that responsibility and capability lies within the Air Force itself. Further, if all of the equipment is at one site, it is clearly the responsibility of one C-E officer to see that such interference is reduced in order to retain effective electronic operation. On the other hand, when the source of interference is on one Air Force site and the receiver on another, the priority of the missions in the interference situation must be considered, as well as the exact nature of the cause of interference. The C-E officers of both sites involved have a responsibility to agree upon a course of action that will alleviate the interference.

b. Equipment of Air Force and Another Government Service.—When an interference situation involves both Air Force equipment and equipment of one or more other government services, the responsibility is not clearly defined. However, the C-E officers concerned, as well as the individuals of equivalent status in the other agencies, must attempt to reach agreement on action that will lead to a satisfactory solution.

c. Equipment of Air Force and Civilian Users.

(1) National Emergency.—In time of a proclaimed national emergency, the Air Force will

1. Agency.
2. Purpose of system.
3. Equipment (transmitter and receiver) nomenclature.
4. Operating frequency or band:
   a. Transmitter tuning range.
   b. Receiver tuning range.
5. Power (peak or average):
   a. Transmitter.
   b. Effective radiated power.
6. Description of emission bandwidth between 3-db, 20-db, and 60-db points, including significant spurious and harmonic contributions.
7. Description of modulation (that is, FM deviation; frequency of tones; and pulse characteristics, including prf, pulse width, pulse coding, etc.).
8. Transmitter stability.
9. Receiver description (that is, superheteordyne, crystal video, etc. If superheterodyne, what i-f? Can local oscillator be set high or low?).
10. Receiver selectivity (3-db, 20-db, and 60-db points, including major spurious responses such as image, i-f isolation, etc.). A selectivity curve is desirable.
11. Receiver sensitivity and noise figure.
12. Transmitter and receiver antenna characteristics, type, polarization, scan or rotation rate (if applicable), gain, azimuth and elevation beamwidth, horizontal and vertical patterns.
13. Extent of use: indicate restrictions.
14. Transmission range (normal).
15. Identifying call signs (if applicable).
16. Security classification: indicate which elements of system require security measures.
17. Precise location of transmitter and receiver: give direction of antenna (vertical and horizontal), if fixed.
18. Name and telephone number of responsible individual.

Figure 35-108.—*Sample Checklist of Major System Characteristics.*

19. Required guard band; information on interference criteria; tolerable signal-to-noise levels; results of environmental tests.

20. Operational limitations:

    a. Interference case history.

    b. Can types of silence be imposed (that is, sector blanking, short periods off the air, avoidance of certain frequencies, reduction of power, alternate channels, etc.)?

Figure 35-108.—*Sample Checklist of Major System Characteristics (Continued).*

have priority over civilian users of the radio spectrum and, hence, may require the civilian users to assume responsibility for interference reduction. However, the C-E officer has a responsibility to be co-operative with the civilian users of the spectrum and with his licensing agency, the Federal Communications Commission.

(2) Peace Time.—In time of peace, the Air Force has legal priority over civilians only within its own assigned frequency bands and the civilian user has legal priority within his assigned bands. No matter what the legal responsibility, it is the moral obligation of the C-E officer to be co-operative with the civilian user in alleviating an interference situation.

d. Missile Test Centers.—Outstanding examples of overall co-operation are necessary to achieve an interference-free situation in the launching of missiles. When equipment is in the field, and military personnel are relying on its everyday performance, very litle technical manipulation can be employed to solve specific operational problems. Users are faced with a basic difficulty; they have no choice but to live with the installed hardware. Consequently, it is evident that some sort of operational coordination is essential. It is interesting to note that industry and certain government agencies have established coordinating committees—the Aeronautical Flight Test Radio Coordinating Council (AFTRCC) and the Coperative Interference Committee (CIC), to cite two examples—to discuss and handle certain planning and operational problems on an informal basis. The CIC, which reports cases of interference to the FCC, has some monitoring equipment. The AFTRCC plans to acquire a field capability. Both the CIC and AFTRCC represent focal points and informal liaison between military and civilitn users.

(1) The Area Frequency Coordinator.—Joint recognition by the services of the spectrum-congestion problem has resulted in the appointment of area frequency coordinators with considerable sucess. A detailed description of the facilities of such an office is given in reference CED 3514.54. Briefly, the AFC has cognizance of all activities in a prescribed area, generally within a 200-mile radius, that employ the radio-frequency spectrum. The office is given an opportunity to comment on proposed frequency assignments, in an attempt to prevent serious conflicts. Monitoring and liaison facilities are available to solve day-to-day problems. The AFC office provides a central record-keeping center, and has the authority to negotiate present difficulties, and to forsee and forestall future interference problems. Figure 35-108 presents typical information maintained by these offices.

.2 Organization of the Plan.—It is the responsibility of the operational personnel to recognize the presence of interference within their systems. Once the existence of interference has been established, the installation C-E officer should be notified. According to current Air Force Regulation AFR 100-16, interference problems should be solved at the communications electronics level if possible. It is the purpose of this CED to aid the Communications-Electronics Officer in this function,by providing a detailed plan for the determination of the interference source(s) and the application of suitable suppression techniques.

a. Basic Elements in Interference Reduction.—The basic philosophy of any interference reduction plan must contain three fundamental steps. They are: (1) identification of the interference by its manifestation at the output of the victim receiver, (2) localization of the interference to a particular source, and (3) application of remedial techniques to reduce or eliminate the interference. The flow chart for interference source identification (Figure 35-109) gives the general outline for accomplishing the first two steps. A sample data sheet is provided in Figures 35-110 and 35-111 as a convenient form for data recording and analysis. The discussion to follow details the considerations that must be given relative to each block in the flow chart.

.3 Identification of Interference Sources.—The first step in the suppression of electromagnetic interference is the determination of the type of the interference source. The signal time and characteristics, including its center frequency, bandwidth, and type modulation, are the fundamental properties of the interference energy utilized in the process of source resolution. Preliminary observations of the effects of the interference should be made at the output of the victim receiver; additional information can be obtained through the use of special instrumentation.

a. Periodicity.—It should be pointed out that man-made interference can be distinguished from natural disturbance by its regular rather than random nature. This is not to say that man-made interference cannot be random for a short period of time. However, if the interference is analyzed over a long time period, some periodicity is usually observable. It is the character of this non-random response that helps to define the particular source.

b. The Interference Center Frequency.—The center frequency of the interference should be observed while tuning the affected receiver, or a noise meter across the band, and this frequency recorded. If the interference signal covers a large bandwidth, the receiver should be tuned over the entire range of the interference to determine if a single maximum output indication, or at least a predominant maximum signal exists. The receiver dial reading is often accurate enough for determining the interference center frequency concerned. In rare instances when more precise frequency information is needed, receiver frequency calibration using the substitution method can be accomplished. The information on interfering-signal center frequency should be recorded in Figure 35-110.

c. Bandwidth.—Interference (as well as all other electromagnetic radiation) can be categorized as either narrow or broad band in spectral

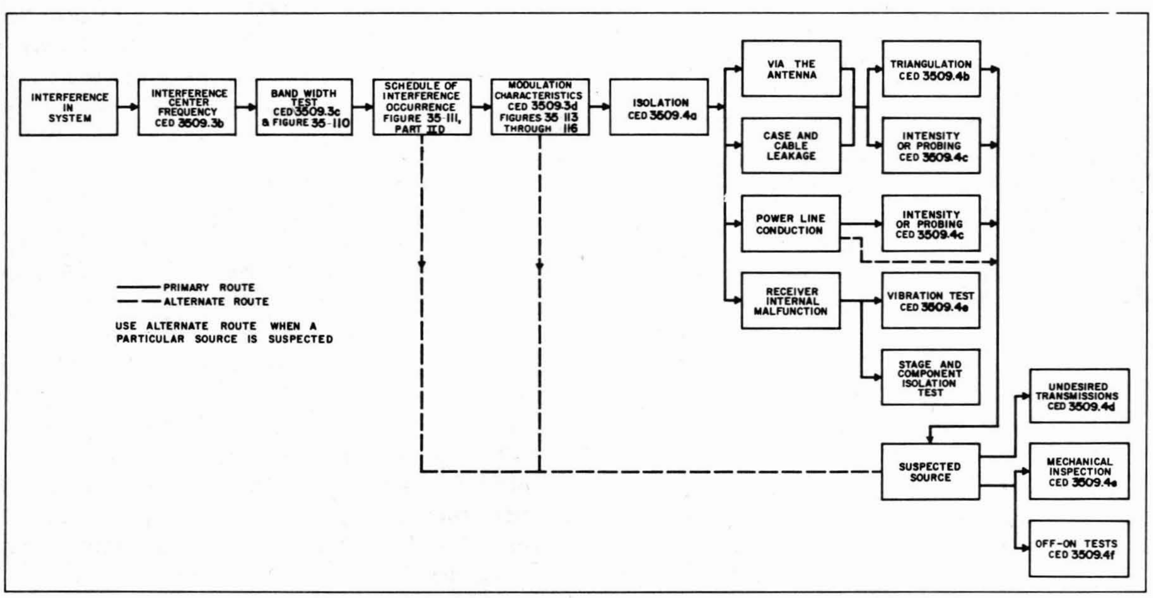


Figure 35-109.—*Flow Chart for Interference Source Identification and Localization.*

SAMPLE DATA SHEET FOR INTERFERENCE ANALYSIS

SAMPLE DATA SHEET FOR INTERFERENCE ANALYSIS			DATE
RECEIVER NOMENCLATURE	RECEIVER SERIAL NUMBER	TUNED FREQUENCY	LOCAL OSCILLATOR FREQUENCY
RECEIVER BANDWIDTH	TYPE ANTENNA	SIZE ANTENNA	ORIENTATION OF ANTENNA
EFFECT OF RECEIVER CONTROLS UPON INTERFERENCE OUTPUT INDICATIONS			
VOLUME CONTROL	SELECTIVITY CONTROL	RF GAIN CONTROL	OTHER
INTERFERENCE CENTER FREQ	APPROXIMATE BANDWIDTH	☐ NARROW BAND	☐ BROAD BAND
MODULATION CHARACTERISTICS			
DESCRIBE:		LIST OF POSSIBLE SOURCES	
		1.	2.
		3.	4.
		5	6.

SCHEDULE OF OCCURRENCES				
DATE	TIME		SEVERITY	REMARKS
	FROM	TO		

INTERFERENCE ENTERS THE RECEIVER VIA:			
☐ ANTENNA	☐ CASE OR CABLE LINKAGE	☐ POWER LINE	☐ RECEIVER MALFUNCTION
TRIANGULATION			
SITE ONE COORDINATES	INTERFERENCE AZIMUTH	SITE TWO COORDINATES	INTERFERENCE AZIMUTH
SITE THREE COORDINATES	INTERFERENCE AZIMUTH	COORDINATES OF INTERSECTION	
LIST OF POSSIBLE SOURCES			
1.	2.	3.	4.
OFF-ON TEST OF SUSPECTED EQUIPMENT			
EQUIPMENT AND EFFECT	EQUIPMENT AND EFFECT	EQUIPMENT AND EFFECT	EQUIPMENT AND EFFECT
VIBRATION TEST OF SUSPECTED EQUIPMENT			
EQUIPMENT AND EFFECT	EQUIPMENT AND EFFECT	EQUIPMENT AND EFFECT	EQUIPMENT AND EFFECT

Attach map of installation and nearby radiating devices, showing physical separations between equipments. Be sure to include all known intentional and unintentional interference sources as well as a sketch of all cable routings.

Figure 35-110.—*Sample Data Sheet for Interference Analysis.*

INTENSITY *(Far—Field Method)*		
SITE 1	COORDINATES	INTERFERENCE LEVEL
SITE 2	COORDINATES	INTERFERENCE LEVEL
SITE 3	COORDINATES	INTERFERENCE LEVEL
SITE 4	COORDINATES	INTERFERENCE LEVEL
SITE 5	COORDINATES	INTERFERENCE LEVEL

LIST OF POSSIBLE SOURCES			
1	2	3	4
5	6	7	8

UNDESIRED TRANSMISSION		
CALL SIGN	TYPE EMISSION	LOCATION

REMEDIAL TECHNIQUES:

Figure 35-111.—*Sample Interference Source Identification Data Sheet.*

BROAD BAND		
TRANSIENT	INTERMITTENT	CONTINUOUS
Aircraft blinker lights	Electric chimes	Belts, machine driving
Function switches	Electric razors	Commutation noise
Motor starters	Electronic computers	Electric typewriters
Thermostats	Electro-surgical apparatus	Florescent lights
Timer units	Motor speed controls	Ignition systems, magnetos
	Office dictation equipment	
	Poor or loose ground connections	Mercury and sodium, arc and vapor lights
	Telephone exchange	Neon signs
	Welding equipment	Pulse generators
		Radar modulator
		Sliding contacts
		Teletypewriter equipment
		Vibrators
		Voltage regulators
NARROW BAND		
	INTERMITTENT	CONTINUOUS
	Diathermy	Dielectric heating
	Doppler-shift radar while scanning	Induction heating
	Radio transmitters	Power-line hum
		Receiver local oscillator
		TV horizontal oscillator

Figure 35-112.—*Table of Interference Source Bandwidths.*

distribution. Under narrow band signals are classed modulated and unmodulated continuous-wave signals whose energy is confined to a relatively narrow band of frequencies. Conventional AM, FM, and PM communications transmitters are included in this group. Broad band interference is a result of nonsinuousiodal signal whose energy is distributed over a large band of frequencies. Short bursts or pulses of energy fall into this category.

(1) *Pulse Spectral Width.*—Specific relationships exist between the bandwidth of a pulse and its time response. Qualitatively, these include: (1) the energy distribution of the pulse across the spectrum is approximately inversely proportional to its time duration and (2) the more rapidly the pulse amplitude builds up or falls off (shorter rise and fall times), the greater is that part of the total energy contained in the high frequency components.

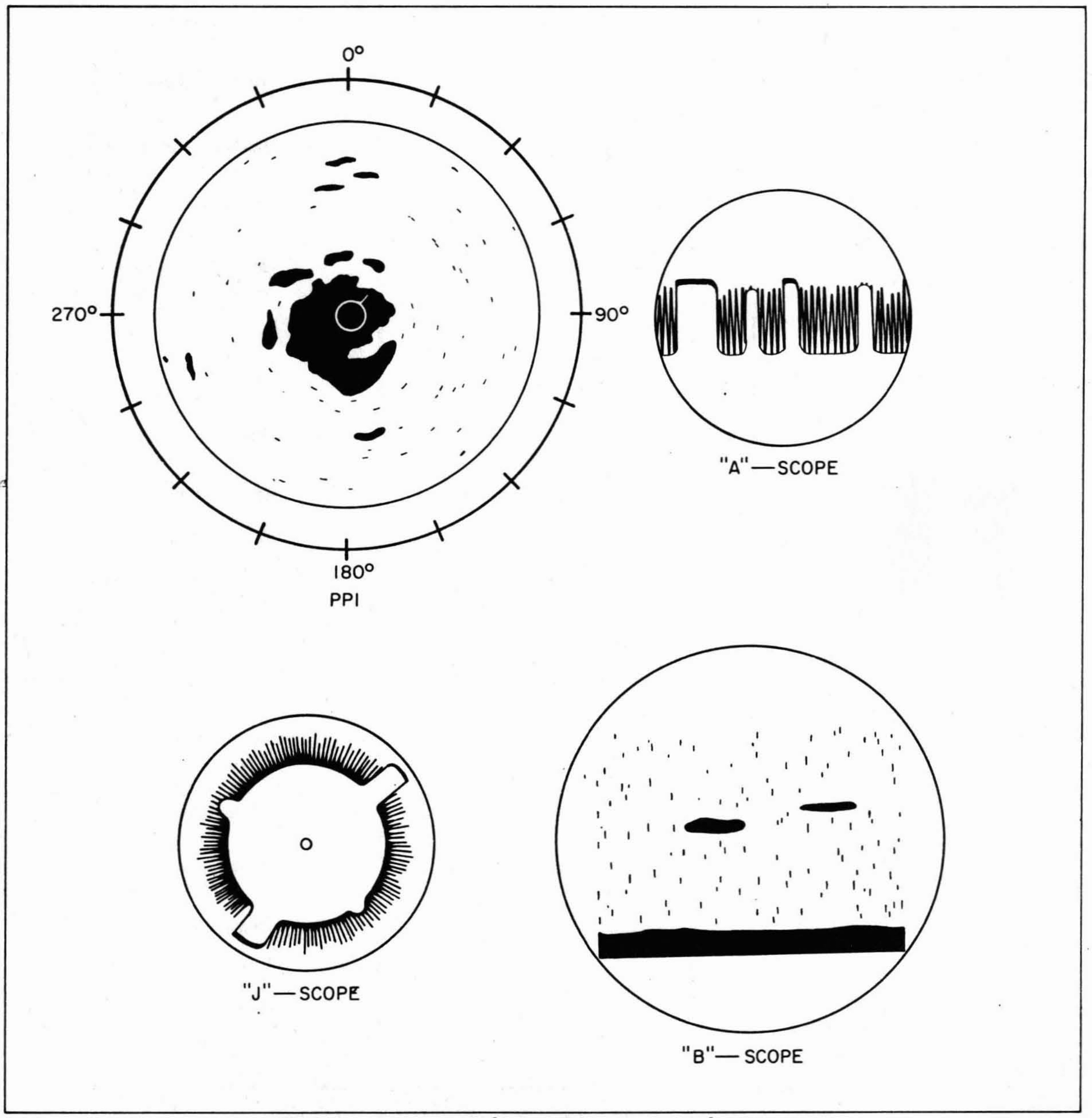


Figure 35-113.—*Interference Patterns on Radar Scopes.*

Thus, extremely broad-band signals are the result of very short pulses.

(2) Noise Bandwidths. — As an aid to source identification, Figure 35-112 classifies noise sources on the basis of bandwidth considerations. In the case of broad-band interference, it is obviously not possible to define bandwidth of a signal in terms of 3- or 6-db points; the description of the bandwidths is therefore a relative one. The table also classifies broad-band interference as being transient (occurring at a fairly infrequent and random rate), intermittant (existing for relatively short periods), and continuous.

(3) Pulse Duration.—For pulse-type interference, such as that generated from a pulse radar modulator, the spectral distribution takes a shape that has successive peaks and nulls. Refer to CED 3502.4i(3)(b) for a discussion of pulse spectrums. By tuning the victim receiver across the band and noting where these nulls and peaks occur, the character of the interfering signal can be determined. For example, the reciprocal of the frequency in megacycles between successive nulls is equal to the interfering pulse width in microseconds. The information obtained from this test should be recorded in Figure 35-110 under "approximate bandwidth".

d. Modulation Characteristics.—Observation of the interference modulation characteristics is a most important aid to the identification of the interference, since each man-made interference source produces its own characteristic modulation. Thus, observation of the victim receiver output permits the interference to be classified into aural and/or visual categories that provide a more definite indication of its source. For the purpose of interference identification in this manual, the receiver output indications will be considered as they are affected by four types of signals. These types include random pulses, periodic pulses, CW signals, and modulated carriers (excluding pulse modulation). The following subparagraphs will discuss the effects on typical communications-electronics equipment caused by the modulation of the interfering signal.

Scope Type	BROAD BAND		NARROW BAND	
	PERIODIC	RANDOM	UNMODULATED	MODULATED
PPI	Fixed or moving dot or spiral pattern.	Random dot pattern or general increase in noise level (pattern cannot be fixed by adjustment of PRF or antenna scan rate).	Variation in the intensity of display.	Very rapidly changing dark and light scope patterns.
A	One or more fixed or moving pulses (running rabbits). Interfering PRF can be adjusted for one fixed (or slowly moving) pulse when the scope is adjusted for maximum range.	Random positioned pulses, or general increase in noise level (grass). Sometimes a reduction in MVS.	Change in noise level generally a reduction. The MVS will also be reduced.	Rapid variations in the noise level with extraneous noise on scope.

Figure 35-114.—*Table of Interference Modulation Characteristics on Radar Scopes.*

(1) Radar Scope Presentation.—There are many types of radar scopes in use today; however, they can be placed in two major categories, as determined by their methods of scope modulation. Category 1 includes types A, J, K, L, M, and N scopes, which are deflection-modulated scopes, Catagory 2 includes types B, C, D, E, F, G, H, I, and P (PPI) scopes, which are intensity-modulated scopes. Interference as it appears upon both types of scopes is shown in Figure 35-113. Figure 35-114 describes the indications which would result from the narrow and broad-band types of interference on type A and PPI scopes.

(2) Navigation Aids. — Two navigation aids, Loran and Shoran will be considered in this paragraph.

(a) Loran.—Loran, a radio aid to navigation, provides a means of locating a geographical position within a given area. Loran equipment operates between 1.8 and 2 mc and between 170 and 180 kc, with a pulse repetition rate of 25 or 33 pulses per second. If a communications system is affected by interference with these characteristics, it is likely that the interfering source is a Loran station. The Loran display consists of two pulses, one from a master transmitter at one site and a second from a slave transmitter located at a different site. The difference in time of arrival of the two pulses is used to provide a navigational fix. Figure 35-115 shows the effect of interference upon the Loran display.

(b) Shoran. — Shoran, another pulsed aid to navigation, is used for accurate positioning in relatively small areas. The Shoran system operates in the region of 230, 250, and 300 mc. It requires transmitter interrogation and thus does not have a fixed pulse repetition rate. The display is similar to Loran, except that the signals from the two stations appear as inner and outer pulses protruding from a circle on the screen of the indicator tube. Their relative positions determine the position of the vehicle. Interference to the Shoran display is similar to that shown for the Loran display. In both systems, interference from pulsed-type equipments takes the form of "running rabbits" or periodic patterns. Since both patterns are relatively easily identified, most pulsed interference in Loran and Shoran equipments is not an operational impediment.

(3) Audio Output of a Communications Receiver.—Man-made interference can normally be distinguished from natural interference by its regular nature. Thus, one step in identifying man-made disturbances is by the observation of regularities in the interference signal pattern at the receiver output. Since many types of man-made interference can be further classified by their characteristic sounds, both aural and oscillographic effects are significant. Figure 35-116 describes some of the audible indications which result if a communications receiver has been adjusted for normal voice reception, and is being subjected to electromagnetic interference. The sample data sheet (Figure 35-110) provides space for a description of the modulation characteristics: the list of possible sources of an interfering signal may be recorded on the sample form, Figure 111.

(4) Detected Outputs of Instrumentation.—At many Air Force installations, the C-E officer will often have special detection devices available, in addition to communication receivers, which can be an aid in the identification of interference sources. There are three general types of such instrumentation within the Air Force. They include spectrum analyzers, panoramic receivers, and field-intensity/radio-interference meters. The spectrum analyzer and panoramic receiver are used for analysis in the time domain.

(a) Spectrum Analyzers and Panoramic Receivers.—The spectrum analyzer is a device which provides a panoramic display of the signal distribution in a selected portion of the radio-frequency band. The device uses a cathode-ray oscilloscope which presents a plot of amplitude verses frequency. A spectrum analyzer can be utilized to identify many characteristics of an interfering signal. For example, techniques for accurate frequency calibration are available, so that determination of signal center frequencies, bandwidths, and amplitudes can be accomplished. If the interference signal is a periodic pulse, the pulse width in microseconds can be determined by noting the major lobe width in megacycles, and dividing this by two. Signal modulation characteristics can also be observed. Figure 35-117 shows analyzer displays for representative types of modulation.

[1] The panoramic receiver is similar in construction to a spectrum analyzer; however, the panoramic receiver usually covers a much wider frequency range. Panoramic adapters are devices which can be added to a communications receiver allowing it to function as a panoramic receiver. Since this device is connected at the communications receiver i-f, the image and spurious rejection ratios are usually large.

(b) Field Intensity and Radio Interference Measuring Equipments.—Specialized noise receivers have been developed which can be used for the identification of interference. Depending upon time constants in the detector circuit of the receiver, measurements can be made in terms of the effective peak valve of the interference, in terms of a weighted or quasi-peak value of interference, or in terms of the average or field intensity value. Refer to CED 3507.1e for a discussion of these circuits. Characteristic responses to various types of interference are given in Figure 35-118.

e. Schedule of Interference Occurrence.—A log should be kept showing the time of occurrence of an interfering signal and its relative severity.

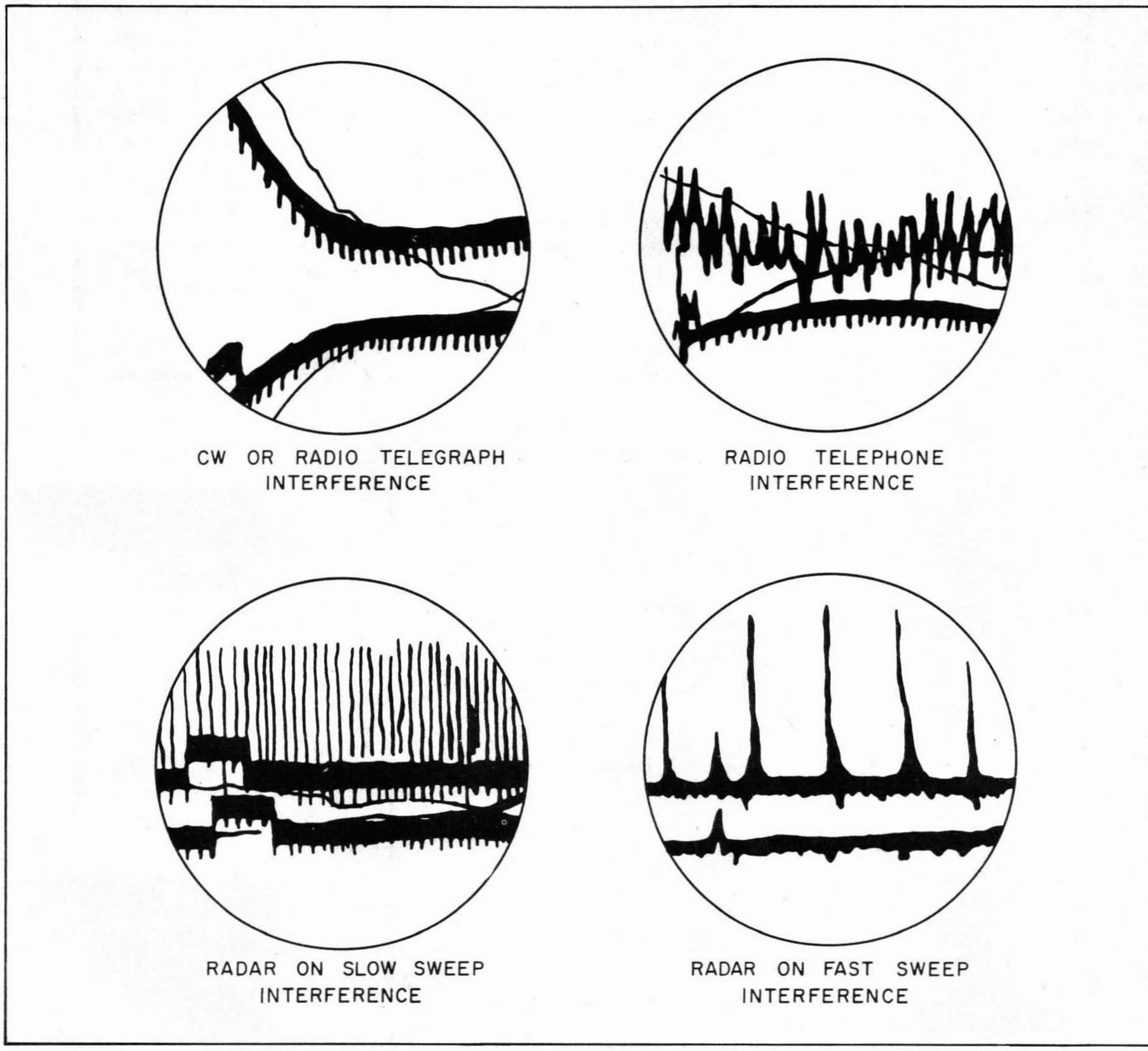


Figure 35-115.—*Typical Interference Patterns as Seen on LORAN.*

RECEIVER AUDIBLE OUTPUT	CHARACTER OF INTERFERENCE	POSSIBLE SOURCE OR MECHANISM
Reduced noise level (or steady tone with BFO operating)	Carrier (only)	Co-channel, spurious intermodulation
Pulsed variation in noise level (or pulsed tone with BFO operating)	Undesired CW or digital transmission	Adjacent channel, co-channel, spurious, intermodulation, cross-modulation
Pulsed variation in noise level (two pulsed tones with BFO operating)	Undesired RTT (FSK) transmission	Adjacent channel, co-channel, spurious, intermodulation, cross-modulation
Pulsed tone	Undesired MCW transmission	Adjacent channel, co-channel, spurious, intermodulation, cross-modulation
Added normal or distorted voice	Undesired voice transmission	Adjacent channel, co-channel, spurious, intermodulation, cross-modulation
Whistling or squealing	Undesired transmission or intermediate frequency oscillation	Adjacent channel, co-channel, spurious, intermodulation, cross-modulation, parasitic and IF oscillation
Rapid variation in noise level (or several pulsed tones with BFO operating)	Undesired facsimile transmission	Adjacent channel, co-channel, spurious, intermodulation, cross-modulation
Steady tone or whining	High-rate periodic pulses	Radar, rotating machines
Buzzing	Medium-rate periodic pulses	Buzzers, vibrators
Popping	Low-rate periodic pulses	Ignition systems, magnetos
Frying	High-rate random pulses	Electric arcs, continuously arcing contacts
Sputtering	High-rate random pulses	Arc welders, arc lamps, diathermy
Clicking	Low-rate random pulses	Code machines, electric calculating machines, mercury-arc rectifiers, relays, switches, teletypewriters, thermostatic controls, electric typewriters
Crackling		Static or corona discharges
Sharp crackle		Ambient noise

Figure 35-116.—*Table of Interference Modulation Characteristics at Communications-Receiver Audio Output.*

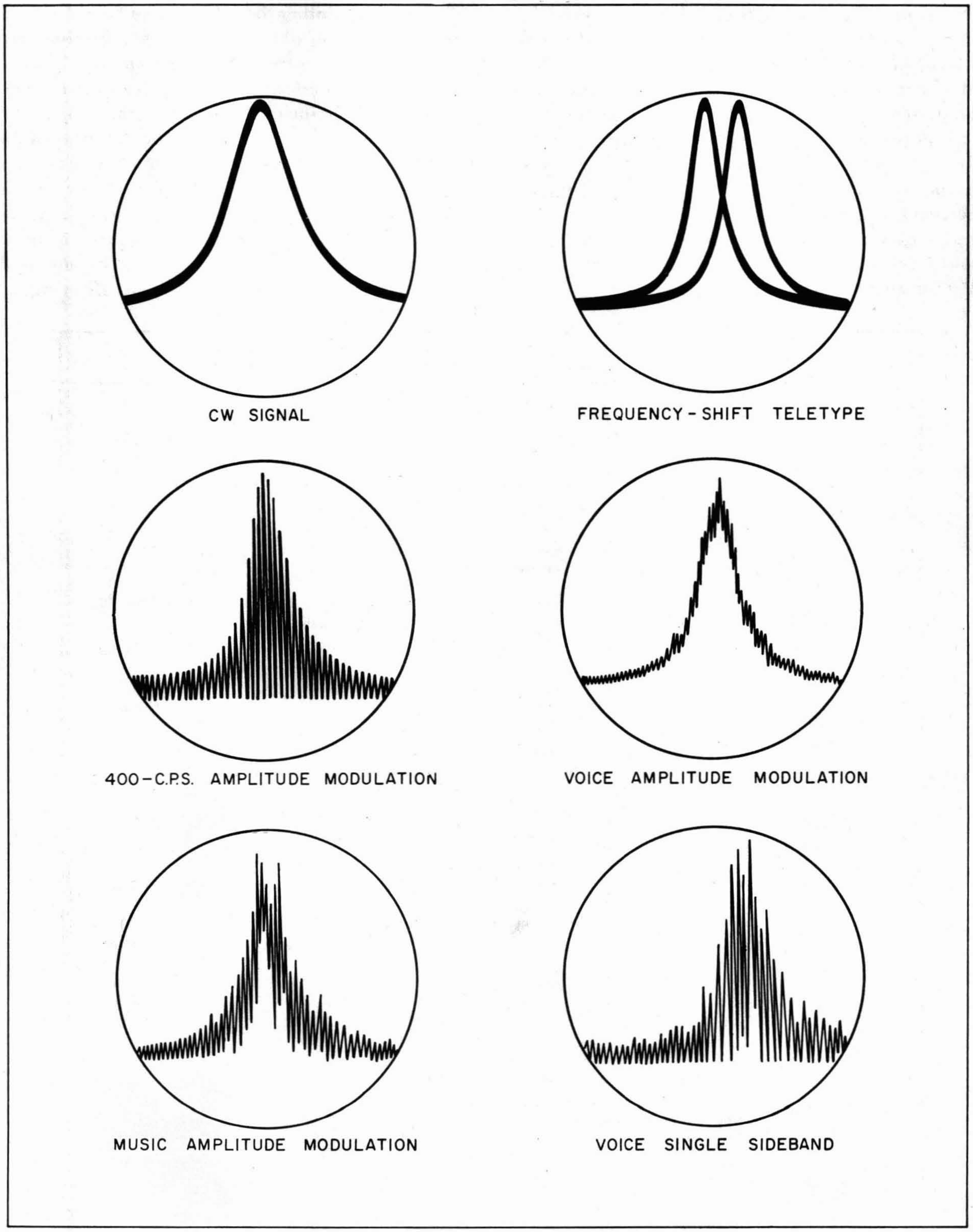


Figure 35-117.—*Spectrum Analyzers Presentations.*

Frequently, some regularity between an event or activity and the appearance of interference can be noted, *i.e.*, schedule of a nearby transmitter, use of specific machinery at certain hours, etc. Any suspected sources should be checked with regard to other signal characteristics to establish whether or not it is the source being sought. If the interference is a result of an intelligible source, it should be checked according to CED 3509.4d. If it is the result of a non-intelligible source, the suspected sources should be checked in accordance with CED 3509.4e and 3509.4f.

.4 Pinpointing the Interference Source.—With the information obtained from the previous tests and checks, it is often possible to specify the exact source of an interfering signal. In many cases, however, at this point in the analysis, the source may only be located to a class or discrete number of potential sources. This section discusses additional methods available to assist the C-E officer and his staff in localizing the interference signal. As the first approach in identifying the source of interference, signal isolation techniques can be employed. Alternatively, or subsequently, utilization of

TYPE OF INTERFERENCE	TYPES OF DETECTOR CIRCUITS		
	Field Intensity or Average Value	Quasi-Peak or Weighted Value	Peak
Carrier (only CW or digital)	Constant large pulsed variations[1]	Constant large pulsed variations[1]	Constant
MCW	Large pulsed variations[1]	Large pulsed variations[1]	Constant
RTT (FSK)	Small rapid variations	Small-rapid variations	Constant
Voice (AM or FM)	Constant[2] or slowly varying	Large variations	Constant
Facsimile	Constant	Almost	Constant
Periodic noise (Pulses)	Large or small variations[3]	Large or small variations[3]	Constant
Low rate random noise	Slow-large variations	Slow-large variations	Almost constant
Medium rate random noise	Medium rate	Medium rate large variations	Almost constant
High rate random noise	Small-rapid variations	High rate medium variations	Almost constant

[1] Variation depends upon signal repetition-rate.

[2] Depending upon per cent modulation and modulating frequency.

[3] Depending upon duty cycle.

Figure 35-118.—*Radio-Interference Meter Indications on Various Types of Interference.*

triangulation and/or probing methods can be used. In addition, mechanical inspection of equipment, as well as off-on or vibration tests may aid in such identification. Electronic aids may range from the instrumentation previously discussed, to other equipment both more and less sophisticated. The final indication of interference localization and suppression, however, can only be determined on the basis of the improved output of the victim receiver.

a. Isolation.—In the interference identification process, it is helpful to determine the exact method by which the interference has gained access to the receiver. While many possible routes exist, a few of them can be pointed to as the most significant. These include entry via the antenna, via case and cable leakage, and via the power line. If these entry paths can be "opened-up" one at a time and the effect on the interfering signal noted, the path or paths contributing to the interference can be determined.

(1) In order to check for antenna-conducted interference, one can disconnect the transmission line from the receiving antenna and, in the case of non-waveguide equipment, ground the antenna terminals. If the interference continues, it is not gaining access to the receiver via the antenna.

(2) To test for power-line conducted interference, the receiver should be operated from a separate primary power source, or tested with suitable line filters in all receiver power lines.

(3) A check for audio and control-cable conducted interference can be made by removing the lines one at a time and noting the reaction in the victim receiver.

(4) If the undesired signal is still present, the equipment should be operated at a remote site or in a shielded room, to determine if the interference is due to case or cable leakage. If this is not possible, the system shielding should be improved in steps, checking each step for a reduction in interfering signal. If the interference still persists, it may be considered to be due to an internal malfunction of the receiver and should be checked in accordance with standard repair procedures. The result of isolation tests should be recorder by checking the appropriate box in Figure 35-110.

b. Triangulation. — Triangulation is a technique which can be used to find the physical location of an interference source. Although it is possible to utilize this method in the near field of the transmitting sources, it is a technique which is more applicable to far-field analysis. The technique is one that is identical to that employed in general direction-finding applications; it utilized a receiver with a directional antenna to determine the direction of signal arrival from two (or more) measurement locations (Figure 35-119). Examples of suitable directional antennas include loops, horizontal dipoles, and systems employing reflectors. The measurement sites should be in open areas free from metallic objects, and the sites should be chosen so that the difference in interference bearings is 30 degrees or larger (preferably 60 to 90 degrees). The bearings can then be plotted on a map with respect to the measurement points. The interception of the interference bearing lines gives the location of the interference source.

(1) If a loop or other bi-directional antenna is used, the directional indication should be obtained by adjusting the loop for a null receiver output. This approach is suggested because a broad indication is achieved when homing for maximum receiver output, while the null gives a very sharp indication.

(2) Radar equipments can be used to detect the bearing of an interference microwave signal. For such applications, the position of the radar antenna should be adjusted until there is a maximum of interference on the presentation system. If the radar receiver becomes saturated it will be necessary to reduce the receiver gain to obtain an accurate indication. The sample data sheet (Figure 35-110) provides a convenient form for tabulation of the data obtained relative to this section.

(3) As an example of this radar triangulation technique, assume Figure 35-120 is a map of a field installation, where interference is being experienced. A receiver is taken successively to sites one and two, the antenna oriented with respect to magnetic north, and the receiver tuned to the interfering signal. The antenna is then rotated to obtain direction-of-arrival information. The following direction of arrival information was obtained: Site one, bearing 150 degrees; Site two, bearing 225 degrees. Since the antennas were oriented with respect to magnetic north, the difference between magnetic

and true north is added to/or subtracted from the bearings and they are then plotted wih respect to true north. The intersection of the bearing lines gives the general area of the interference source.

c. Exploration with Measuring Equipment.—It is often possible to determine the site from which interference originates by measuring the intensity of the interfering signal at several locations. The method is based on a general decrease in signal level with an increase in the distance from the source. Standard radio interference and field intensity receivers are the most desirable instruments for this application; however, most communication receivers with adequate sensitivity can be used. Since the ear is not sensitive to small changes is noise level, a metering device is very useful. If a standard communications receiver is used, the S meter will provide relative strength information. With other receivers, a d-c vacuum tube volt-meter may be connected to the AVC bus, or to the detector output.

(1) Intensity Method (Far Field). — Although this test is included for the completeness of the manual, it is difficult to make and often very time consuming. It is therefore advisable that the triangulation technique be used if possible. The premise upon which this exploration test is based is the fact that a line drawn through locations of equal signal intensity will form a closed curve. This curve or equal contour line always encloses the source. (See Figure 35-121.) In the field application of this technique, the receiver is adjusted for a specific gain and then moved to several locations within a suspected area. At each site, the relative strength of the interference signal is measured. These levels are plotted on a map, and lines are drawn through the equal intensity points. If a closed curve does not result, the interference source is not within the area probed and it will be necessary to obtain more measurement data. If a closed curve is obtained, the sensitivity of the system should then be reduced and further measurements made within the enclosed area. The contours should be redrawn and the tests continued in this manner until the source is localized. The receiver is preferably equipped with an omnidirectional antenna and the measurement areas

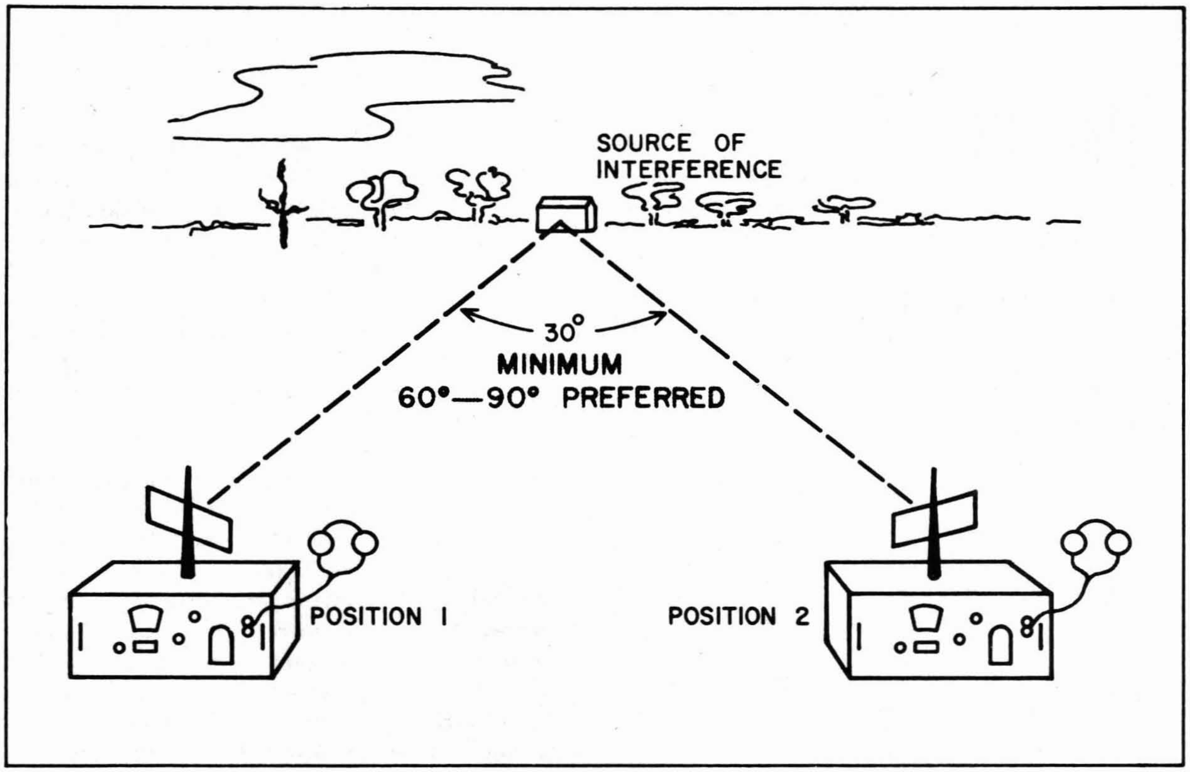


Figure 35-119.—*Locating Interference Source by Triangulation.*

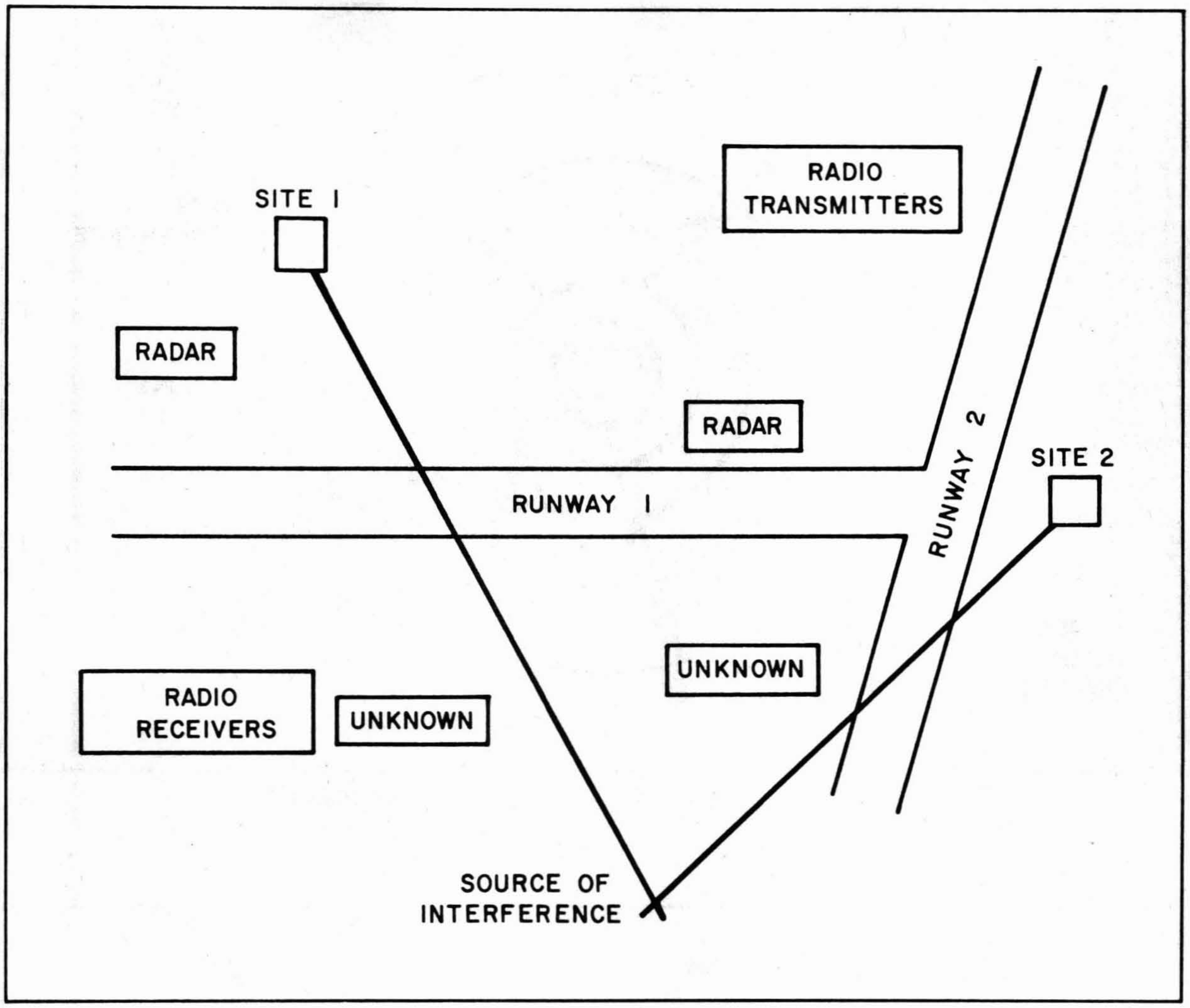


Figure 35-120.—*Map of Installation Showing Triangulation Technique.*

should be selected to be as free from metal obstructions as possible. In lieu of an omni-directional antenna, others are frequently used with a fixed polarization. If the interference source is near metal objects, erroneous data can be obtained. It should also be noted that this test is not applicable when the interference is received by ionospheric propagation.

(2) Probing (Near Field).—Probing is one of the most successful methods of determining which components of an equipment or system are generating interference. In Figure 35-122, a small, insensitive antenna, in conjunction with a receiving device, is used to obtain the relative interference level in the immediate area of a source. The antenna should be oriented for maximum pick up; as the probe antenna approaches the interference source, the interference level in the receiver will be general increase; if the probe is directed away from the interference source, the level will decrease. A small loop and electric-field (E) probe are the most convenient devices to use as antennas. If they are not immediately available, usable antennas can be fabricated according to the directions of Figure 35-123. A coaxial cable should always be used to connect the loop or E-probe antenna to the receiver.

(a) If a particular source is suspected as a result of the last tests it should be listed on the data sheet.

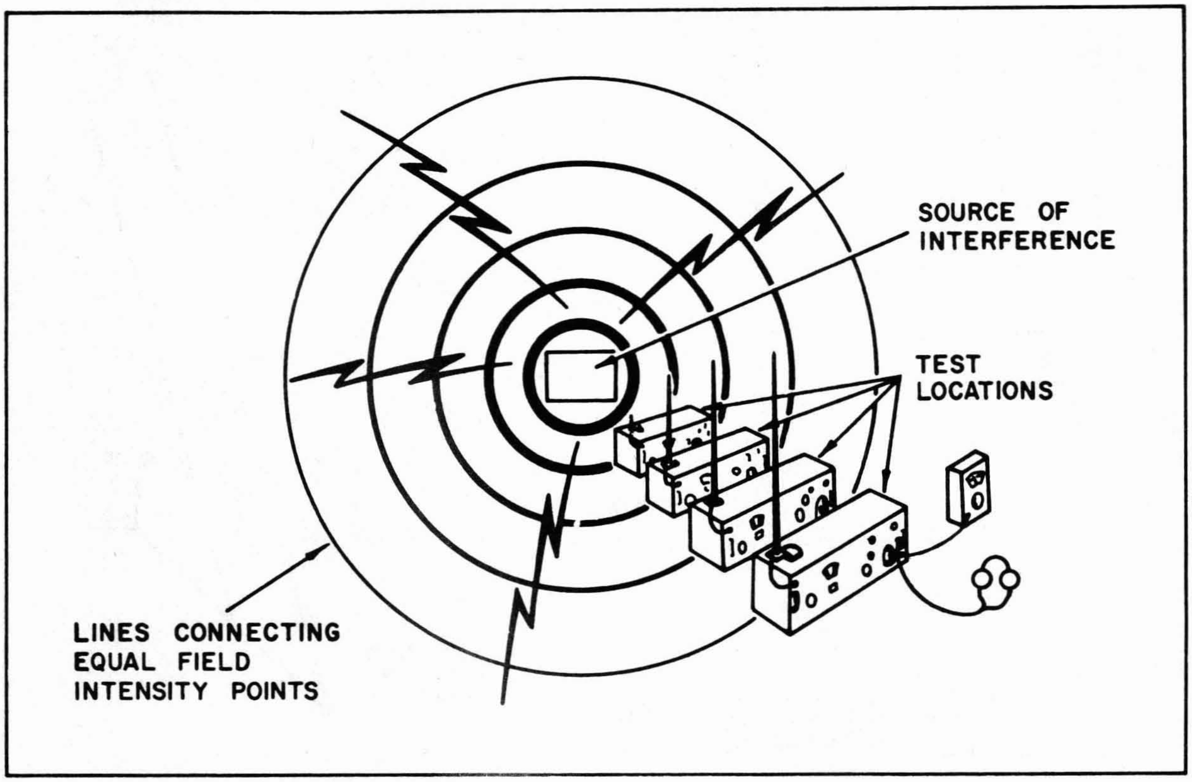


Figure 35-121.—*Locating Interference Source by Signal Intensity Method.*

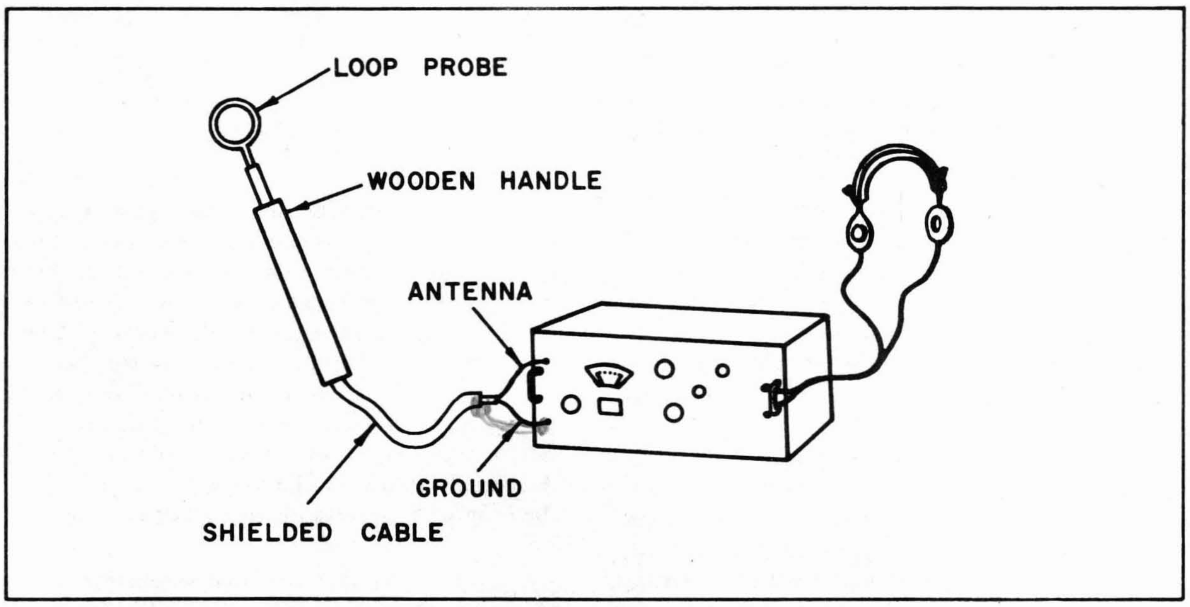


Figure 35-122.—*Locating Interference Source Using Probe Antenna Connected to Receiver.*

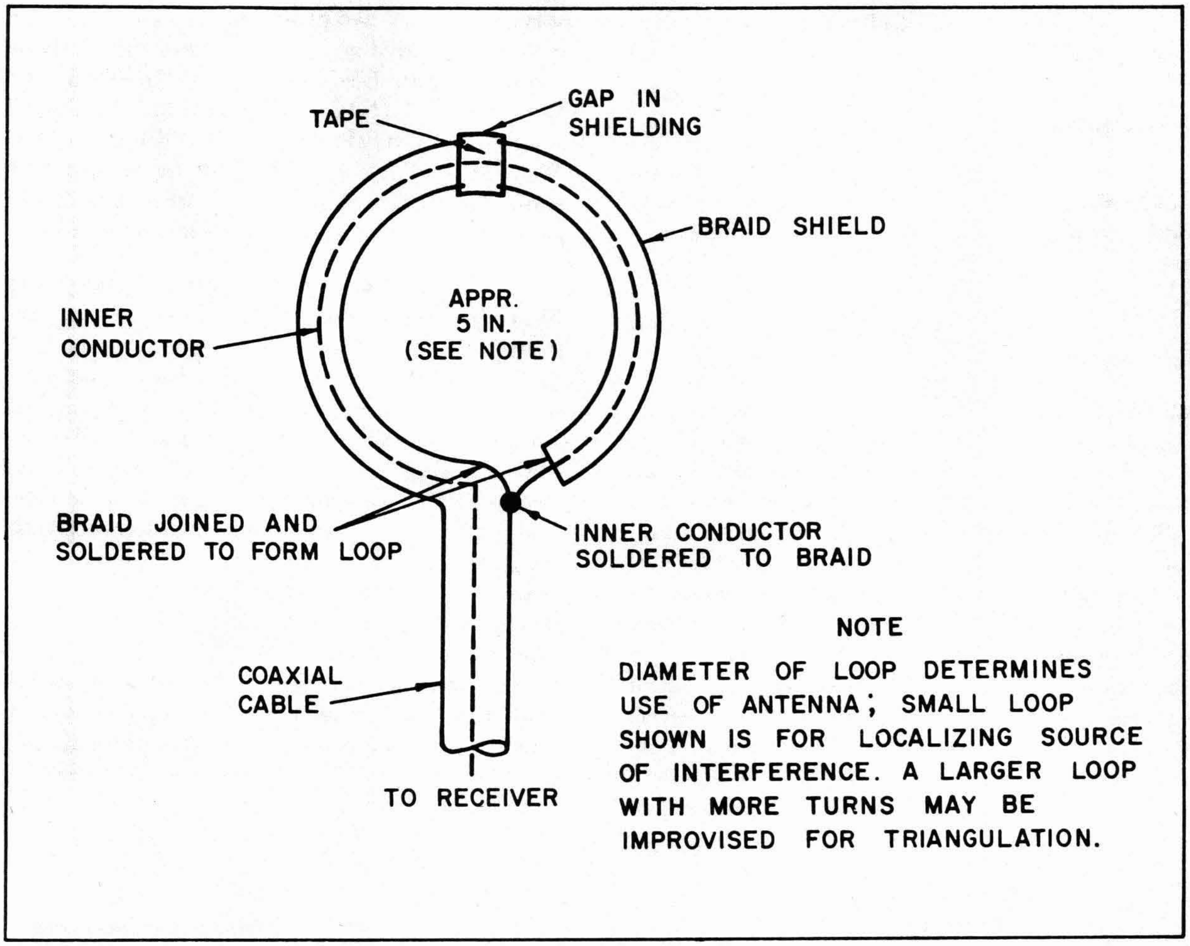


Figure 35-123.—*Improvised Loop Antenna.*

d. Undesired Transmission.—If interference results from an undesired radio transmission, information as to its call sign, frequency, type of emission, and duty record, as well as other data that might aid in station identification, should be observed and recorder. CED 2408.lb, *Radio Communications System Operation,* contains a list of the call sign prefixes which have been allocated according to international agreement. If the culprit station is under the jurisdiction of the civil authority within the United States, it will be known to the FCC. Available at any of the FCC's district offices is a list containing the frequency, call sign, type of emission, bandwidth, and location of all domestic stations. Figure 35-124 is a map showing the location of the FCC district offices and areas of jurisdiction, while Figure 35-125 gives the addresses of these offices. For obvious reasons, military assignments are not on the above list, but the information on nearby equipments can be obtained from the base communication office of the appropriate service installation.

(1) If the station call sign indicates that the transmission originates from a non-military station in a foreign country, its location can be determined by referring to The Broadcasting Stations of the World. This book is a list of all radio broadcasting and television stations on domestic channels, except for those in the continental United States. The list includes the call letters, and/or station name, location, power, frequency, and ownership of each station. The list is published in four parts as follows:

(a) Part 1 - Indexed alphabetically by country and city.

(b) Part 2 - Indexed according to frequency, in ascending order.

(c) Part 3 - Indexed first by letters and second by station name or slogan.

(d) Part 4A - Frequency modulation broadcasting stations indexed by country and city, and by frequency.

(e) Part 4B - Television stations indexed by country and city, and by frequency.

When interference from an unauthorized transmission is experienced, the resultant incompatibility should be resolved at the lowest echelon of command possible. If the interference results from a local station, the assistance of appropriate local military or civil authorities should be solicited in resolving the problem. If local attempts at coordination fail, commanders should forward a complete report to the next highest echelon of command in accordance with AFR 100-16. A convenient form for this report is shown in Figure 35-126. Coordination between major air commands is authorized for resolving interference problems. When interference cannot be cleared at major air command or theater level, the report should be forwarded to DIRECTOR OF COMMUNICATIONS ELECTRONICS, ATTN: AFOAC-F, HEADQUARTERS USAF, WASHINGTON 25, D.C. This report should be submitted in accordance with instructions in CED 2411., *Radio Communications Systems Operation.*

e. Mechanical Inspection of Suspected Sources.—Mechanical inspection of a suspected source can often be an aid in determining the actual interference generator. Most broadband noise results from the breakdown of an electric field, and such a breakdown is sometimes accompanied by the emission of visible light. If the suspected source is operated in a darkened room or at night, the observation of light (except for that from normal lighting, tubes, etc.) indicates the generation of interference. The suspected source should also be checked for the mechanical condition of wire, cables, wire insulation, grounds, insulators, connectors, shafts, belts, plugs, jacks, guy wires, etc. Lubricated surfaces should be checked for over and under lubrication. Dust and dirt should be removed—particularly in

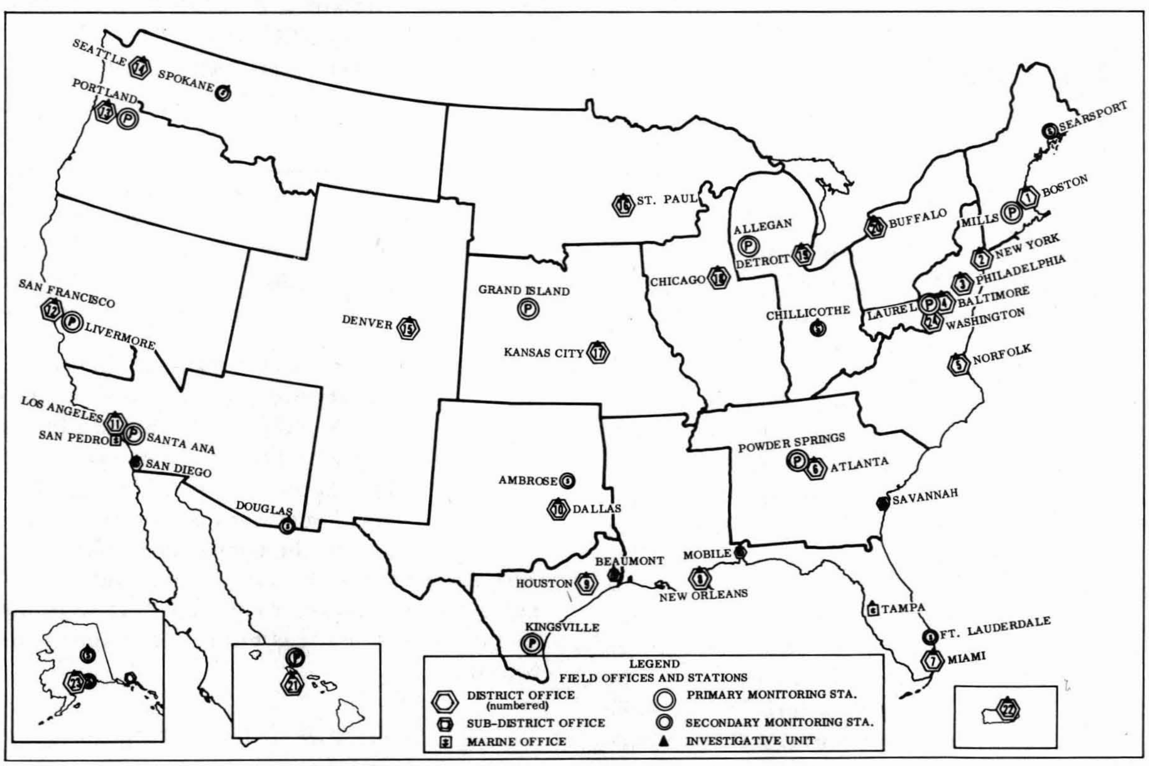


Figure 35-124.—*FCC Field Offices and Monitoring Stations.*

areas associated with high voltage. Equipment wiring and components should be checked for loose connections or intermittent grounds. Sometimes a suspected interference source can be checked by tapping or vibrating while monitoring the interference signal. Moving the wires and any accessible components of a suspected source is also an excellent way of probing for interference.

f. Timing of the Suspected Source (Off-On Test).—After the interference source has been localized to a small area by triangulation or other means, possible sources may be checked by operating them one at a time. If the source has some duty cycle, it can be compared to the occurrence of interference. If the possible source has an off-on control, the test can be performed by turning the suspect off and on while noting the reaction of the victim receiver. Although it is sometimes more convenient to use a portable receiver for checking sources, the final analysis should always include a check with the victim receiver.

Station	Location	Address
PRIMARY MONITORING STATIONS		
Allegan Monitoring Station	Allegan, Michigan	P. O. Box 89
Grand Island Monitoring Station	Grand Island, Nebraska	P. O. Box 788
Kingsville Monitoring Station	Kingsville, Texas	P. O. Box 632
Laurel Monitoring Station	Laurel, Maryland	P. O. Box 31
Livermore Monitoring Station	Livermore, California	P. O. Box 989
Millis Monitoring Station	Millis, Massachusetts	P. O. Box 458
Portland Monitoring Station	Portland 16, Oregon	P. O. Box 5165
Powder Springs Monitoring Station	Powder Springs, Georgia	P. O. Box 98
Santa Ana Monitoring Station	Santa Ana, California	P. O. Box 2215
Lanikai Monitoring Station	Lanikai, Oahu, Hawaii	P. O. Box 1142
SECONDARY MONITORING STATIONS		
Fairbanks Monitoring Station	Fairbanks, Alaska	P. O. Box 810
Ft. Lauderdale Monitoring Station	Ft. Lauderdale, Fla.	P. O. Box 5098
Chillicothe Monitoring Station	Chillicothe, Ohio	P. O. Box 251
Ambrose Monitoring Station	Denison, Texas (Ambrose)	P. O. Box 366
Searsport Monitoring Station	Belfast, Maine (Searsport)	P. O. Box 44
Spokane Monitoring Station	Spokane, Washington	P. O. Box 191
Douglas Monitoring Station	Douglas, Arizona	c/o Postmaster
Anchorage Monitoring Station	Anchorage, Alaska	P. O. Box 719

Figure 35-125.—*Listing of FCC Monitoring Stations.*

SAMPLE RADIO INTERFERENCE REPORT			DATE
TO:		FROM:	
DATE(s) AND TIME(s) INTERFERENCE EXPERIENCED *(GMT)*			
INTERFERED STATION		INTERFERING STATION	
CALL SIGN		CALL SIGN	
FREQUENCY		FREQUENCY	
BANDWIDTH		TYPE	
LOWEST FREQUENCY	HIGHEST FREQUENCY	TRANSMISSION *(A1, A2, etc.)*	TRAFFIC
STRENGTH OF INTERFERENCE		BEARING O" STATION	
REMARKS *(Include detailed report of action taken to eliminate the interference locally)*			

Figure 35-126.—*Radio Interference Report.*

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SECTION IV—PRACTICAL EXAMPLES AND TEST PROCEDURES

3510. PRACTICAL EXAMPLE I: INTERFERENCE SUPPRESSION OF RADAR EQUIPMENT.

.1 Introduction to Hypothetical Problem.—In order to illustrate the application of the various steps involved in defining and solving typical electromagnetic interference problems, some examples will be considered in the next two chapters of this manual. The problems are assumed to result from a number of military and civilian equipments operating in relatively close proximity. In these examples, the assumed geography, population center, and military installations are all hypothetical. However, the interference problems which will be specified are typical of these which have occurred in practice. Since the examples are realistic, some degree of familiarity with interference problems and their solutions can be gained by studying them carefully.

.2 Shoresville—Hypothetical City. — Assume the situation depicted in Figure 35-127. Shoresville is a coastal city with a population of 1,200,000 and covering an area of about 70 square miles. It has a concentrated area of heavy industry on its northern edge. It contains the types of electromagnetic radiating equipment usually associated with a large urban area: AM, FM, and TV transmitters; police, taxi-cab, and amateur stations; radar and radio equipment at its airport; and industrial equipment. On the tip of the peninsula is an ACW (Aircraft Control and Warning) Station with its radar equipments located on a natural promontory overlooking the sea so as to provide maximum radar detection range. To the northwest of Shoresville is an Air Defense Command (ADC) Base with interceptors to provide area defense against possible enemy air attack. Surrounding the city for short-range, point defense against air attack is an Army Air Defense Area (ADA) Group consisting of Nike surface-to-air missile systems and associated radars for target acquisition. Based upon this hypothetical situation, Two interference problems will be presented and discussed — those which might be faced by:

a. The C-E officers responsible for the ground-based and airborne electronics equipment at the ADC Base.

b. The C-E officer at the ACW Station. Each of the problems will be discussed separately. The first will represent examples of mutual radar interference; the second, of communications interference.

.3 Statement of the Radar Interference Problems.—The C-E officer of the ACW Station has received the following reports:

a. Reports from the ACW radar operators that the PPI scope of their AN/FPS-3 search radar often is partially covered by some form of interference or jamming at times other than during the scheduled jamming exercises.

b. Complaints from the ADA Group that their AN/TPS-1D radars are receiving interference from the ACW Station.

c. Complaints from the Federal Aviation Agency (FAA) at Shoresville Municipal Airport of interference to its ASR-3 ground-controlled-approach radar from the ACW Station.

d. Complaints from ADC Base of interference to its AN/CPN-18 ground-controlled approach radar. The C-E officer of the ACW Station will be concerned about the reported interference to his AN/FPS-3 since the interference may impair his radar's detection capability, resulting in reduced operating efficiency of the station. However, he should also be concerned about the reported interference to the radars of the other nearby units and should cooperate with their personnel in an attempt to determine the sources of the interference to these radars. The C-E officer at the ACW Station should assist in arriving at a workable solution to any problems in which his equipments are either the interference sources or victims. The other military units

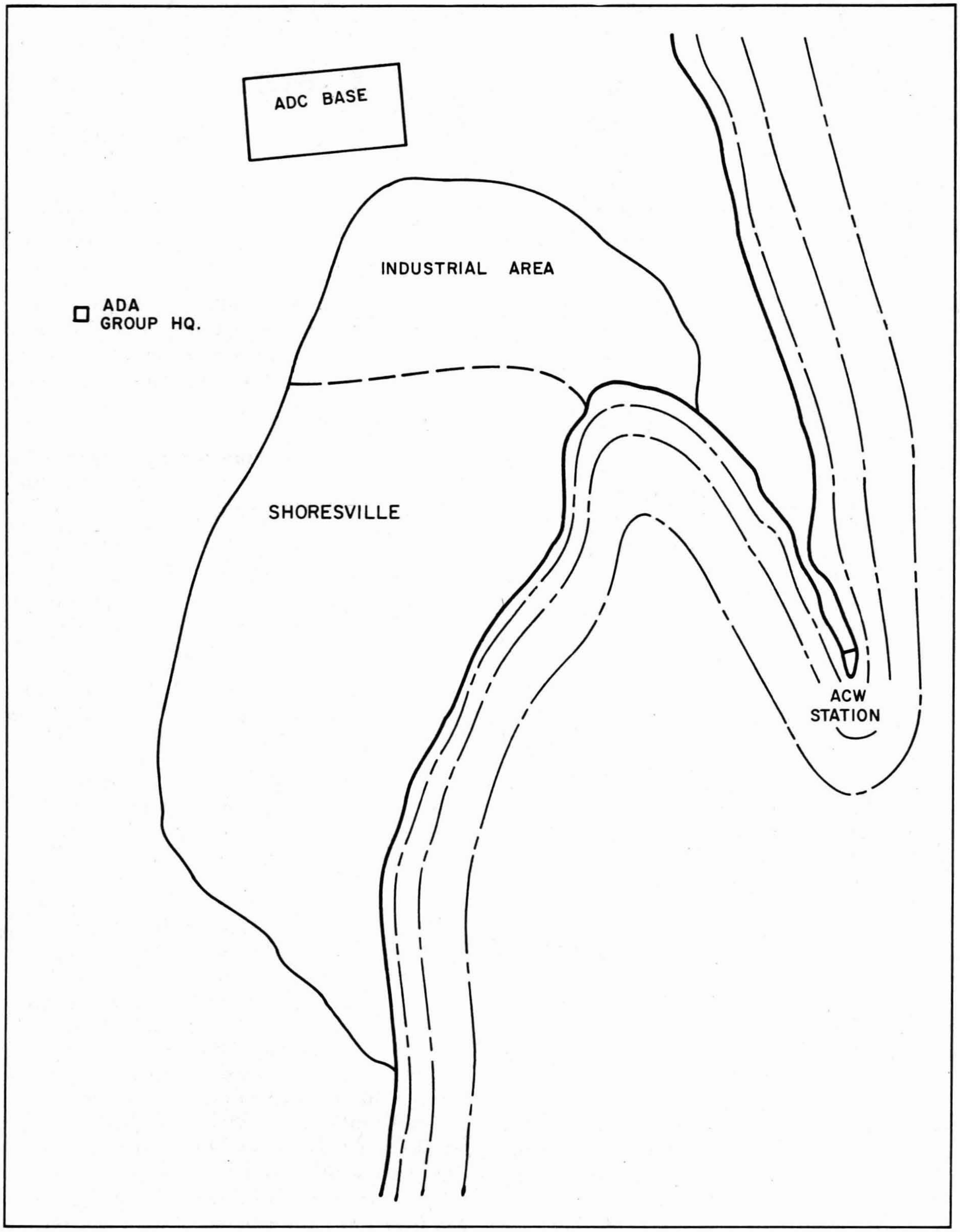


Figure 35-127.—*Shoresville and Nearby Military Organizations.*

have their own missions to perform, while the civilian airport is concerned with commercial flight safety. It is important that all of the aforementioned communications-electronics equipment function properly and with as little interference as possible.

.4 Initial Investigation.—The initial step to be taken is the positive identification of the sources of interference for each of the cases reported. To make such an identification will require obtaining the types of information outlined in CED 3502. In order to obtain this information, the C-E officer should: examine carefully the ACW Scope Condition Reports prepared by the ACW Surveillance Officer; examine the PPI scope of the AN/FPS-3 when it is receiving interference, and question the operating personnel regarding the similarities or differences between the interference currently being encountered and that observed at previous times. The C-E officer should also obtain descriptions of the interference which is effecting: the AN/CPN-18 radar at the ADC Base; the AN/TPS-1D radars at the ADA Sites; and the ASR-3 radar at the Municipal Airport. Operating frequencies of all the victim radars should be ascertained. Assume that these three steps yield the following results:

a. The ACW Scope Condition Reports indicate that the AN/FPS-3 radar scope has two types of extraneous displays:

(1) Approximately six solid spirals which cover the entire scope (similar to the condition shown in Figure 35-128).

(2) Sets of either dots or broken spirals (similar to the conditions shown in Figures 35-129 and 35-130), which occur in PPI sectors about 10 or 12 degrees wide. For each scan of the PPI there is always a sector of dots or broken spirals centered at an azimuth of about 340 degrees, and, in addition, for each PPI scan, two similar sectors appear at random azimuths on the PPI.

b. Examination of the AN/FPS-3 PPI scope verifies the report of the six spirals over the entire scope, and of dots covering one sector centered at 340 degrees and another sector appearing at random. The ACW operators report that the small sectors now covered with dots sometimes are covered by a small arc or by spirals, and that the type of pattern—dots, broken spirals, or arcs,—may remain constant in its presentation for hours or even

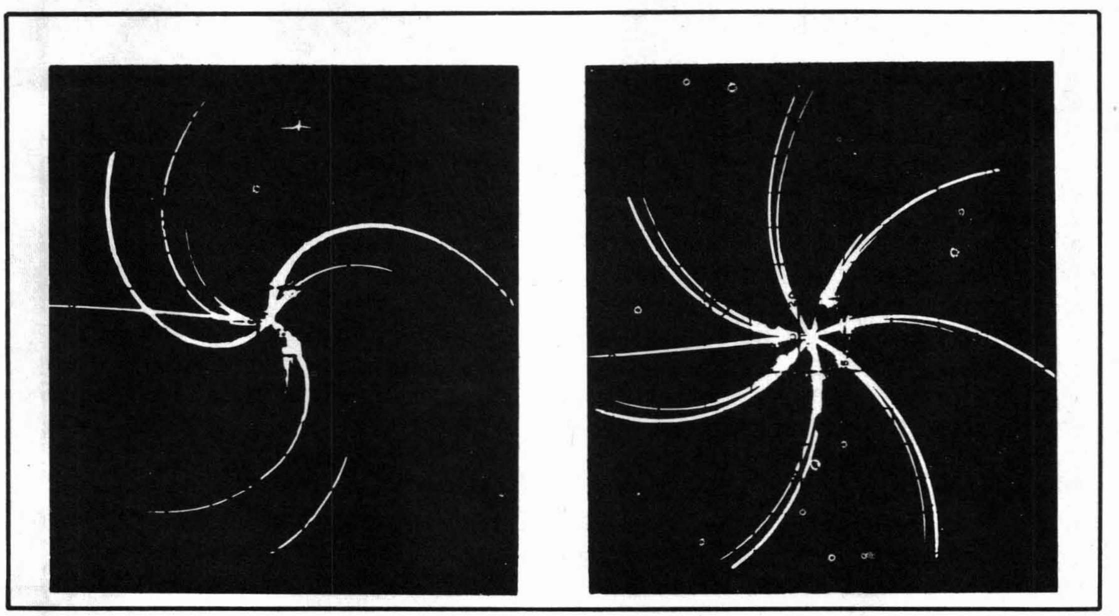


Figure 35-128.—*PPI Interference—Solid Spirals.*

days, and then rapidly switch to another type. The operators report that the interference is very distracting to them. The radar's operating frequency is 1320 mc.

c. The descriptions of interference from the other units are:

(1) The ADC Base states that its AN/CPN-18 radar often has bright spiral patches of interference over a large area of its scope, with the widest streaks occuring at azimuths of about 140 degrees. Sometimes the interference is comparatively weak. When this occurs, a sector centered at about 320 degrees is clear of interference. The radar's operating frequency is 2880 mc.

(2) The Municipal Airport reports that for the last two weeks it has been receiving intense spiral interference over almost all of the PPI scope of its ASR-3 radar. The interference has the form of broad spirals which appear to be most intense at an azimuth of about 40 degrees. The radar's operating frequency is 2710 mc.

(3) The ADA Group states that two of its three AN/TPS-1D radars are receiving interference. The third AN/TPS-1D is normally not operated unless one of the other two is turned off for maintenance. Of the two that are operated, the Site C radar operating at 1335 mc has three bright solid interference spirals which extend over all azimuths of its scope. The radar at Site A, operating at 1285 mc, has a dot pattern over sectors about 10 to 15 degrees wide. For each scan of the PPI, a sector centered at about 160 degrees is covered with interference. Also, approximately once every other scan a small sector is covered with interference; this sector is randomly located on the scope. To facilitate analyzing the problem, the interference conditions should be tabulated as indicated in Figure 35-131. Based on the reports and observations of spiral and dot-type of interference, it can tentatively be concluded that the interference in all cases is caused by radars. The next step in the analysis is to determine the locations and types of all the radars which might possibly be the sources of trouble. Usually, but not always, interference to an L-band radar is caused by another L-band radar; interference to an

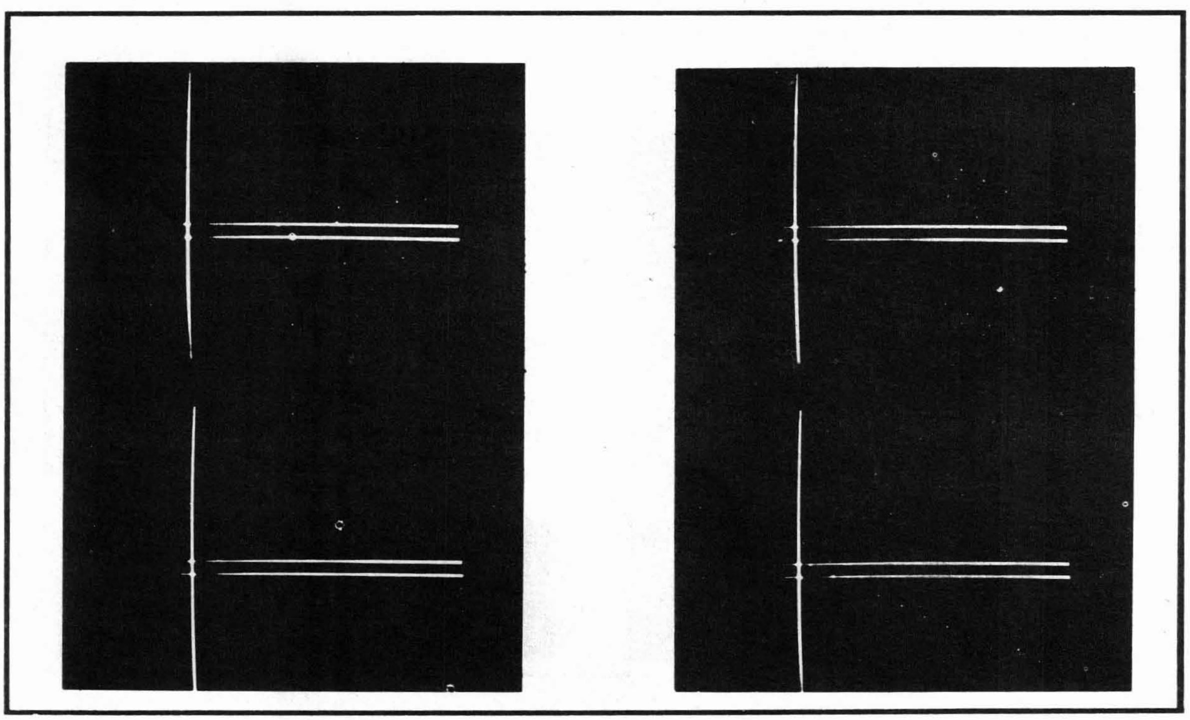


Figure 35-129.—*PPI Interference—Dots.*

S-band radar is caused by another S-band radar; etc. In this problem we are concerned with interference to the following radars:

L-Band

AN/FPS-3
AN/TPS-1D

S-Band

ASR-3
AN/CPN-18

Other Bands

None

Hence, it is probable that the interference is caused by radars operating in the L- and S-bands. Therefore, a determination should be made of the identity and locations of all L- and S-band radars operating within perhaps 25 to 50 miles of Shoresville. Possible interference can occur between radars spaced *hundreds of miles* apart, but usually consideration of an area within 50 miles or less will be sufficient for interference between *ground-based* radars. By contacting the local military units (ADA Group and ADC Base) and civilian agencies (Municipal Airport and FCC) the identities and locations of these radars are determined and plotted on a map as shown in Figure 35-132. This map can then be used to help ascertain the interference sources. The important electromagnetic characteristics of these radar types should be determined and tabulated as in Figure 35-133. As discussed in CED 3509.4b, the triangulation method can be employed to find the approximate location of the source of interference. This technique requires a portable or mobile receiver (operating in the same frequency band as the interference) and a directional antenna which can be positioned in azimuth. Two "fixes" must be taken, one can determine a line—or azimuth direction from the receiver—along which the interference source is located. It may still be possible to identify the source with single direction information if only one potential source lies on this line. The radar receiver which receives the interference can be used in its normal operating location and operating condition instead of a portable receiver, to obtain one fix on the source. The radar's directional antenna and the radar scope can easily provide the directional fix. The received interference signal is usually a maximum when its

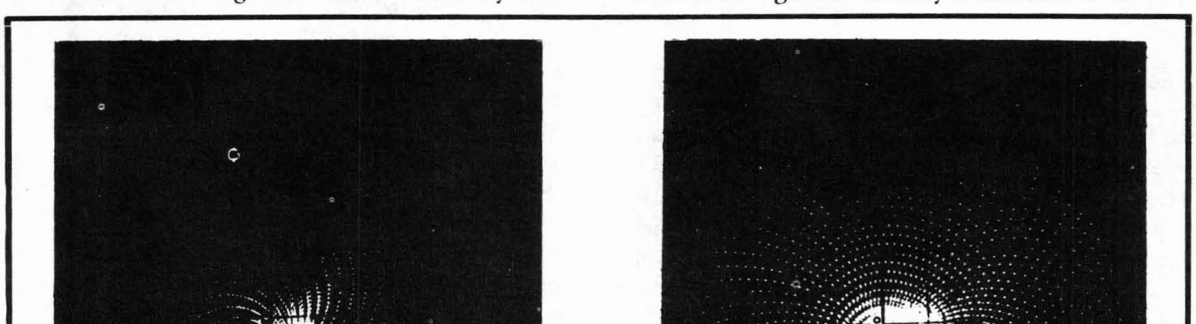


Figure 35-130.—*PPI Interference—Broken Spirals.*

Radar Receiving Interference	Type of Radar	Operating Frequency	Using Agency	Description of Interference Received
AN/FPS-3	Search	1320 mc	ACW	Six solid spirals extending over all sectors of the scope Dots or spirals in sectors centered at 340° and at random
AN/TPS-1D (Site A)	Search	1285	ADA	Dots in sectors centered at 160° and at random
AN/TPS-1D (Site C)	Search	1335	ADA	Three solid spirals extending over all sectors of the scope
AN/CPN-18	GCA Search	2880	ADC	Bright spiral streaks; worst streaks at 140°
ASR-3	GCA Search	2710	FAA	Intense spiral interference; worst at 40°; has occurred during the last two weeks

Figure 35-131.—*Radar Interference Conditions.*

antenna is pointed at the interfering radar. Hence, the azimuth at which the received interference signal is consistently a maximum is usually the azimuth along which the interference source is located.

.5 Analysis of L-Band Problem.—In the problem being considered, sets of dots or broken spirals were observed on the PPI scope of the AN/FPS-3 over a sector centered at 340 degrees. Therefore, it is likely that an interference source is located at an azimuth of 340 degrees from the ACW Station. A dashed line drawn at an azimuth of 340 degrees from the ACW Station on the map of Figure 35-132 is seen to pass close to two Nike batteries and AN/TPS-1D Site A. Since interference to the AN/FPS-3 —an L-band radar—is more probable from another L-band radar, it is probable that the AN/TPS-1D radar at Site A is the source of the dot or broken-spiral interference. Since the only other L-band radar known to be regularly operating in the area is an AN/TPS-1D at Site C, it is tentatively concluded that this radar is the source of the solid-spiral interference to the AN/FPS-3. The sources of interference to the two AN/TPS-1D's can be deduced similarly: Interference to the radar at Site A is a maximum when its antenna is pointed at an azimuth of 160 degrees. A line drawn at an azimuth of 160 degrees from Site A on the map of Figure 35-132 passes close to two Nike batteries and to the ACW Station. It is most probable that the interference is coming from the AN/FPS-3, which operates in the same band as the AN/TPS-1D. The radar at Site C could be receiving its bright spiral interference from either the AN/FPS-3 or from the AN/TPS-1D at Site A. Let it be assumed that the Army personnel at Site A turn their AN/TPS-1D off briefly and that the interference to their Site C radar does not disappear. Then it is almost certain that the AN/FPS-3 is the cause of the interference. This is not surprising since the AN/FPS-3 was found to be receiving heavy interference from the AN/TPS-1D at Site C, and the characteristics of the AN/TPS-1D and AN/FPS-3 are somewhat similar. Therefore mutual interference between the two is not unlikely. The sources of interference to the L-band radars have now been tentatively determined and are summarized in Figure 35-134. The sources of the interference should be *positively* identified by turning off briefly the suspected source of the interference, or adjusting the PRF of the suspected source, and observing any change in the victim receiver. In cases where there are no other radars in the vicinity operating in the frequency band of interest, this procedure will result in positive identification. Such a condition is assumed to exist in this case. In the event positive

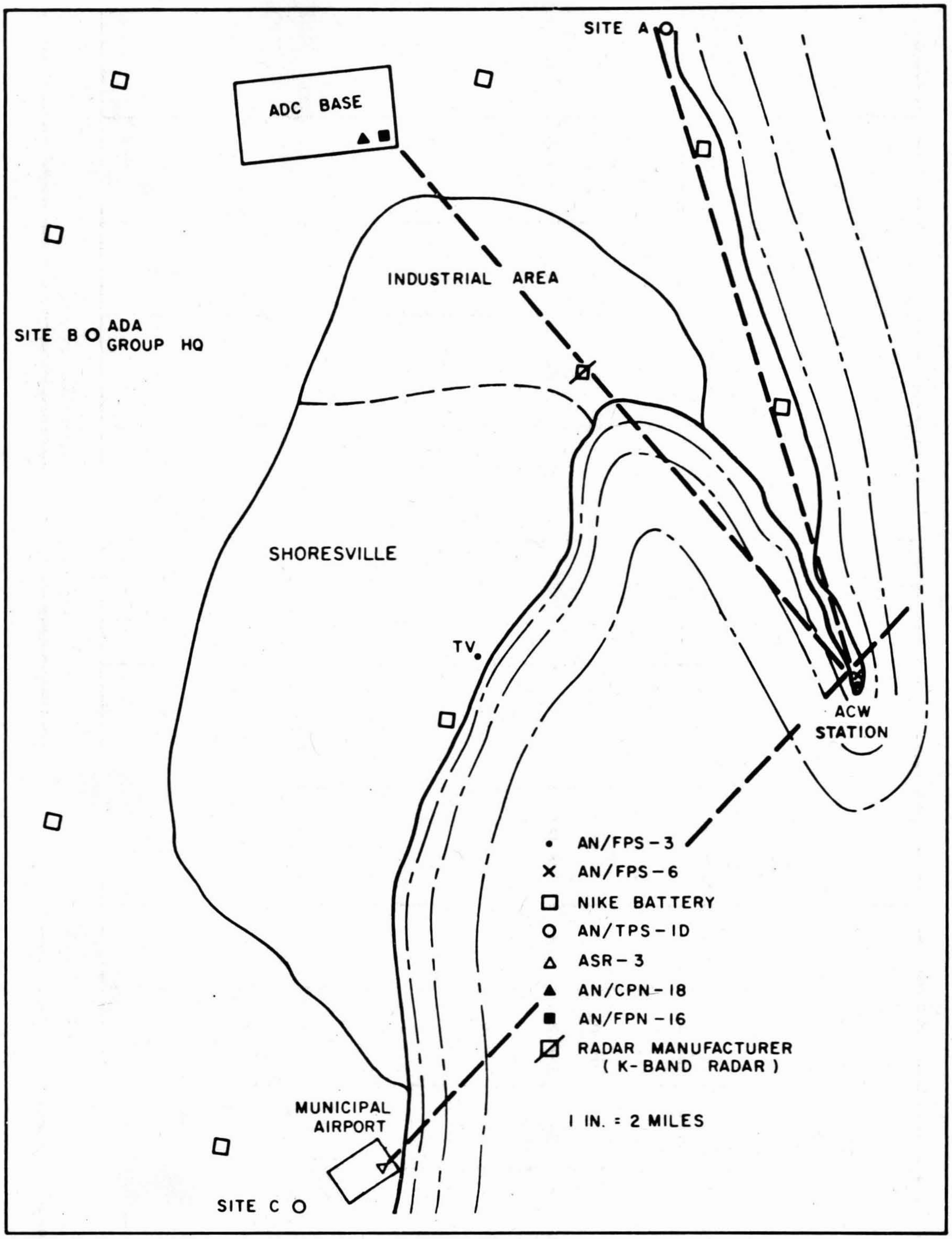


Figure 35-132.—*Radars Within 35 Miles of Shoresville.*

Radar Nomenclature	Type of Radar	Location	Using Agency	Radar's Frequency Range (mc)	Transmitter Tunable or Fixed Frequency	Transmitter Peak Power (kw)	Receiver Sensitivity (dbm)	Gain of Main Antenna Lobe (db)	Width of Main Lobe	Antenna Scanning	Antenna Polarization
AN/FPS-3	Search	ACW Station	ACW	1220-1350	T	500	−105 (est.)	36	1.3	Horizontal 3.3-10 rpm	H
AN/FPS-6	Height Finder	ACW Station	ACW	2700-2900	F	5,000	....	39	3.2	Vertical 20 or 30 cpm	V
ASR-3	GCA Search	Shoresville Airport	FAA	2700-2900	T or F	700	−102	36	2.2	Horizontal at 25 rpm	H
AN/CPN-18	GCA Search	ADC Base	ADC	2700-2900	T	700	−102	35	1	Horizontal 10 or 18 rpm	H
AN/FPN-16	GCA Precision	ADC Base	ADC	9000-9160	..	45	....		1.1	20° Hor., 7° vert.	
AN/TPS-1D	Search	Sites A, B, and C	ADA	1220-1350	T	500	−104	27	4	Horizontal 0 - 15 rpm	H
Nike Acq.	Search	8 Batteries	ADA	3100-3500	T	1,000	....	29	1.4	Horizontal 10, 20, 30 rpm	H
Nike Target Tracker	Tracker	8 Batteries	ADA	8500-9600	T	250	....	40	1.2	Tracking	V
Nike Missile Tracker	Tracker	8 Batteries	ADA	8500-9600	T	250	....	40	1.2	Tracking	V
Nike Missile Beacon	Beacon	8 Batteries	ADA	8900-9500		0.5 - 1	....	0	None	None	C

Figure 35-133.—*Radar Potential Sources of Interference and Essential Characteristics.*

Radar Receiving Interference	Description of Interference	Probable Source
AN/FPS-3	Dots or broken spirals	AN/TPS-1D (Site A)
	Six solid spirals	AN/TPS-1D (Site C)
AN/TPS-1D (Site A)	Dots	AN/FPS-3
AN/TPS-1D (Site C)	Three solid spirals	AN/FPS-3

Figure 35-134.—*Probable Sources of Interference to L-Band Radars.*

identification does *not* result, one should first suspect that the radar map (Figure 35-132) is not complete and that there is at least one or more other radars in the vicinity that operate in the frequency band of interest. Then, it would be necessary to investigate further to ascertain the identity and location of the additional radars. However, another possibility that should not be overlooked is that a radar in another frequency band, e.g., S-band, may be operating improperly and radiating spurious energy in the band of interest. However, it is assumed in this example that positive identification is established; then the sources of interference to all the L-band radars are known.

.6 Analysis of S-Band Problem.—The interference sources effecting two S-band radars (the AN/CPN-18 and the ARS-3) can be determined in a manner similar to that which the L-band interference sources were found. First consider the interference to the ASR-3, located at the Shoresville Airport. Since its worst interference is received from an azimuth of 40 degrees, it is very probable that the source of interference is located along the azimuth. Therefore, on the map of Figure 35-132, a dashed line is drawn at an azimuth of 40 degrees from the Shoresville Airport. This line is seen to pass very close to the ACW Station. Therefore, it is probable that the interference is coming from the ACW Station. Since the AN/FPS-6 radar operates in the same frequency band as the ASR-3, it is believed to be the interference source. Positive identification can most easily be made by observing the ASR-3 scope while either briefly turning off the AN/FPS-6 transmitter, or changing its PRF, or orienting its antenna towards the ASR-3 and then away from the ASR-3. It is assumed here that turning the AN/FPS-6 off momentarily eliminates all interference to the ASR-3, and hence, that the AN/FPS-6 is causing the interference to the ASR-3. To determine the source of interference to the AN/CPN-18 at the ADC base, it is noted that maximum interference is received along an azimuth of 140 degrees from the ADC base. To determine the source, a line is drawn at an azimuth of 140 degrees from the position of the ADC Base on the map in Figure 35-132. It is seen to pass close to the commercial radar manufacturer and also close to the ACW Station. Since the manufacturer is building and testing low-power K-band radars, only it is likely that the interference is not coming from that source but from the AN/FPS-6. This is again verified by noting that momentarily turning off the AN/FPS-6 transmitter eliminates the interference to the AN/CPN-18. The source of interference to the S-band radars has now been identified as in Figure 35-135. Further inquiry as to the possible reason why the ASR-3 radar has been receiving more interference during the past two weeks reveals that the magnetron in the AN/FPS-6 was changed two weeks ago. Therefore, a possible change in the AN/FPS-6's operating frequency may be the reason.

Radar Receiving Interference	Source of Interference
ASR-3	AN/FPS-6
AN/CPN-18	AN/FPS-6

Figure 35-135.—*Sources of Interference to S-Band Radars*

.7 Solution of L-Band Problem.—The interference is most severe between the AN/FPS-3 and the AN/TPS-1D at Site C. This is true because:

a. Those two radars are only 14 miles apart and their locations overlooking the sea result in the two radars being within line-of-sight of each other. The transmission loss (or propagation loss) between the two radars is therefore comparatively small, resulting in large interference signals.

b. The frequency separation between the two radars is only 15 mc. Therefore their interference signals are much greater than they would be if their frequency spacing were increased somewhat. It is also noted that there is no interference between the Army's two AN/TPS-1D's. They are interference-free because:

(1) They are 24 miles apart with an overland path intervening. The transmission loss is therefore comparatively larger.

(2) They have a 50-mc frequency separation, resulting in an appreciable further attenuation of the interference signals. A rough plot of the available operating band, showing the frequencies in use, would appear as shown in Figure 35-136.

c. The lower half of the band is unused, causing needless congestion in the upper half. Hence, it appears that an appropriate readjustment of operating frequencies might help to reduce the interference. It will be noted later that changing the frequencies will *not* eliminate all the interference in this case. As discussed in CED 3503.5a, the detailed structure of antenna patterns of most radars is not known, and it is necessary to *assume* certain pattern characteristics for purpose of calculation. For simplicity, it is assumed here that a radar antenna pattern, in the horizontal plane, can be approximated by a main lobe having the beam-width and gain equal to the radar's nominal beam-width and gain, and side and back lobes having a gain of 0 db. Such simplified antenna patterns are depicted in Figure 35-137. Also given in the figure is a list of the possible types of coupling from the antenna of the interfering radar to that of the victim radar. By comparing the initial descriptions of the interference with the descriptions in the "Remarks" column of Figure 35-137, one can see that interference is due to Type II, III, and IV coupling. In order to determine the reduction of interference which can be obtained by readjusting frequencies, calculations will be performed to determine the frequency separations required for each pair of radars in order to eliminate the interference which occurs through each of the four types of antenna coupling. The problem is solved by considering two radars at a time, assuming one to be the interference source and the other the victim, and then reversing the roles of the two radars. Since we are here concerned with three radars (one AN/FPS-3 and two AN/TPS-1D's), there are six sets of calculations to perform. Each required set of calculations can be performed by merely entering in Figure 35-138 the values for a few required characteristics of the two radars and the intervening path between the radars. All of the required values can be obtained from the characteristics tabulated previously (Figure 35-133), except (1) the basic transmission loss between each pair of sites (Item d), and (2) a graph of spectrum-selectivity to permit determining the values for Items f, i, l, and p from Items e, h, k, and o, respectively. The basic transmission loss is discussed in CED 3503, and the spectrum-selectivity is discussed in CED 3504. In the latter, it is stated that the spectrum-selectivity wave is approximately the same as the envelope of the transmitter spectrum. This approximation is assumed to be valid in the radar interference example being considered, and transmitter spectrum data have been used for plotting the required spectrum-selectivity curve. The graph of

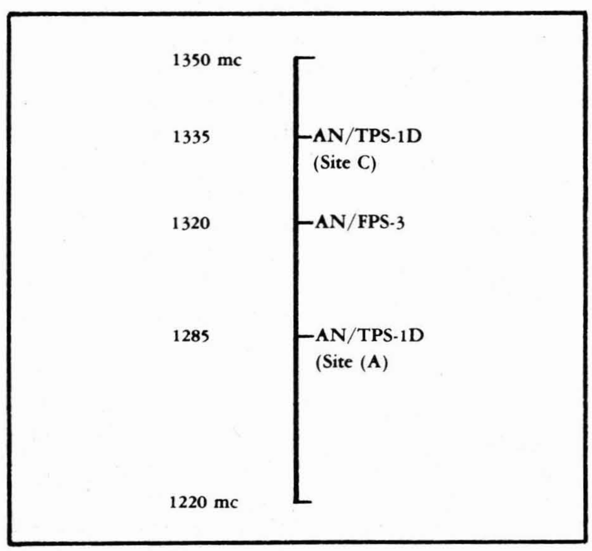
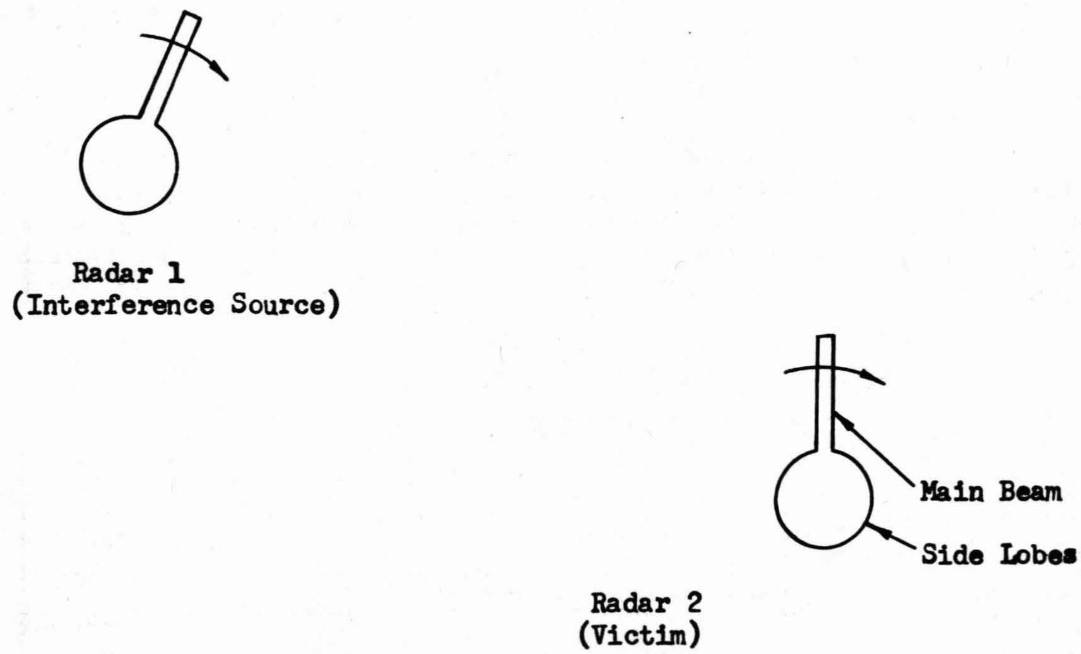


Figure 35-136.—*Occupancy of L-Band.*



Type of Coupling	Remarks
I (Main Lobe)[1] to (Main Lobe)$_2$	High level of interference signal, but occurs very, very rarely
II (Main Lobe)$_1$ to (Side Lobes)$_2$	Causes interference in limited sectors positioned randomly on scope
III (Side Lobes)$_1$ to (Main Lobe)$_2$	Causes interference in limited sector in fixed position on scope
IV (Side Lobes)$_1$ to (Side Lobes)$_2$	Causes interference in all sectors of scope

[1] Subscript denotes "Radar 1" or "Radar 2".

Figure 35-137.—*Types of Coupling Between Rotating Radar Antennas.*

spectrum-selectivity which will be used for this problem is given in Figure 35-139. It is here assumed that the curve applies to both interference from an AN/TPS-1D to an AN/FPS-3, and interference from an AN/FPS-3 to an AN/TPS-1D. The values of basic transmission loss will be assumed to be:

(1) 121 db between AN/FPS-3 and AN/TPS-1D (Site C). This is the free-space loss under the assumed line-of-sight conditions.

(2) 130 db between AN/FPS-3 and AN/TPS-1D (Site A). This is 10 db greater than the free-space loss, which is about 120 db. The value 10 db greater than the free-space loss was chosen as the two radars are assumed to be just beyond line-of-sight of each other.

(3) 151 db between AN/TPS-1D (Site A) and AN/TPS-1D (Site C). This is 25 db greater than the free-space loss which is about 126 db, The value 25 db greater than the free-space loss was chosen as the two radars are well beyond line-of-site of each other; the skyline of the urban area intervenes between them.

d. Inserting into Figure 35-138 the required values from Figure 35-139 plus the values of basic transmission loss permits one to calculate Items e, h, k, and o. Items f, i, l, and p can then be determined from the spectrum-selectivity graph. The results of the calculations are tabulated in Figure 35-140. The results indicate (Item f in Column 1) that a minimum frequency separation of 30 mc between the AN/FPS-3 and the AN/FPS-1D at Site C is required so that the AN/FPS-3 will not experience Type IV coupling, which at present is causing intererence spirals in all sectors of the AN/FPS-3 scope. The results also indicate that it

SAMPLE WORK SHEET FOR CALCULATION OF MUTUAL RADAR INTERFERENCE		DATE
RADAR NR 1 *(Interference Source)* TYPE / RADAR NR 2 *(Victim)*		TYPE
a. Peak Transmitter Power of Radar Nr 1	dbm	dbm
b. Sensitivity of Radar Nr 2 to Interference[1]	dbm	dbm
c. Total Attenuation Required of Interference Signal for No Interference Through Type IV Coupling		(b—a) db
d. Basic Transmission Loss	db	
e. Spectrum-Selectivity Attenuation Required for No Interference Through Type IV Coupling (item d minus c)		db
f. Frequency Separation Required for No Interference through Type IV Coupling (item e and footnote 2)	mc	
g. Gain of Main Lobe of Radar 1	db	
h. Spectrum-Selectivity Attenuation Required for No Interference through Type II or IV Coupling (item e plus g)		db
i. Frequency Separation Required for No Interference through Type II or IV Coupling (item h and footnote 2)		mc
j. Gain of Main Lobe of Radar 2	db	
k. Spectrum-Selectivity Attenuation Required for No Interference through Type III or IV Coupling (item e plus j)		db
l. Frequency Separation Required for No Interference through Type III or IV Coupling (item k and footnote 2)		mc
m. Frequency Separation Required for No Interference through Type II, III, or IV Coupling (larger value of i or l)	mc	
n. Sum of Gains of Main Lobes of Radar 1 and Radar 2 (item g plus j)	db	
o. Spectrum-Selectivity Required for No Interference through Type I, II, III or IV Coupling (item e plus n)		db
p. Frequency Separation Required for No Interference through Type I, II, III or IV Coupling (item o and footnote 2)	mc	

[1] *Sensitivity to interference is estimated to be about 10db poorer than sensitivity to radar's own signal because the interference pulses are not synchronized with the victim radar's scope timing circuits, i.e., because the two radar's pulse-repetition-frequencies will not be identical.*

[2] *See Spectrum-Selectivity Graph.*

Figure 35-138.—*Sample Work Sheet for Calculation of Mutual Radar Interference.*

is impossible to prevent the AN/FPS-1D at Site C from causing interference to the AN/FPS-3 through Type I, II, or III coupling. This condition exists because the maximum value of attenuation of the spectrum-selectivity is 80 db, whereas values of 88, (Item h), 97 (Item k), and 124 db (Item o) are required.

e. A spacing of 82 mc will eliminate the Type II coupling from the AN/FPS-1D at Site A to the AN/FPS-3. Since this spacing is greater than the 80 mc required (Item l in Column 4) to eliminate the Type III coupling from the AN/FPS-3 to the AN/TPS-1D at Site A; this interference will also be eliminated. However, Type II coupling from the AN/FPS-3 to the AN/TPS-1D at Site A and Type III coupling from the AN/TPS-1D at Site A to the AN/FPS-3 cannot be completely eliminated (Item i in Column 4 and Item l in Column 3). Type I coupling cannot be prevented since Items o in Columns 3 and 4 are greater that the attainable maximum of 80 db. The calculations also show that the two AN/TPS-1D radars will not receive interference from each other through Type II, III, or IV coupling (Item m) if their frequencies differ by at least 22 mc. Since they presently have a greater frequency separation than required (50 mc) they do not interfere with each other. (Type I coupling can occur, but is extremely rare for radars with rotating antennas and is neglected.) In view of the above results, the frequency plan of Figure 35-141 is recommended. This plan provides the greatest frequency separation (110 mc) between the AN/FPS-3 and the Site C AN/TPS-1D, which have the least geographic isolation between them; the two AN/TPS-1D's are separated by 25 mc, compared with the calculated minimum required separation of 22 mc; and the AN/FPS-3 and the Site A AN/TPS-1D are separated by 85 mc. Some interference between the AN/FPS-3 and the AN/TPS-1D's may still be encountered in very limited sectors on the scopes, while AN/TPS-1D's will probably not interfere with each other.

.8 Solution of S-Band Problem.—Since the interference to the ASR-3 has been much greater during

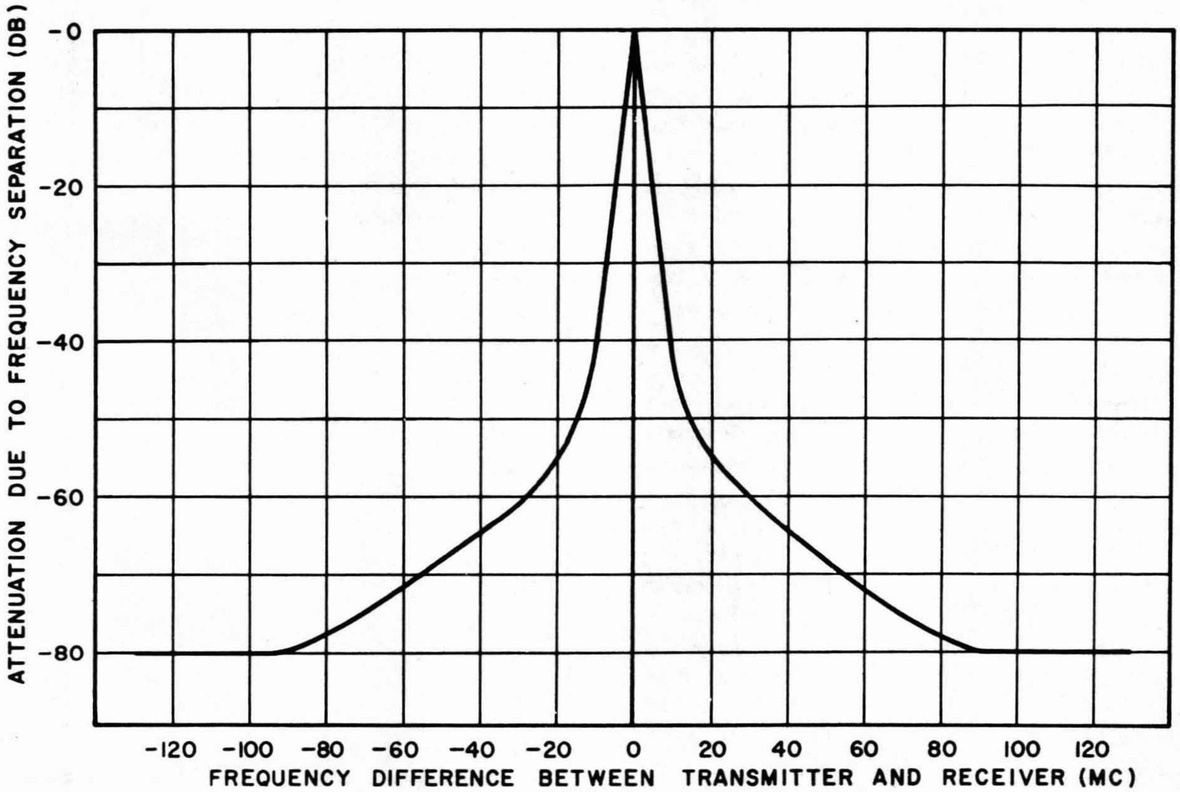


Figure 35-139.—*Spectrum-Selectivity Factors for TPS-ID to TPS-ID or TPS-ID to FPS-3.*

Radar 1 (Source)	AN/TPS-1D (Site C)	AN/FPS-3	AN/TPS-1D (Site A)	AN/FPS-3	AN/TPS-1D (Site A)	AN/TPS-1D (Site C)
Radar 2 (Victim)	AN/FPS-3	AN/TPS-1D (Site C)	AN/FPS-3	AN/TPS-1D (Site A)	AN/TPS-1D (Site C)	AN/TPS-1D (Site A)
a. (dbm)	87	87	87	87	87	87
b. (dbm)	−95	−94	−95	−94	−94	−94
c. (db)	182	181	182	181	181	181
d. (db)	121	121	130	130	151	151
e. (db)	61	60	52	51	30	30
f. (mc)	30	28	16	16	8	8
g. (db)	27	36	27	36	27	27
h. (db)	88	96	79	87	57	57
i. (mc)	..	..	..	..	22	22
j. (db)	36	27	36	27	27	27
k. (db)	97	87	88	78	57	57
l. (mc)	..	..	..	80	22	22
m. (mc)	..	..	..	..	22	22
n. (db)	63	63	63	63	54	54
o. (db)	124	124	115	114	84	84
p. (mc)	..	..	..	..	..	..

Figure 35-140.—*Arrangement of Data from Calculations of Mutual Radar Interference—L-Band.*

the last two weeks when the AN/FPS-6 has been operating with a new magnetron, it appears that a frequency change has caused the increased interference to the ASR-3 while, at the same time, it has reduced the interference to the AN/CPN-18. A plot of the operating frequencies of the three radars, including the old and new frequencies of the AN/FPS-6, has been made and is given in Figure 35-142. The plots show the three radar operating frequencies and, in addition, the image-response frequencies of the ASR-3 and the AN/CPN-18. These two radars' receivers have no frequency selectivity ahead of their mixers; therefore they have equal response at their desired signal frequencies and at their image frequencies 60 mc away. Since image response can significantly increase a radar's susceptibility to interference, it is necessary that they be considered. The plot for the time period to the last two weeks shows that the AN/FPS-6 was operating only 10 mc away from the image frequency of the AN/CPN-18 and 40 mc away from the image frequency of the ASR-3. During the last two weeks the AN/FPS-6 has been operating 35 mc away from the AN/CPN-18 image, but within 15 mc of the ASR-3 image. This small frequency separation (15 mc) and the short overwater path between the AN/FPS-6 and ASR-3 are probably responsible for the severe interference now being received by the ASR-3. It is assumed that only fixed-tuned magnetrons are available for use in the AN/FPS-6, and that new magnetrons all operate at a frequency near 2785 mc. Since the AN/FPS-6 is now operating in the lower half of the band (i.e., below 2800 mc), it would probably be desirable

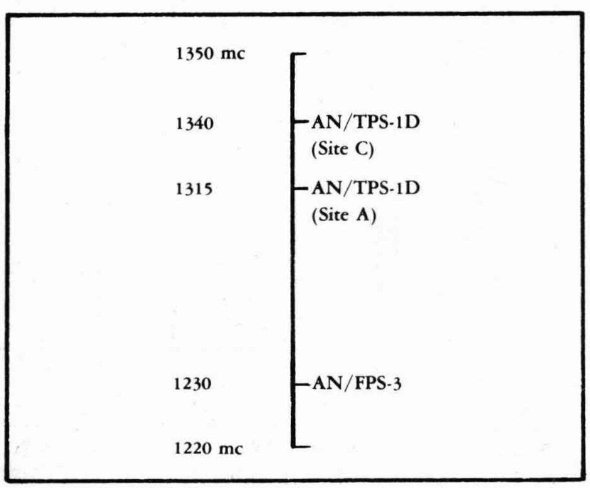
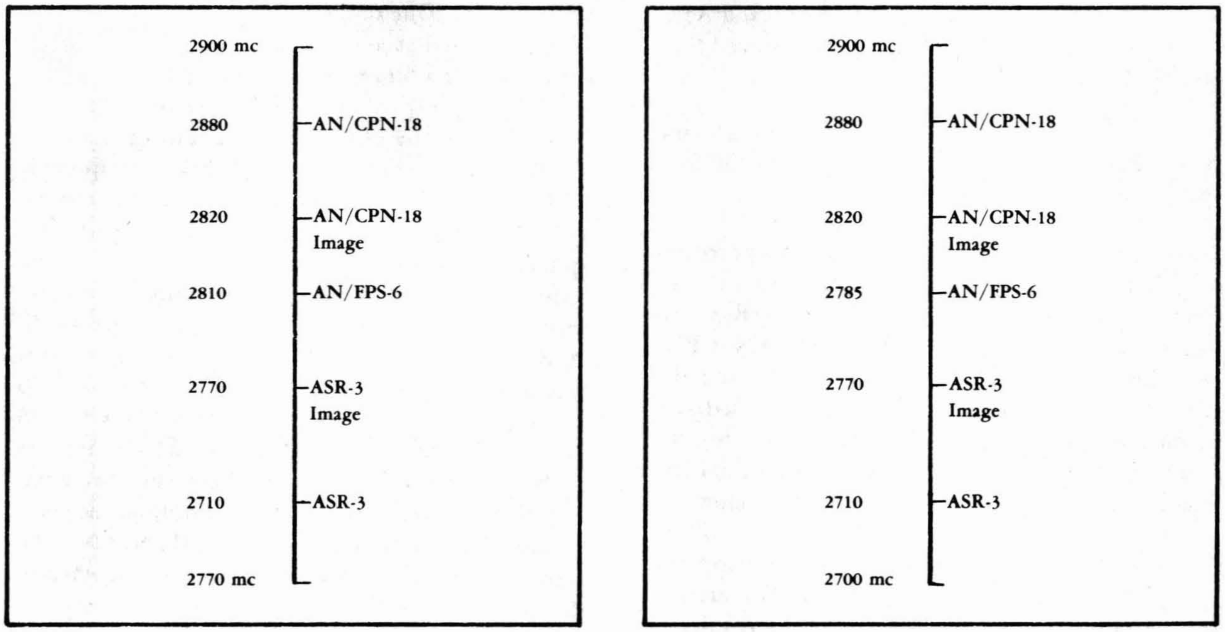


Figure 35-141.—*Recommended Occupancy of L-Band.*



(A) Prior to Last Two Weeks

(B) Last Two Weeks

Figure 35-142.—*Comparative Occupancy of S-Band.*

that the ASR-3 operate in the upper half of the band so that it can be separated from the AN/FPS-6 as widely as possible in frequency. Since the AN/CPN-18 is farther away from the AN/FPS-6 with an overland path intervening, it may be able to operate in the lower half of the band along with the AN/FPS-6. The radars would occupy relative parts of the band as shown in Figure 35-143.

a. It is necessary to determine if such an arrangement can be suitable, and, if so, the recommended operating frequencies for the AN/CPN-18 and ASR-3. It appears that these radars should operate at, or as close as possible to 2700 mc and 2900 mc, respectively, so as to provide maximum frequency separation from the AN/FPS-6. The required frequency separations will now be determined. The required frequency differences between the AN/FPS-6 and the sentitive frequencies (signal and image) of the ASR-3 and the AN/CPN-18 can be determined by entering the appropriate data in Figure 35-138 and performing the indicated calculations, as was done in solving the L-band problem. Some of the necessary data can be obtained from Figure 35-133. However, again the basic transmission loss and the spectrum-selectivity curve need to be known. The basic transmission loss is assumed to be:

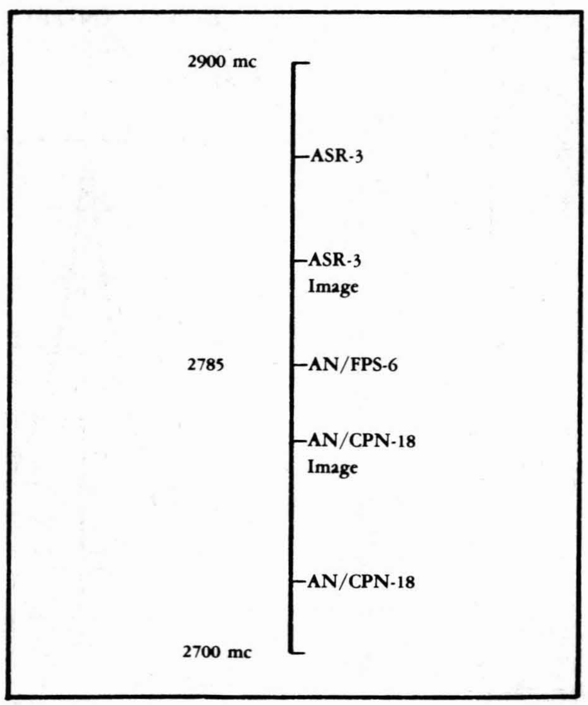


Figure 35-143.—*Tentative Redistribution of Equipment in S-Band.*

(1) 127 db between AN/FPS-6 and ASR-3. This is the free-space loss under the assumed line-of-sight conditions.

(2) 143 db between AN/FPS-6 and AN/CPN-18. This is 15 db greater than the free-space loss.

Figure 35-144 presents the graph of the spectrum-selectivity factor which is assumed to apply for interference from the AN/FPS-6 to the ASR-3, and interference from the AN/FPS-6 to the AN/CPN-18. This curve assumes that the ASR-3 (or the AN/CPN-18) is operating with its local oscillator 30 mc above the transmitter frequency, causing the image response to be 60 mc above the signal frequency. If the local oscillator is operated below the signal frequency, then the image response will be 60 mc below the signal frequency. Entering the appropriate values into Figure 35-138 for each of the two cases of interference yields the results in Figure 35-145. It is seen that it is possible to eliminate Type IV coupling from the AN/FPS-6 to the other radars by operating the ASR-3 at least 100 mc away from the AN/FPS-6, and operating the AN/CPN-18 at least 79 mc away from the AN/FPS-6. The freqeuncy plan of Figure 35-146(A) will probably provide satisfactory results.

b. Due to the dip between the two peaks of the assumed spectrum-selectivity curve, it is possible to select a different frequency of the AN/CPN-18 which may provide still less interference. This condition can be obtained by operating the AN/CPN-18 30 mc below the AN/FPS-6 frequency. The AN/FPS-6 frequency is then midway between the AN/CPN-18's signal frequency and image frequency and coincides with the dip or null on the spectrum-selectivity curve. The frequency arrangement would then be that shown in Figure 35-146(B). According to the spectrum-selectivity curve, this frequency plan would provide 54 minus 48 or 6 db more interference rejection for the AN/CPN-18 than would the previous plan; therefore it appears to be preferable. In an actual case, the spectrum-selectivity curve is highly dependent upon the spectrum of the interfering transmitter. If the AN/FPS-6 transmitter spectrum is broader than assumed in drawing the spectrum-selectivity curve, or if the receiver selectivity curve is broader, then the dip between the peaks of the curve will not be as deep as shown, and greater interference may result by having the AN/FPS-6 operate at that frequency.

c. From the results tabulated in Figure 35-145, it is noted from items i and l that Type II

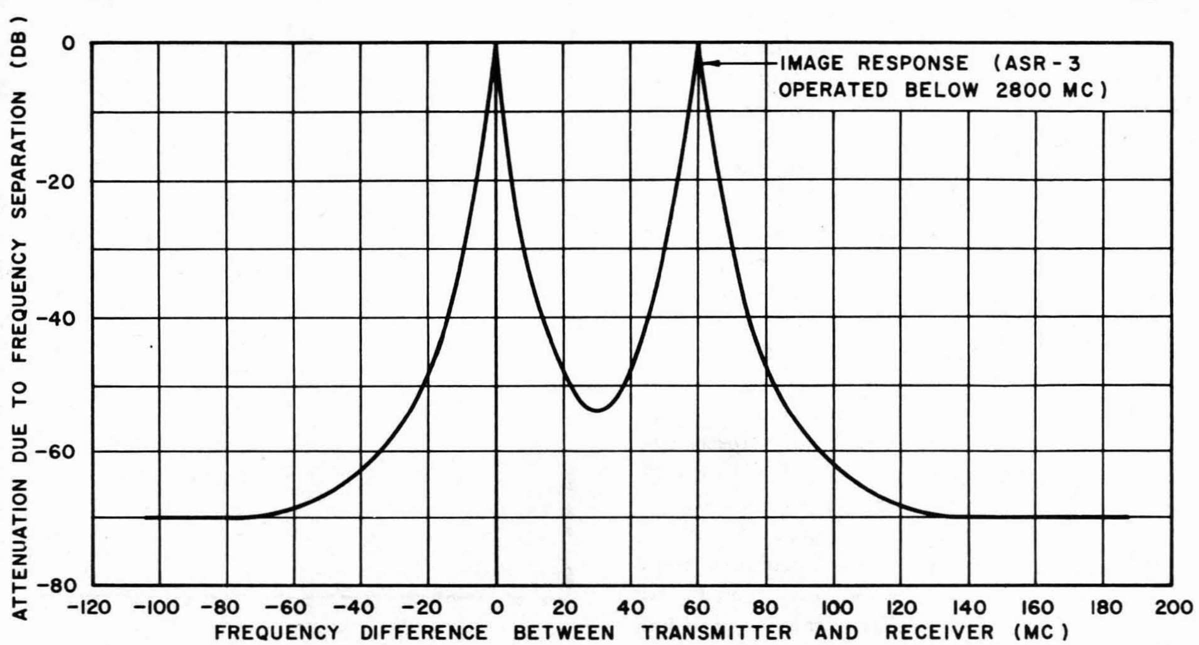


Figure 35-144.—*Spectrum-Selectivity Factor for AN/FPS-6 to ASR-3 and AN/FPS-6 to AN/CPN-18.*

Radar 1 (Source)	AN/FPS-6	AN/FPS-6
Radar 2 (Victim)	ASR-3	AN/CPN-18
a. (dbm)	97	97
b. (dbm)	−92	−92
c. (db)	189	189
d. (db)	127	143
e. (db)	62	46
f. (mc)	100	79
g.[1] (db)	29	29
h. (db)	91	75
i. (mc)	..	..
j.[1] (db)	26	25
k. (db)	88	71
l. (mc)	..	..
m. (mc)	..	..
n[1] (db)	65	64
o. (db)	127	110
p. (mc)	..	..

[1]Since Radars 1 and 2 have cross-polarized antennas, 10 db has been subtracted from the figures which otherwise would be entered for Items g, j, and n. The 10 db represents additional attenuation of discrimination which the horizontally-polarized antennas of the ASR-3 and the AN/CPN-18 provide when receiving a vertically-polarized signal such as from the AN/FPS-6.

Figure 35-145.—*Arrangement of Data from Calculations of Mutual Radar Interference—S-Band.*

and III coupling cannot be eliminated; *i.e.*, interference to either of these radars will occur if its antenna points at the AN/FPS-6, or if the AN/FPS-6 antenna points at it. Since the antennas of the AN/CPN-18 and the ASR-3 must rotate, they will receive interference in a fixed narrow sector of the scope. However, if the AN/FPS-6 points at either the AN/CPN-18 or the ASR-3, then interference will occur in all sectors of their scopes. It is desirable, therefore, in addition to the use of a frequency plan, to restrict the azimuth pointing angle of the AN/FPS-6 antenna so that it does not point towards (perhaps within 10 degrees) of the AN/CPN-18 or the ASR-3 unless absolutely necessary.

3511. PRACTICAL EXAMPLE II: INTERFERENCE SUPPRESSION OF GROUND-BASED COMMUNICATIONS EQUIPMENT.

.1 The Hypothetical Problem.—The C-E officer of the ADC Base at Shoresville has received the following information:

a. Reports from ADC Base personnel of intermittent interference to five of the ground-based receivers of the UHF air-to-ground voice communications system.

b. Reports of interference of the AN/TRC-24 radio relay link between the ADC Base and the ACW Station.

c. Reports that the ground-based Shoran transmitter at the ADC Base sometimes becomes inoperative due to over-interrogation.

.2 Initial Investigation.—The first steps are: to determine the specific equipments experiencing the interference, and to obtain a description of the interference. In order to facilitate identifying the sources, information of the types outlined in CED 3510. will be required. The information can be obtained from reports written by the operators or maintenance personnel, from discussions with these personnel or from actual observation of the affected equipments when the interference is occurring. The assumed results of this investigation are summarized in Figure 34-147.

.3 Analysis of Problem.—Since all of the affected equipments operate in the VHF or UHF bands, it is probable (but not certain) that the interference sources operate in the VHF or UHF bands. Therefore, the next step is the compilation of a list of the transmitters operating in these frequency bands both *at* and *in the vicinity of* the ADC Base. Some judgment must be exercised in deciding on the geographical area within which interfering

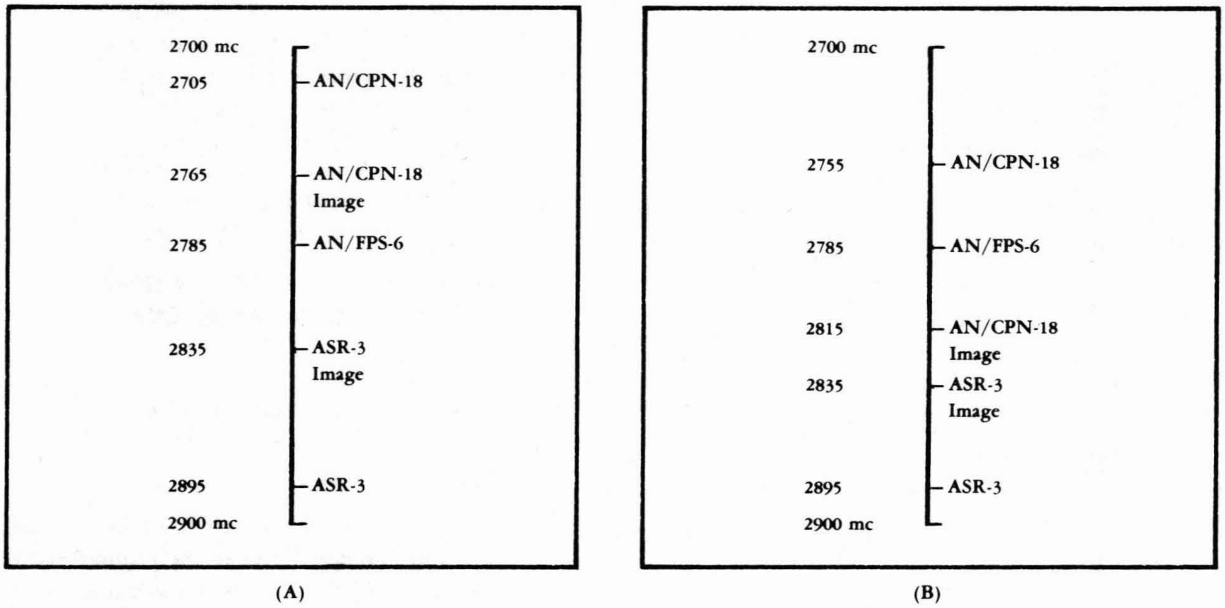


Figure 35-146.—*Proposed Frequency Assignments.*

Equipment Receiving Interference	User of Equipment	Operating Frequency (mc)	Description of Interference Received
R-361/GR	AACS	236.6	Occasional loud buzzing noise.
R-361/GR	AACS	289.4	Crosstalk from channels at 297.6 mc and 305.8 mc.
R-361/GR	AACS	305.8	Crosstalk from channels at 289.4 mc and 297.6 mc.
R-361/GR	AACS	342.8	Crosstalk from channel at 345.8 mc.
R-361/GR	AACS	345.8	Crosstalk from channel at 342.8 mc.
R-361/GR	AACS	363.8	Continuous high noise level during daytime and evening; absent at night.
R-417/TRC-24	Radio Relay Squadron	333.5	Occasional disruption of service.
IP-68/CPN-2A	SHORAN Beacon Flight	230.0	Beacon is sometimes over-interrogated, causing disabling of transmitter.

Figure 35-147.—*Results of Initial Interference Investigation.*

transmitters may be located. No fixed rule can be given. However, as a guide, it is suggested that in the VHF and UHF band, transmitters be included within about 25 miles of the affected equipments. The equipments tabulated in Figure 35-148 and 35-149 will be assumed for the purpose of illustration.

a. Interference to Channel at 236.6 MC.—A buzzing or an audio tone in a communications receiver, such as is assumed to occur here, is sometimes caused by a nearby radar transmitter, and this possibility should be checked. It is assumed here, however, that the occurrence of the buzzing is independent of whether the radars are on or off. It is also assumed that a short test of turning on and off all the other VHF and UHF equipment on the ADC Base (Figure 35-148) shows that none of these equipments is the source of the interference.

(1) Examination of the frequencies listed in Figure 35-149 also indicates that no VHF or UHF equipment in the vicinity of the ADC Base is operating at or near the channel frequency of 236.6 mc and that second harmonics are 4 mc away from the channel. Hence, it is probable that some source not previously listed is causing the interference. One additional potential source of interference is electronic equipment aboard ocean-going ships passing

Frequency (mc)	Receiver	Transmitter	Emission	Function
230.0	IP-68/CPN-2A	....	..	Shoran
236.6	R-361/GR	T-282/GR	A3	Air to ground
253.4	R-361/GR	T-282/GR	A3	Air to ground
289.4	"	"	"	"
297.6	"	"	"	"
305.8	"	"	"	"
330.0	....	T-230/CPN-2A	P9	Shoran
333.5	R-417/TRC-24	....	F3	Radio Relay
336.5	....	AN/TRC-24	"	"
342.8	R-361/GR	T-282/GR	A3	Air to ground
345.8	"	"	"	"
363.8	"	"	"	"
369.5	....		"	"
369.5	....		"	"
2775	AN/CPN-18	AN/CPN-18	P9	GCA Radar
9080	AN/FPN-16	AN/FPN-16	P9	GCA Radar

Figure 35-148.—*VHF and UHF Equipments at the ADC Base.*

near Shoresville. Still another possibility is that of electronic equipment aboard aircraft operating in the area. The aircraft operating from the ADC Base do not utilize any additional VHF frequencies which could cause difficulty. However, strategic aircraft frequently fly over the area. They are assumed to utilize the Shoran navigation system (CED 3509.3d (2)(b)), in which the aircraft alternately interrogate two ground stations by means of trains of high-power pulses. One of the Shoran ground stations is located at the ADC Base and, as shown in Figure 35-148, it transmits at 330 mc. Although not shown in the figure, it is interrogated at a frequency of 230 mc. Since Shoran interrogation pulses are only 0.7 microseconds wide, they have a broad-lobed spectrum similar to a radar. At a frequency 6.6 mc above the nominal center frequency, the spectral density is approximately 25 db below the spectral density at the center frequency. It is this spectrum splatter from the airborne Shoran transmitter, operating at 230 mc, that is responsible for the interference to the air-to-ground channel operating at 236.6 mc.

(2) This problem is based upon an almost identical one which has arisen in practice.[1] In the actual case, interference to an AN/R-278/GR receiver was experienced from an airborne Shoran

Frequency (mc)	Transmitter	Function	Location	Using Agency
54-60	200 kw E.R.P.	TV	Downtown Shoresville	Channel 2
112.0		Flight Control	Shoresville Municipal Airport	FAA
115.8		"	"	"
116.3		"	"	"
147.2	1 kw	Amateur	Shoresville	Amateur
152.7	1 kw	Police	Shoresville	Police
180-186	200 kw E.R.P.	TV	Downtown Shoresville	Channel 8
333.5	AN/TRC-24	Radio Relay	ACW Station	ACW
1220-1350	AN/TPS-ID	Search	Radar Sites A, B, & C	ADA
1220-1350	AN/FSP-3	GCI Search	ACW Station	ACW
2700-2900	AN/FSP-6	Height-Finding	ACW Station	ACW
2700-2900	ASR-3	GCA	Shoresville Airport	FAA

Figure 35-149.—*VHF and UHF Equipments in Vicinity of the ADC Base.*

[1]See page 6 of AD-306 986, Reference: CED 3514.53.

transmitter up to about 25 miles away. Operating frequencies assumed in this problem are identical to those in the actual case.

(3) Until such time as spectrum splatter can be reduced by improved modulation techniques, the most feasible means for reducing interference of this type is to increase the frequency separation of the equipments. Therefore, a new frequency assignment should be requested. Any new frequency must, of course, be compatible with the other frequencies in use so as to avoid cross-modulation, intermodulation, harmonics, etc. A procedure for determining third-order intermodulation compatibility and a graph of cross-modulation characteristics for the R-361 have been determined.

b. Interference to Channels at 289.4 and 305.8 MC.—The fact that at least three channels appear to be interfering with one another suggests that the trouble may be due to intermodulation. The most important type in UHF communications systems is third-order intermodulation in which signals of frequencies A and B mix in a nonlinear element to produce frequencies of 2A-B and 2B-A. (Other third order products such at 2A+B and 2B+A fall outside the 225- to 400-mc communications band and therefore do not cause interference to other equipments in this band.) The three frequencies involved in the interference problem are 289.4 mc, 297.6 mc, and 305.8 mc. It should be noted that the difference between the first two frequencies is equal to the difference between the last two frequencies:

297.6 - 289.4 = 8.2 mc
305.8 - 297.6 = 8.2 mc

Equality of frequency differences between channels, as occurs here, is the condition which can lead to interference arising from third order intermodulation products of the form 2A-B. It is seen that:

2 x 297.6 mc - 289.4 mc = 305.8 mc
2 x 297.6 mc - 305.8 mc = 289.4 mc

Therefore third order intermodulation from these three frequencies can produce interfering signals at two of the three frequencies.

(1) The expected magnitudes of the interfering signals can be calculated if data are available regarding the intermodulation characteristics of the equipment involved. Although transmitter intermodulation and receiver intermodulation can both occur, it will be assumed here that the transmitter-to-transmitter separations are much less than the transmitter-to-receiver separations, and therefore, that transmitter intermodulation is predominant. A nomograph for calculating the magnitude of third-order transmitter intermodulation (or cross modulation) products is given in Figure 35-175. To calculate the magnitude of the signal products of interest, the following information will be assumed:

All transmitter-to-transmitter antenna spacings: 25 feet

All transmitter-to-receiver antenna spacings: 600 feet

All antenna gains: 6 db

All transmitter output powers: 100 watts = 50 dbm.

From the reference nomograph it can be found that the third-order intermodulation product (at the affected receiver) is 111 db below the transmitter output power, or 50 dbm - 111 db =-61 dbm. This signal is therefore 46 db above the receiver sensitivity of -107 dbm. It is not surprising then that interference is being encountered.

(2) To eliminate the interference, one of the three frequencies should be changed. The new frequency should be selected so as to be compatible with the other frequencies in use.

c. Crosstalk between Channels at 342.8 and 345.8 MC.—The channels at 342.8 mc and 345.8 mc are only 3 mc apart. Such a small spacing can result in both adjacent-channel interference and cross modulation. To eliminate this interference, separation should be increased to at least 15 mc. One of the two frequencies should therefore be replaced by an acceptable frequency alternate.

.d Interference to Channel at 363.8 MC.—The interference to the channel at 363.8 mc is encountered during the daytime and early evening and apparently does not depend upon the operation of any other equipment at the ADC Base. Hence, it appears that the interference is due to one or more of the equipments listed in Figure 35-149. Examination of the operating frequencies listed in that figure shows that the interference cannot be co-channel or adjacent-channel interference. Also, receiver intermodulation and transmitter intermodulation are both unlikely since the interference source is miles away from the affected receiver.

(1) Another possibility is that transmitter harmonics may be the interference source. Usually, second and third harmonics are the strongest, so they should be considered first. Second and third harmonics of the transmitter frequencies listed in Figure 35-149 are given in Figure 35-150. Examination of the frequencies in this figure reveals that the second harmonics of the transmitter operating at 180 to 186 mc overlaps the channel of interest. It is therefore possible that the second harmonic of this transmitter (TV channel 8) is the source of interference. To ascertain whether this is the source, the operation of the effected channel should be observed at the times when channel 8 goes on and off the air. If the interference appears when the TV channel goes on the air and disappears each time the channel leaves the air, then it can be concluded that this is the interference source. It is assumed here that the test results in verification that the TV station is causing the interference.

(2) Next, remedial action is required. One possibility would be to obtain a different frequency assignment for the air-to-ground communications channel so that it will no longer fall within a harmonic band of the TV transmitter, and this is the course of action which would ordinarily be taken. However, a different solution to the problem will be presented here to show that, although a change in operating frequency would be desirable, it may not be absolutely necessary. This solution will show the TV transmitter is radiating a much stronger second harmonic than legally permitted, and that correction of this condition will substantially reduce the interference being experienced by the communications channel.

Fundamental (mc)	2nd Harmonic (mc)	3rd Harmonic (mc)
54-60	108-114	162-168
112.0	224.0	336.0
115.8	231.6	347.4
116.3	232.6	348.9
147.2	294.4	441.6
152.7	305.4	458.1
180-186	360-366	540-546
333.5	667.0	1000.5

Figure 35-150.—*Major Harmonics of Transmitters Listed in Figure 35-149.*

(3) The nominal output power of the channel-8 TV transmitter is assumed to be 200 kw, or 83 dbm. The legal maximum amount of second harmonic energy permitted to be radiated by this transmitter is 60 db below the power in the fundamental, *i.e.,* 23 dbm. Assuming a zero-db gain both for the TV transmitting antenna at the second harmonic and for the air-to-ground receiving antenna and a transmission loss of 110 db (the free-space basic transmission loss over a 12-mile path at 364 mc) indicates that the maximum permissible second-harmonic power received at the receiver on the ADC Base is about -87 dbm. If this energy is spread over a band about 6-mc wide and if the receiver has a pass band only about 0.1-mc wide, only about 1/60th of the receiver energy will enter the receiver. Therefore, an additional attenuation of about 18 db must be added. The received power should then be about -105 dbm, which is 2db above the receiver's sensitivity of -107 dbm. Therefore, if the TV transmitter is radiating the legal maximum amount of second-harmonic power, the interference signal will be just slightly greater than the receiver's sensitivity.

(4) The presence of a strong interference signal, as assumed in our problem, suggests that the TV transmitter may be radiating more than its legal maximum second-harmonic power. It is appropriate to contact the local FCC district office and request verification that the TV station is not exceeding its legal maximum harmonic output. It is assumed here that it is found that the TV station's second harmonic is only 40 db below its fundamental, accounting for the high interference level encountered. It is then the responsibility of the FCC to enforce the regulation limiting the maximum permissible harmonic radiation.

(5) As indicated previously, even if the legal maximum of second-harmonic radiation is not exceeded, the interference signal at the ground-based receiver will still be slightly above receiver sensitivity. In addition, the airborne receivers operating at this frequency will be subject to the same interference but, perhaps, of even a higher level, because the aircraft sometimes operate closer to the TV station than the 12-mile separation between the ADC Base and the TV station. Therefore, obtaining a different operating frequency for the air-to-ground channel still appears desirable.

e. Interference to AN/R-417/TRC-24 Radio Relay.—The AN/TRC-24 receiver, operating at 333.5 mc, is experiencing interference (Figure 35-151) in receiving signals from theACW Station. Due to the proximity of the Shoran transmitter operating on 330 mc, the Shoran transmitter should initially be suspected as the interference source. Verification can be accomplished by observing the AN/TRC-24 operation when the Shoran transmitter is operating.

(1) The situation may possibly be improved by interchanging the radio relay transmitter and receiver frequencies at the ADC Base and the ACW Station. (See Figure 35-152.) Then the radio-relay receiver at the ADC Base will operate at 336.5 mc, or 6.5 mc away from the nearby Shoran transmitter. With its antenna providing some discrimination against the Shoran signal, the radio-relay receiver might now be free of the interference. However, if it is, a check should now be made to be sure that the radio-relay receiver at the ACW Station, now operating at 333.5 mc, is not receiving interference from the Shoran transmitter. It is fairly remote from the Shoran transmitter, but its antenna is directed at the ADC Base, and hence, it cannot discriminate against the signal of the Shoran transmitter.

(2) If interference is still present in the radio-relay system, appropriate frequencies—more widely separated from that of the Shoran transmitter—are required.

f. Interference to AN/IP-68/CPN-2A Shoran.—Since the Shoran receiver at the ADC Base is operating in the lower part of the UHF band, it is appropriate to first suspect that a UHF transmitter at the ADC Base may be causing the interference (over-interrogation). It is therefore desirable to perform a brief test with the numerous UHF ground-to-air transmitters and the Shoran receiver in an attempt to determine the interference source. Since the UHF ground-to-air transmitters are voice modulated, the test can be conveniently performed by monitoring the video output of the Shoran receiver with a set of headphones while a test count is made on the various UHF channels, one at a time. It is assumed here that the test count is heard from the transmitter operating at 236.6 mc, but that no other channels are heard in the Shoran receiver output. It may then tentatively be concluded that that channel is the interference source and arrangements should be made for obtaining a different frequency for that transmitter. The new frequency should be checked for compatibility with the others in use in the area.

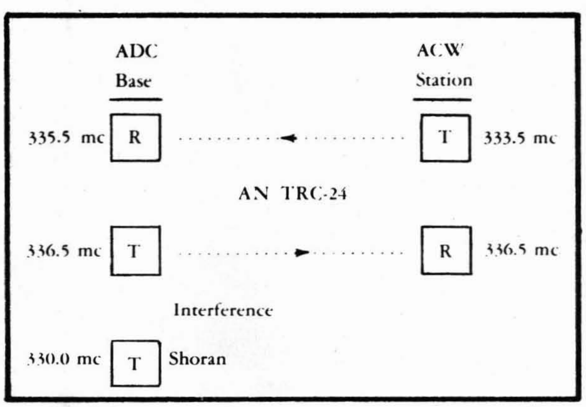


Figure 35-151.—*Original Radio-Relay Installation with Interference.*

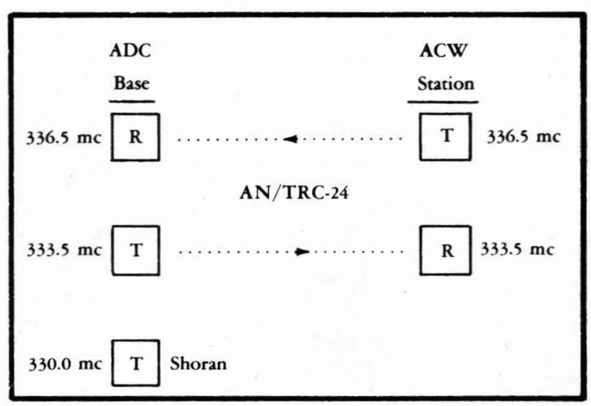


Figure 35-152.—*Rearrangement of Installation to Decrease Interference.*

(1) The performance of the Shoran equipment should subsequently be observed to determine if any interference is still encountered. It is assumed here that no further interference is experienced and that the cause of the original interference was the 236.6 mc channel as suspected. The large bandwidth (7 mc) of the Shoran receiver, along with therelatively close spacing of frequencies (6.6 mc) was the cause of the interference.

.4 Summary.—The previous paragraphs have discussed the following types of communications interference problems:

a. Adjacent-channel interference due primarily to a broad-spectrum transmitter.

b. Third-order transmitter intermodulation.

c. Receiver cross modulation.

d. Second-harmonic interference.

e. Adjacent-channel interference due primarily to a broad-spectrum transmitter.

f. Adjacent-channel interference due primarily to broad receiver selectivity.

It is unlikely that so many interference problems would be encountered at any single installation where care is exercised in the placement of equipments and in the selection of their operating frequencies. Nevertheless the problems are typical of those which may be encountered.

3512. TEST PROCEDURES.—In some instances, specialized tests are required in order to obtain data upon which to base an interference prediction. Other more general tests, while not absolutely unique to electromagnetic interference, are particularly important in this area. Tests of both kinds are included in this chapter for reference use. The chapter is organized into four major categories: (1) excerpts from FCC Rules and Regulations, Part 18, governing industrial, scientific, and medical equipment, (2) tests on radio communications transmitters, (3) tests on AM radio communications receivers concerning both interference susceptibility and interference generation, and (4) corresponding tests on FM receivers. Test procedures for radar equipment are presently being developed and will be included in a later revision of this manual.

.1 Excerpts from FCC Rules and Regulations, Part 18.

a. Arc-Welding and Industrial-Heating Equipment.

(1) "Broad band type of emission from arc welding equipment shall be measured by an instrument having performance characteristics similar to the "Proposed American Standards Specification for a Radio Noise Meter 0.15 to 25 Megacycles/second...." "Quasi Peak values of field strength shall be measured "and" on frequencies below 5775 mc, except industrial, scientific and medical (ISM) frequencies (see Figure 35-153), shall be suppressed so that the radiated field strength does not exceed 10 uv/m at a distance of one mile or more from the equipment." Measurements must also be made near power lines so that the "radiation of energy from power lines on frequencies other that ISM frequencies does not have a field strength in excess of 10 uv/m at a distance of one mile or more" from the equipment and a distance of 50 ft. from the power line.

(2) "Radiation of radio frequencies energy from any arc welding equipment on any frequency above 5775 mc except ISM frequencies, shall be reduced to the greatest extent practicable."

ISM FREQUENCY	FREQUENCY TOLERANCE
13,560 kc	± 6.78 kc
27,120 kc	± 160.00 kc
40,680 kc	± 20.00 kc
915 mc	± 25 mc
2,450 mc	± 50 mc
5,850	± 75 mc
18,000 mc	± 150 mc

Figure 35-153.—*List of Industrial, Scientific, and Medical (ISM) Frequencies.*

(3) Arc welding equipment "may be operated on any frequency except frequencies in the bands 490-510 kc, 2170-2194 kc, and 8354-8374 kc."

(4) "Equipment operating on an ISM frequency may be operated with unlimited radiation on that frequency. Equipment operated on other frequencies must suppress radiation on the fundamental carrier frequency as well as other frequencies required by this part."

b. Medical Diathermy Equipment.

(1) The equipment may be operated on an ISM frequency "without regard to the type or power emissions being radiated." Spurious and harmonic radiations on frequencies other than those specified shall be suppressed so that such radiations do not exceed a strength of 25 uv/m at a distance of 1,000 feet or more from the medical diathermy equipment causing such radiations.

(2) "A station license is not required for operation of medical diathermy equipment in frequencies other than "ISM frequencies if the equipment has "a rectified and filtered plate power supply, power line filters and sufficient shielding so that the emission of radio frequency energy generated by such operation, including spurious and harmonic emissions, shall not exceed a strength of 15 uv/m at a distance of 1,000 feet or more from the equipment."

.2 Tests on Transmitters.—In the process of interference prediction, certain interference transmitter characteristics are required. It is the purpose of this section to delineate some presently used methods of measurement (CED 3514.13 and .50). Not included is the power-line conducted interference test which should follow the procedures outlined in the current radio-interference specifications MIL-I-26600 (USAF) and MIL-I-6181D.

a. General Considerations.—The following conditions obtained during the transmitter tests:

(1) The dummy antenna is a 50-ohm resistive load for operating frequencies above 20 mc, and either a 50-ohm or 300 ohm resistive load for frequencies of 20 mc and below.

(2) The line stabilization network is the IRE standard network.

(3) A signal sampling device is used, where needed, to measure the output level of each frequency emitted. This device may be a voltage divider, power attenuator, directional coupler, or a suitable band-rejection filter, or combination thereof.

(4) The modulation test frequency is 1000 eq. cps, if not specified otherwise.

(5) Pulsed transmitters (including radars) are modulated at the various PRF's and pulse widths supplied by the modulator in normal use. In each test, the PRF and pulse width are recorded.

(6) The output of AM eq. and FM transmitters is A_0 of F_0 for the output power and spurious emission tests.

(7) The standard test modulation is 30 percent, 60 percent and 90 percent of rated deviation for sideband splatter tests.

(8) The standard interfering power levels are 20, 40, and 60 db eq. below the rated output power of the transmitter at the antenna terminals.

(9) The standard test frequencies are three points on each band, e.g., low, mid, and high.

(10) Sideband splatter is defined as those portions of the modulation sidebands that fall outside the assigned channel. Overmodulation, excessive modulator bandwidth, and or modulator nonlinearities are possible causes.

(11) The tuning procedure for the transmitter under test is the same as that specified in its technical manual. If not specified, the procedure will be:

(a) With coupling adjusted for a minimum, tune the plate circuit for minimum current.

(b) Increase the coupling.

(c) Retune the plate circuit for minimum current.

(d) Repeat this procedure until the recommended plate current is obtained. (In some cases, this procedure will not result in maximum possible output power.)

b. Special Equipment.

(1) Couplers.—A device for coupling large amounts of power from one coaxial system to another, with a specified insertion loss, is necessary for some transmitter tests. An example of this requirement is the transmitter intermodulation test. In this test, it is necessary to vary the coupling in several steps to determine the variations of intermodulation characteristics with respect to the interfering signal level. For this purpose, the coupling unit shown in Figure 35-154 should be constructed. The outputs from two transmitters are coupled through this unit to their respective loads, and a small amount of power from one transmitter output is coupled into the other. The coupling element is a small capacitor mounted in a General Radio type 874-X insertion unit.

(a) Technical Considerations. — The amount of power coupled into one coaxial system from another coaxial system by means of the coupler is a function of: the value of capacitance in the insertion unit, the load impedance of the first coaxial system; and the load and source impedance of the second coaxial system. The capacitance values shown in Figure 37-155 should be approximately correct, provided the transmitter output and load impedances are approximately 50 ohms. If these impedance values are not 50 ohms, it is necessary to adjust the value of capacitance in the coupler to obtain the desired coupling. These couplers may be used over a frequency range from 150 kc to approximately 300 mc. Above 300 mc, the shunting effect of the coupler introduces standing waves on the transmitter transmission line.

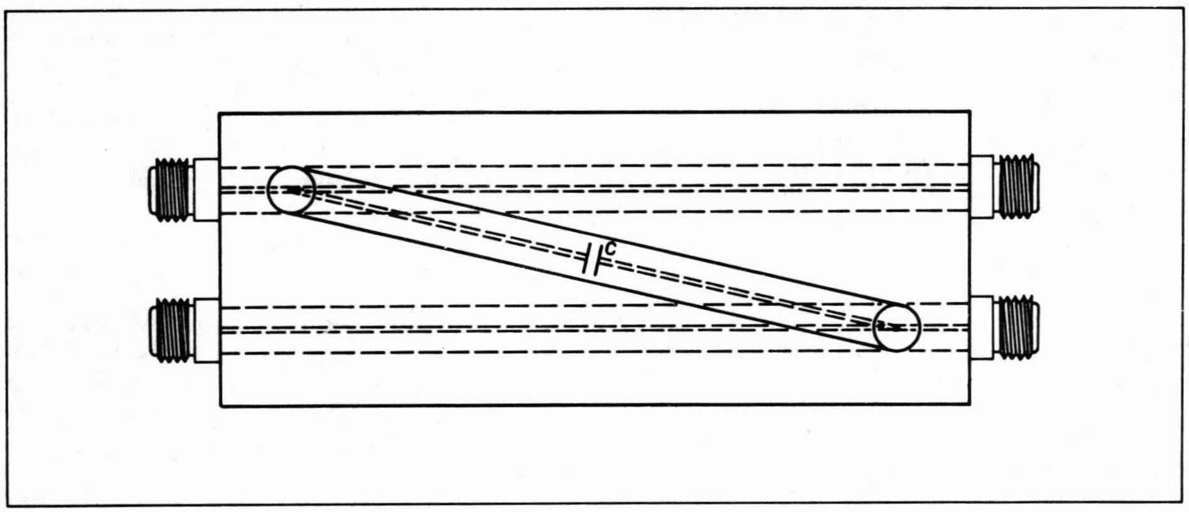


Figure 35-154.—*Coupling Unit.*

Frequency (mc)	−20db Coupling Capacitance (μμf)	−40db Coupling Capacitance (μμf)	−60db Coupling Capacitance (μμf)
10	30.0	5.0	1.00
62	6.6	1.0	0.50
162	3.0	0.5	0.05

Figure 35-155.—*Approximate Coupler Capacitance for Specified Coupling Values.*

(b) Relative Attenuation.—The absolute value of attenuation introduced by the coupler is not important. The important quantity is the db difference between the desired and interfering carrier levels at the attenuator which is used to sample the output of the transmitter under test. For example, if intermodulation effects are desired for an interfering signal 20 db below the desired carrier, a coupling unit is selected which will result in a difference of 20 db between the interfering signal level and the desired signal level.

(c) Insertion Loss.—With the attenuator adjusted to provide the desired level of signal to the measuring equipment, connect a signal generator tuned to the frequency of interest to the input of the attenuator. With the attenuator terminated in a 50-ohm load and the output connected to a RI/FI (Radio-Interference and Field-Intensity Meter) tuned to the signal generator frequency, adjust the signal generator output attenuator to obtain a useable indication on the RI/FI meter. Record this reading and the signal generator output attenuator reading in dbm. Remove the attenuator being calibrated and connect the signal generator directly to the RI/FI meter. Adjust the signal generator attenuator to obtain the same RI/FI meter reading obtained previously. Record the signal generator output attenuator reading in dbm. The difference between the two-signal generator attenuator readings is the attenuation of the attenuator, in db, at the signal generator frequency. An attenuator calibration curve for this particular attenuator setting may be obtained by plotting this point on semilog graph paper with log-frequency abscissa and attenuation-db ordinate, and by construction of a straight line with a 20-db-per-decade slope through this point. A second measured point may be desirable as a check on the accuracy of the first. The attenuator should be recalibrated when the scale setting is changed and/or when the setup is appreciably changed.

(2) Radio-Interference and Field-Intensity Meters.—Radio-interference and field-intensity (RI/FI) meters are used in a large number of the transmitter tests. They are used primarily as two-terminal voltmeters to measure CW and noise spectra. Noise spectra may be converted to db eq. above 1 uv/mc as follows: Divide the corrected microvolt reading by the bandwidth of the instrument and convert to db above 1 uv/mc by use of Figure 35-190. Since the RI/FI meter is basically a calibrated receiver, it is subject to overload, spurious responses and intermodulation in the same manner (although not necessarily the same extent) as any other receiver. The discussion in CED 3512,2b(2)(b) will serve as a guide in identifying these responses. This discussion is in terms of the NF-105 but also applies to any similar instrument. Figure 35-85 lists commercial and military RI equipment eq. specifications.

(a) Use in Interference Tests.—The NF-105 is used extensively in the interference tests both as a two-terminal r-f rms voltmeter and as a r-f peak voltmeter. In the power output test, spurious and harmonic emissions test, and intermodulation test, the NF-105 is used as a two-terminal r-f rms voltmeter with the signal generator substitution method used to obtain the final power readings. The substitution method is used in lieu of internal calibration in the above tests because the 1- to 2-db error inherent in the meter dial calibration may be significant in these data. The NF-105 is used in conjunction with its internal calibration as a peak-reading voltmeter in the transmitter and receiver power-line conducted-interference tests. The peak readings thus obtained allow the CW-conducted data to be converted to dbm, and the broadband and-conducted data to be converted to db eq. above one microvolt per mc.

(b) Procedure for Identifying Spurious Responses.—There is a possibility that the high level carrier at the input of the NF-105 may cause an output indication at one or more of the spurious response frequencies of the NF-105 which may be mistakenly identified as a spurious output from the transmitter under test. Hence, it is necessary to identify the spurious response frequencies of the NF-105 at the particular carrier frequency of interest. One method of accomplishing this identification is to apply the output of a signal generator, which has been adjusted to the carrier frequency and level, through a low-pass filter to the input of the NF-105. With the input attenuator of the NF-105 set to the 0 db position, the NF-105 is tuned through the range from 150 kc to 1000 mc and the frequencies and magnitudes of all of the spurious responses are eq. recorder. If any of the output indications obtained with a transmitter connected to the NF-105 exactly agrees with respect to frequency and amplitude with a spurious response, this output may be rejected.

(c) Procedure for Identifying Intermodulation.—When two or more relatively high signals are within the r-f bandwidth and are simultaneously present at the input of the NF-105, it is possible that troublesome intermodulation products may be generated within the instrument. This problem is particularly important in the transmitter intermodulation test where a desired signal and an interfering signal of relatively high level are present at the input of the NF-105 and a measure of the intermodulation within a transmitter is being attempted. In this case, and in other cases where conditions are conducive to internal intermodulation, it is necessary to establish whether or not intermodulation is taking place within the instrument. One method is to apply the outputs of two signal generators, which have been adjusted to the frequencies and levels of the two highest-level signals to be encountered, to the input of the NF-105. With the input attenuator in the 0-db position, tune the NF-105 to the first two or three intermodulation-product frequencies. If no output indications are obtained, the intermodulation within the instrument is not significant. If one or more output indications are obtained, an isolation network should be inserted between the signal generators to establish that the intermodulation is not taking place in the signal generators. If output indications at the intermodulation frequencies are obtained with the isolation network inserted, then the dynamic range of input signals must be decreased until the NF-105 intermodulation products disappear.

c. Output Power.—The output power of a transmitter is a good indication of the overall condition of the transmitter. Also, the amplitudes of the interference emanating from the transmitter are related to the output power; thus, it is important to know the output power of the transmitter over its entire operating range. Since it may vary considerably over an operating range, and may also vary from band to band in multiband transmitters, the output power should be measured at several tuned frequencies spaced throughout the operating range.

(1) Required Equipment.—The following equipment is required:

(a) Resistive dummy load capable of dissipating the maximum output power of the transmitter.

(b) Mutual-inductance (waveguide-below-cutoff) attenuator, or capacitive-type attenuator, and a 50-ohm attenuator.

(c) Short connecting cables.

(d) Signal generator with calibrated output.

(e) RI/FI meter.

(f) Shielded enclosure.

(g) Signal sampling network.

(2) Test Setup. — For the test setup, see block diagram, Figure 35-156. The band rejection network is not required in the output power test.

(3) Test Procedure.

(a) With the coaxial switch in position one, tune the transmitter under test to a standard test frequency, in accordance with the tuning procedure outlined in the transmitter technical manual.

(b) Tune the RI/FI meter to the transmitter carrier frequency. Adjust the attenuator and/or the RI/FI i-f gain to give a mid-scale reading.

(c) Calibrate the attenuator in accordance with CED 35 12.2b(1)(c).

(d) Set the coaxial switch to position two.

(e) The output of a signal generator is tuned to the transmitter carrier frequency. Adjust the output attenuator of the signal generator until the same mid-scale reading is obtained. Record the signal generator output in dbm required to give this mid-scale reading. Add the attenuator in db of the attenuator to the signal generator output in dbm to obtain the transmitter output power in dbm.

(f) Repeat the above steps, with the exception of (c) for all additional test frequencies necessary to adequately cover the tuning range of the transmitter under test.

(4) Presentation of Test Data. — These data should be presented in tabular form as shown

below. In the frequency column also note tuning-band information; in the output column, show whether the output is peak, quasi-peak or average.

Frequency (mc)	Output (dbm)

d. Spurious and Harmonic Emissions.— The purpose of this test is to scan the spectrum from 0.15 to 1000 mc/sec so as to evaluate any spurious and harmonic outputs of the transmitter under test. This test is performed with the transmitter terminated in a resistive load which has an impedance equal to the rated transmitter output impedance. Although communications-type transmitters are not used with the same antenna at all times, the test provides a basis for the comparison of different transmitter types. When performing this test, precautions must be taken to avoid recording spurious responses of the RI/FI meter rather than the transmitter outputs.

(1) Required Equipment. — Same as output-power test CED 3512.2c(1), except that the band rejection network is required.

(2) Test Setup. — Same as output-power test, CED 3512.2c(2), including the band rejection network.

(3) Test Procedure.

(a) Same as test procedure, CED 3512.2c(3)(a) through (c), output-power test.

(b) With the coaxial switch set to position one, slowly tune the RI/FI meter through the range from 150 kc to 1000 mc with the RI/FI meter input attenuator set to minimum (0-db position).

(c) Each time an output is found, adjust the RI/FI meter input attenuator to obtain an on-scale reading of the meter. Adjust the tuning to obtain a maximum reading and record this frequency reading.

(d) Set the coaxial switch to position two. Adjust the frequency control and output attenuator of the signal generator to duplicate the reading obtained with the transmitter. Record the signal generator output in dbm.

(e) The output power at the transmitter output terminals in dbm is obtained by adding the attenuator in db of the attenuator at the measured frequency (obtained from the attenuator calibration curve) to the signal generator output attenuator dial reading in dbm.

(f) CED 3512.2d(3)(a) through (e) are repeated for each output found in the range from 150 kc to 1000 mc.

(g) In the case of a multiband transmitter, CED 3512.2d(3)(a) through (f) are repeated for at least one standard test frequency on each band.

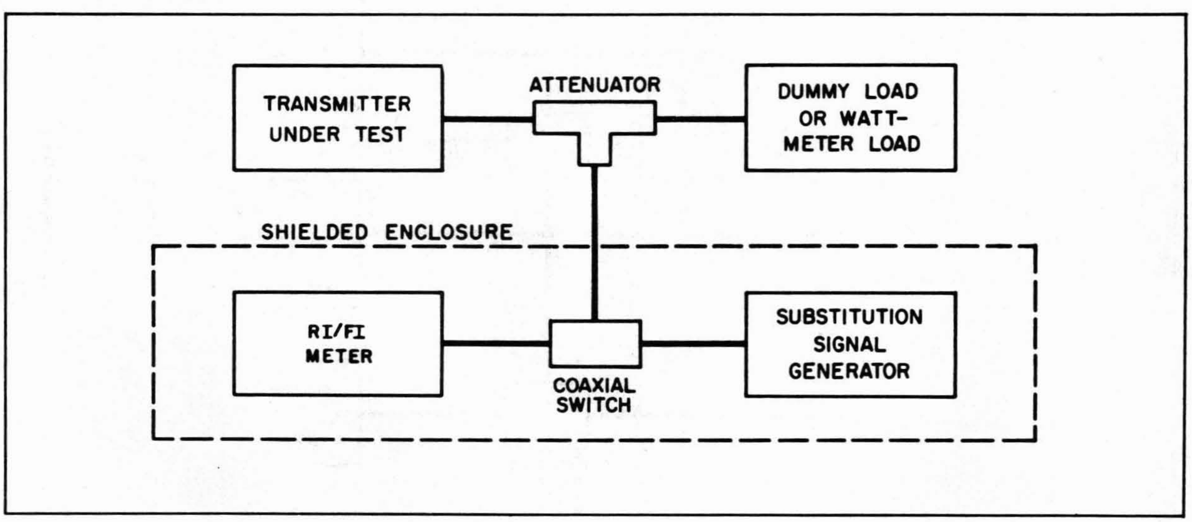


Figure 35-156.—*Block Diagram of Output-Power Test Setup for Transmitters.*

(4) *Presentation of Test Data.*—These data are to be presented in the following tabular form. The heading of each table should consist of five columns.

Transmitter		Spurious Frequency		
Fundamental mc	Tuning-Band No.	Frequency mc	Origin	Power Output dbm

Under Origin show the source of the spurious frequency, if known, *e.g.*, 3rd harmonic of fundamental. In the power-output column, show whether the output is peak or average; in the frequency column also note tuning-band information.

e. Cross Modulation.—This test evaluates the cross-modulation-generating properties of the output stage of a transmitter. The level of cross-modulation products obtained when an external signal is coupled into a transmitter output circuit depends on the selectivity of the coupling circuit, the level of the interfering signal, and the nonlinearity of the output stage. Spurious frequencies will then be generated in accordance with the equation;

$$f_s = nf_o \pm mf_i \qquad (47)$$

where f_s= spurious frequency generated; f_o= frequency of transmitter under test; f_i= frequency of interfering signal; and m, n = 0, 1, 2, 3,, ... The spurious frequencies generated, which are relatively near the fundamental frequency of the transmitter, will be radiated at much higher levels due to the selectivity of the output circuit. For example, if transmitter No. 11 receives a signal from transmitter No. 2, and $f_2 = f_1 + f$, the spectrum of frequencies generated will include $f_1 \pm f$, $f \pm 2f$, $f_1 \pm 3f$, ..., $f_1 \pm nf$. In order to be radiated, these frequencies must be passed by the output circuit of the transmitter. Therefore, the measurable output spectrum will be terminated at $f_1 \pm nf$ where n may be as large as 13 for low-Q output circuits, high amplitude interfering signals, and small Δf's.

(1) *Required Equipment.*

(a) Same as output-power test, CED 3512.2c(1).

(b) Additional transmitter with resistive load for interfering signal source.

(c) Coupling attenuator, CED 3512.2b (1).

(2) *Test Setup.*—For test setup, see block diagram, Figure 35-157.

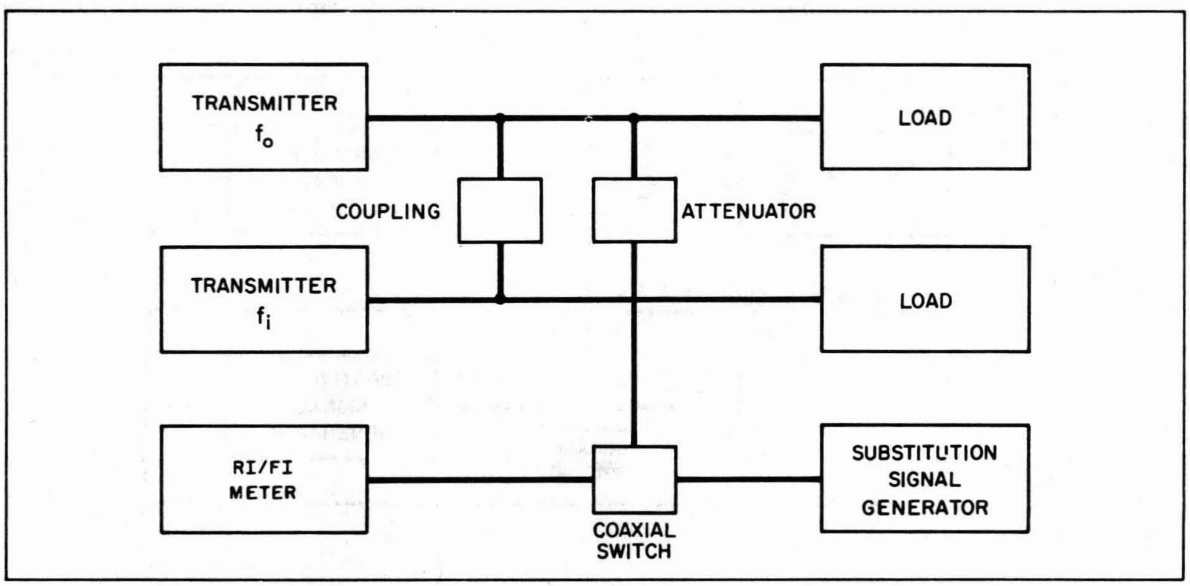


Figure 35-157.—*Block Diagram of Cross-Modulation Test Setup for Transmitter.*

(3) Test Procedure.

(a) Same as CED 3512-2c(3)(a) through (e), power output test, with the transmitter at f_o.

(b) Tune the interfering transmitter to a frequency f_i, approximately one percent higher than f_o.

(c) Tune the RI/FI meter to f_i.

(d) Switch the input of the RI/FI meter from the transmitter to the signal generator output.

(e) Adjust the signal generator frequency and output level to duplicate the reading obtained with the transmitter. Record the generator frequency and output in dbm.

(f) Add the attenuation in db of the attenuator to the signal generator output reading in dbm to obtain the power output at f_i.

(g) Insert an attenuator in the coupling unit so that the ratio of the power coupled from the output at f_i to the output at f_o is approximately 20 db.

(h) Tune the RI/FI meter in steps of Δf above f_i and in steps of f below f_o and repeat steps (e) and (f) above each time an output is found.

(i) Repeat steps (g) and (h) above for a power level at f_i 40 db below that of f_o.

(j) Repeat steps (g) and (h) above for a power level at f_i 60 db below that of f_o.

(k) Repeat steps (b) through (j) above for $f = 10$ percent of f_o.

(l) Repeat steps (b) through (j) above for $f = 10$ percent of f_o.

(4) Presentation of Test Data.—These data will be presented in the following form:

Frequency (mc)	*Output (dbm)*	*Frequency Identification*	*Coupling (db)*	*Spacing (mc)*

f. Sideband Splatter.—Sideband splatter is defined as those portions of the modulation sidebands that fall outside the assigned channel. Sideband splatter may be caused by excessive modulator bandwidth and/or nonlinearities in the modulator stages. The test described here consists of the well-known two-tone test, and a dynamic noise-loaded test. This test shall be performed on AM, FM, and suppressed-carrier transmitters only.

(1) Required Equipment.

(a) Dummy load.

(b) Attenuator.

(c) Spectrum analyzer.

(d) Modulation or deviation monitor.

(e) Shielded enclosure.

(f) Two audio-signal generators.

(g) Band-limited random-noise generator.

(h) Short connecting cables.

(i) Camera or recorder.

(j) Signal sampling network.

(2) Test Setup.—For the test setup, see block diagram, Figure 35-158.

(3) Test Procedure.

(a) Tune the transmitter under test to a standard test frequency.

(b) Adjust or select one attenuator to provide the proper voltage to operate the spectrum analyzer.

(b) Adjust the spectrum analyzer to position the carrier in mid-position on a 10-kc/sec sweep presentation.

(d) Adjust or select one attenuator to provide the proper voltage to operate the modulation or deviation monitor.

(e) Tune one audio signal generator to 1 kc/sec and the other signal to 2 kc/sec and connect the output to the transmitter modulator input.

(f) Maintain the output levels of the audio generators equal and adjust the levels to obtain 30-percent modulation or deviation.

(g) Photograph the presentation obtained with a polaroid camera. Adjust the camera so that the exposure time will include two sweeps.

(h) Repeat step (g) above for 30-kc/sec sweep width.

(i) Repeat steps (c) through (h) above for 60-percent modulation or deviation.

(j) Repeat steps (c) through (h) above for 90-percent modulation or deviation.

(k) Disconnect the two audio-signal generators from the modulator input and connect the band-limited noise generator.

(l) Repeat step (c) above.

(m) Adjust the output of the noise generator to obtain 30-percent modulation or deviation.

(n) Photograph the presentation obtained. The exposure should include two sweeps.

(o) Repeat step (n) above for 30-kc/sec sweep width.

(p) Repeat steps (l) through (o) above for 60-percent modulation or deviation.

(q) Repeat steps (l) through (o) for 90-percent modulation or deviation.

(4) Presentation of Test Data.—The data to be presented include the photographs taken and graphs of the data obtained. With points obtained from the photographs, plot the two-tone and noise-side-band-splatter spectrums with the frequency in kc as the abscissa and the amplitude in dbm as the ordinate.

g. Case Radiation.—The object of the case radiation test is to determine the frequency, source and field strength of radiation from the transmitter case and from its associated cabling, such as power cables, remote control cables, etc. The test is a composite of two tests. The first test, called the field probing test, determines the frequency and source of the electromagnetic radiation from the case. The second test, called the field intensity test, determines the field intensity of the electromagnetic radiation from the case at a distance of one meter from the point of maximum radiation.

(1) Required Equipment.

(a) Electric and Magnetic Field Probing Test.

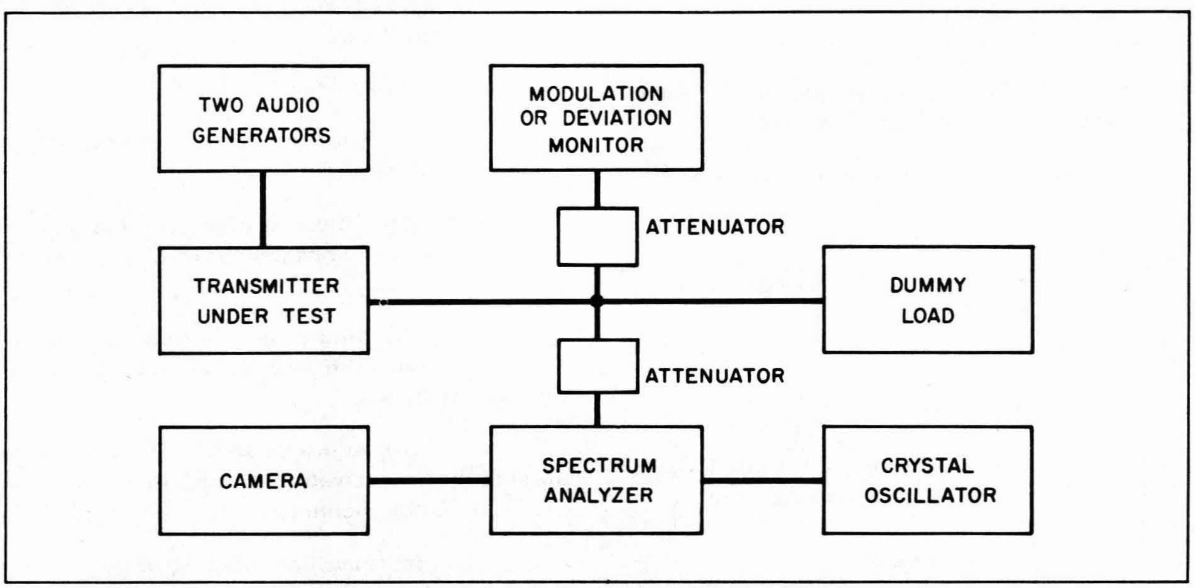


Figure 35-158.—*Block Diagram of Sideband Splatter Test Setup for Transmitter.*

[1] 3-inch loop probe.

[2] 6-foot coaxial cable.

[3] RI/FI meter.

[4] Transmitter dummy load.

[5] Signal generator.

(b) Field Intensity Test.

[1] Empire Devices LP-105 loop antenna or equivalent.

[2] Empire Devices DM-105 dipole antennas or equivalent.

[3] 20-foot coaxial cable.

[4] RI/FI meter.

[5] Transmitter dummy load.

[6] Signal generator.

(2) Test Setup.—For the magnetic field probing test and the field intensity test, set up the transmitter on a 6 by 8-foot ground plane.

(3) Test Procedure.

(a) Magnetic Field Probing Test.

[1] The source of radiation from a transmitter case can be any oscillator, doubler, multiplier stage, final amplifier or any parasitic or spurious oscillator. It has been found, however, that the case radiation is very similar to the spurious and harmonic radiation from the transmitter output. Thus, it is sometimes helpful to have the results of the spurious and harmonic test for several test frequencies when conducting this test.

[2] Adjust the transmitter for normal operation on one of the standard test frequencies as prescribed in its technical manual. Record the transmitter frequency and serial number.

[3] Place the 3-inch loop probe near, or on, the transmitter case, and tune the RI/FI meter until a signal is found. Record this frequency.

[4] Move the probe in the vicinity of the case until a point of maximum radiation is found for each detected frequency, as indicated on the field intensity meter. Substitute a signal from a signal generator tuned to the detected frequency and adjust the signal generator output to give the same reading on the RI/FI meter. Record the frequency and output in dbm of the signal generator and record the location of maximum signal area.

[5] Repeat steps [3] and [4] above until all radiation sources and frequencies have been located by tuning the RI/FI meter through the frequency range 150 kc to 1000mc.

(b) Field Intensity Test.

[1] Set up the transmitter as prescribed in CED 3512.2g(2) and adjust in accordance with CED 3512.2g(3)(a)[2]. Record the transmitter frequency and serial number.

[2] For frequencies less than 30 mc, connect the LP-105 twelve-inch loop antenna to the RI/FI meter through the special 20-foot coaxial cable provided. For frequencies above 30 mc, use the DM-105 dipole antennas.

[3] Place the antenna one meter from a point of ***maximum leakage*** determined from CED 3512.2g(3)(a).

[4] Tune the RI/FI meter through the frequency range of 150 kc to 1000 mc and note each detected transmitter emission.

[5] Adjust the antenna, if the dipole is used, to one-half wavelength at the emitted frequency each time an output is detected.

[6] Substitute a signal from the signal generator tuned to the detected frequency and adjust the signal generator output attenuator to give the same reading on the RI/FI meter. Record the frequency and output in dbm of the signal generator.

(4) Presentation of Test Data.

(a) Magnetic Field Probing Test.—The results of the magnetic field probing test should be tabulated in the following form.

Frequency (mc)	*Available Power (dbm)*	*Frequency Identification*

(b) Field Intensity Test.—The results of the field intensity test should be tabulated in the following manner after correction for the antenna factor.

Frequency (mc)	*Available Power (dbm)*	*Frequency Identification*

.3 Susceptibility Tests on AM Receivers.—This section describes tests for determining the interference susceptibility of AM communications receivers. The test results are required particularly for the interference prediction processes of CED 3508. Conventional sensitivity and selectivity tests should be performed according to Military Specification MIL-STD-449 and are not repeated here. All other tests should be performed as per the following instructions.

a. General Considerations.—The following conditions obtained during AM receiver tests:

(1) Signal generators used in these tests have effective internal impedances of 50 ohms. Any signal generators that have internal impedances different from 50 ohms are padded with the proper resistance values to produce an effective 50-ohm impedance.

(2) Signal levels are in dbm, *available power,* at the signal generator output.

(3) Modulation is 30 percent at 400 cps for the desired signal or the interference signal in single-signal generator tests.

(4) Modulation is 30 percent at 1000 cps for the desired signal in two-signal generator tests.

(5) An exception to (4) above, occurs in the intermodulation test, in which one interfering signal is modulated 30 percent at 400 cps and the other interfering signal is unmodulated.

(6) A 6 decibel (S+N)/N ratio is the standard audio output ratio, unless otherwise specified.

(7)The dummy antenna is the IRE standard for desirable characteristics tests (sensitivity, selectivity, AVC characteristics, electric fidelity).

(8) Dummy antennas are pure resistance for all other tests.

(9) The line stabilization network is the IRE standard network.

(10) Standard test frequencies are three points on each band, *i.e.,* low, mid and high.

(11) A receiver band is defined as the range over which the receiver may be tuned without any coils or capacitors in the internal circuit being changed. *Switching crystals in the local oscillator circuits is not considered a band change.*

(12) "Mean signal level" is taken as -39 dbm. (This is equivalent to 5000 microvolts, open-circuit voltage.)

(13) "Sensitivity audio output" is as defined in the technical manual of the receiver under test, usually under the heading of sensitivity in the final testing section. This audio-gain-control setting will be used for all tests unless otherwise specified.

(14) Standard interfering signal levels are −7, −13, and −33 dbm.

(15) Exact tuning procedures for the receiver under test are given below.

(a) If the receiver has a calibration oscillator and the BFO is known to be accurately calibrated, the receiver is tuned to a test frequency by zero-beating the BFO with the calibration oscillator. The calibration oscillator is then switched off, and the signal generator is tuned for a zero beat without a change in the BFO setting.

(b) With the signal generator output modulated 30 percent at 400 cps and set at a level just a few decibels above the threshold sensitivity of the receiver, the receiver antenna trimmer is adjusted for a maximum output indication.

(c) If the receiver has no calibration oscillator, the signal generator is first accurately tuned to the test frequency by means of a frequency meter, and the receiver is then tuned for a zero beat with the BFO on. In the absence of a BFO, the receiver is tuned for a maximum output (S+N)/N ratio.

b. IF, Image, and Spurious Responses.

(1) Background.—The i-f, image, and spurious responses of a receiver are one of the major

sources of interference. They are involved, directly or indirectly, in nearly every type of interference that has been observed in the laboratory.

(a) Frequency.—Almost all spurious responses are due to the first mixer and may be given by

$$f_{sr} = \left| \frac{p\, f_{lo_1} \pm f_{if_1}}{q} \right| \qquad (48)$$

where f_{sr} is the frequency of the spurious response, f_{lo} is the first local oscillator fundamental frequency, $f_{if\ 1}$ is the first intermediate frequency, and p and q are positive integers (zero included, in the case of p). The number of spurious response frequencies also depends on the operation of the local oscillator. On those bands where the oscillator runs at a subharmonic of the injected frequency, more spurious responses are likely to exist.

(b) Magnitude.—The magnitude of the i-f, image or spurious response is, in part, a function of the r-f amplifier filter circuits and, in part, due to the characteristics of the mixer. Usually large responses may be caused by poor tracking in the r-f amplifier tuned circuitry or by improper operation of the mixer. Other unusually large responses, especially at frequencies much higher than the receiver-tuned frequency, are due to leakage around the tuned circuits and to spurious resonances.

(c) Multiple Conversion Responses.—Multiple-conversion receivers may have spurious responses due to the second and third local oscillators, but they are not usually so large as those due to the first conversion and may often be neglected in interference studies. They are calculated by equation (48) with the proper local oscillator and i-f frequencies substituted.

(d) Test for IF, Image, and Spurious Responses.—Image, i-f, and spurious responses are ordinarily evaluated by a single-signal generator test in the following manner: With the receiver tuned to one of the standard test frequencies, the signal generator should be tuned over a wide range of frequencies to discover receiver output responses at frequencies other than the one to which it is tuned. These other frequencies, except for i-f and image, are called spurious responses. Each such response frequency is measured and the signal level is adjusted to give some prescribed output indication. The value of this signal may be compared to that value of desired signal at the tuned frequency which produces the same output indication. The ratio of these two levels, usually expressed in decibels, is called the i-f, image, or spurious-response rejection ratio. Care should be taken that the harmonic output of the signal generator is sufficiently attenuated that it will not affect the observation of receiver responses. In particular, low-pass filter should be used when spurious responses are being measured at frequencies well below the receiver tuned frequency in order to attenuate all generator harmonics to levels below the receiver's threshold sensitivity.

(2) Required Equipment.

(a) Shielded Test Area.

(b) RF signal generator with provision for amplitude modulation of 30 percent at 400 cps.

(c) 50-ohm resistor.

(d) Frequency meter.

(e) Resistive pad or attenuator.

(f) Distortion analyzer.

(g) Short connecting cables.

(3) Test Setup.—The test setup should be in a shielded room with the apparatus on a grounded metal (copper-clad) bench top (see block diagram, Figure 35-159). The receiver audio output should be terminated in its specified load impedance. The frequency meter is coupled to the signal generator by means of a resistive pad or attenuator. Care must be taken to insure that the frequency meter does not also couple into the receiver.

(4) Test Procedure.

(a) Set the receiver controls as follows:

AVC switch . . . . .On

RF gain . . . . Maximum

Audio gain . . . . For sensitivity-test output

Selectivity . . . . Maximum bandwidth

Limiter switch . . . . Off

BFO . . . . Off

(b) Set the receiver to the lowest frequency band.

(c) Tune the receiver and signal generator to a standard test frequency at the low end of this band.

(d) Set the generator modulation to 30 percent at 400 cps.

(e) Adjust the generator output so that the distortion analyzer shows a 6-decibel $(S + N)/N$ ratio. Record the generator output in dbm and the frequency.

(f) Increase the signal generator output level to full output.

(g) Tune the signal generator until a point is found at which the receiver responds. Adjust the generator output, P_i, to give a 6-decibel $(S + N)/N$ ratio as measured by the distortion analyzer.

(h) The above step is repeated to measure all responses in the range from 150 kc to 1000 mc.

(5) Presentation of Test Data.—The test data are presented in tabular form, as shown below.

Frequency (mc)	*Sign*	*p*	*q*	P_i *(dbm)*	*Spurious Response Rejection (db)*

The sign and p and q numbers are those which satisfy the spurious response equation. The spurious response rejection ratio is the difference, in decibels, between the interfering-signal level (P_i) and the sensitivity-test input (P_{do}).

c. Co-Channel Response.—The co-channel test evaluates the performance of a receiver with respect to interference at the same frequency as the desired signal. The information obtained in the test is the loss in effective sensitivity due to the interfering signal.

(1) Required Equipment.

(a) Shielded test location.

(b) Two r-f signal generators with provisions for amplitude modulation of 30 percent at 400 cps and 1000 cps.

(c) Resistive pads (dummy antennas).

(d) Distortion analyzer.

(e) Short connecting cables.

(2) Test Setup.—The setup should be in a shielded room with the apparatus on a grounded metal (copper-clad) bench top. See Figure 35-160 for connection of the equipment.

(3) Test Procedure.

(a) Set receiver controls to same position as in CED 3512.3b(4)(a).

(b) Tune the receiver to a standard test frequency.

(c) Separately tune both the desired and interfering signals to the receiver tuned frequency. Apply 30 percent, 400 cps modulation to the desired signal and 30 percent, 1000-cps modulation to the interfering signal.

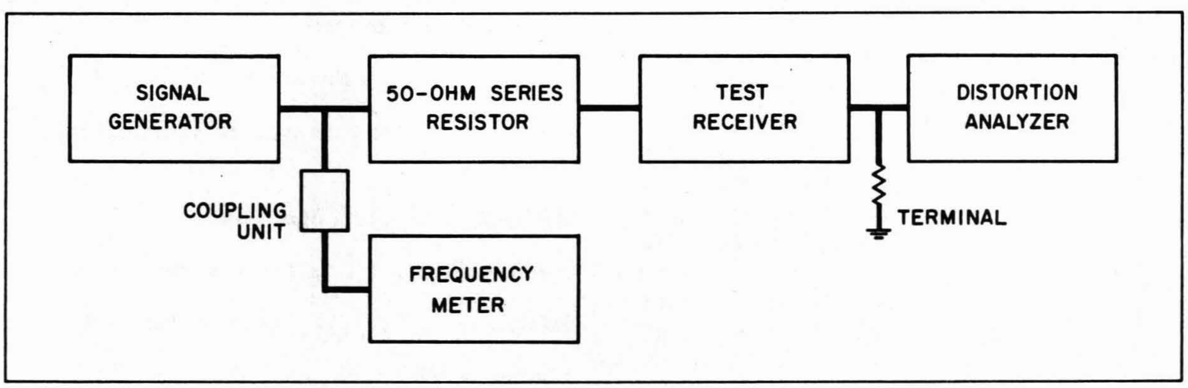


Figure 35-159.—*Block Diagram of Spurious Response Test Setup for AM Receivers.*

(d) Turn the interfering signal level as far down as possible and adjust the desired signal level to produce a 6-decibel (S + N)/N ratio in the receiver output. Record this level.

(e) Turn the desired signal level all the way down. Then adjust the level of the interfering signal, which has been temporarily modulated at 400 cycles, to produce a 6-decibel (S + N)/N ratio, and record this level as P_{do}. This is the sensitivity of the receiver using a 50-ohm series resistor.

(f) The difference between readings obtained in (d) and (e) above yields a factor that must be used to correct the desired signal level for the attenuation in the pad. For example, suppose the reading from (d) is —90 dbm and the reading from (e) is —109 dbm. The difference between these is 19 db. Therefore, 19 db must be *subtracted* from all subsequently measured desired signal levels to correct for the pad attenuation.

(g) Leave the interfering signal (P_i) at the level measured in (e) but change the modulation back to 1000 cps. Raise the desired signal (P_d) to a level at which it is audible above the interfering signal. Adjust the frequency of the interfering signal very slightly, if necessary, to produce the *worst obtainable interference.* Readjust the level of the desired signal to produce a 6-decibel (S + N)/N ratio. Record this level.

(h) Increase the interfering signal level in convenient steps of 10 or 20 db, and increase the desired signal each time to restore the 6-decibel (S + N)/N ratio. Record these levels. These steps should be continued until the maximum output of the desired signal generator has been approached.

(i) Now set the desired signal level to the "mean standard" value of —39 dbm, allowing for the correction factor obtained in (f). Vary the level of the interfering signal in steps of about 6 db from that value at which it just begins to cause interference to that value at which the (SN + N)/N ratio is degraded to about one or two db. Record interfering signal levels and (S + N)/N ratios for each step.

(4) Presentation of Test Data. — The test data are presented in graphical form. For the first test P_i is the abscissa and P_d i the ordinate. For the second test P_i is the abscissa and (S + N)/N ratio is the ordinate.

d. True Selectivity.

(1) Background. — The two-signal true selectivity test is a measure of the response of a receiver to weak and strong desired signals in the presence of weak and strong off-channel interfering signals. Interference to the desired signal is simultaneously due to one or more of the following causes: increase in noise, cross-modulation, spurious responses, and desensitization. Thus, this test is a measure of the ability of the receiver to perform its normal function despite these forms of interference caused by off-channel signals.

(a) Desensitization.—Desensitization is caused by the interfering-signal carrier and is most

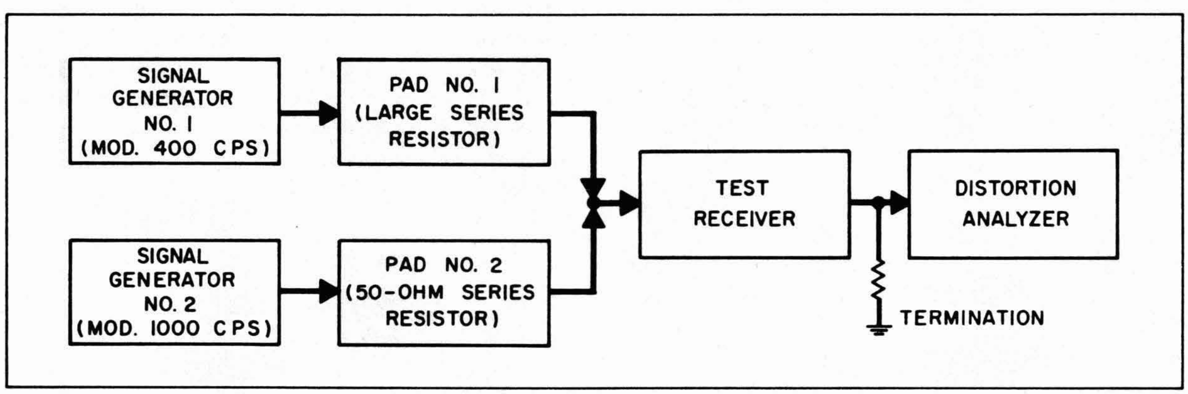


Figure 35-160.—*Block Diagram of Co-Channel Test Setup for AM Receivers.*

likely to occur when the desired and interfering signals are on adjacent channels. It may be due to the AVC or to overloading in the input stages.

(b) Cross Modulation.—Cross modulation is the type of interference in which the modulation of the interfering signal is heard in addition to that of the desired signal. It is caused by nonlinearities in the r-f and mixer stages in which the modulation of the interfering signal is imposed on the desired signal. This type of interference is observed primarily during periods when no modulation is applied to the desired signal. If the desired signal is modulated, this interference will introduce distortion, with the result that the intelligibility of the desired signal will be degraded.

(c) Image and Spurious Responses.—Image and spurious responses are observed mainly as a whistle or beat-note interference. This interference results from the fact that the interfering signal is converted to the intermediate frequency, where it beats with the desired signal.

(2) Required Equipment. — The required equipment is the same as for the Co-Channel Test, CED 3512.3c(1), except that a frequency meter is also needed.

(3) Test Setup. — The test setup is the same as for the co-channel test, CED 3512.3c(2), except that a frequency meter is loosely coupled to the interfering signal to monitor its frequency. If the frequency meter is sufficiently sensitive, the coupling may be accomplished with a loop of wire wrapped around the output jack of the interfering signal generator. Otherwise, a pad consisting of a high series resistance may be used to couple from the signal generator to the frequency meter.

(4) Test Procedure.

(a) The same as (a) through (f) of the test procedure for the co-channel test, CED 3512.3c(3).

(b) Set the interfering signal to one of the standard levels. This level will be held fixed for the remainder of the given test. Now detune this signal enough in frequency so that interference effects disappear.

(c) Tune the interfering signal back toward the tuned frequency. When one of the types of interference mentioned above becomes evident, increase the desired signal to restore a 6-decibel $(S + N)/N$ ratio. Record this level of desired signal, P_d. (Note: Whenever a spurious response is detected, it is important to adjust the interfering signal frequency to give the worst possible interference, as in (g) of the test procedure for the co-channel test.)

(d) Continue tuning the interfering signal toward the receiver tuned frequency, measuring enough points along the way to define the shape of a curve, until the difference between the interfering signal frequency and the tuned frequency is 10 kc. (It may not be possible to tune the interfering signal as close as 10 kc to the tuned frequency and still maintain a 6-decibel $(S + N)/N$ ratio. If not, measure the closest point at which the 6 db ratio is still obtainable.)

(e) Repeat steps (c) and (d) with the interfering signal tuned to the other side of the tuned frequency.

(f) Repeat steps (b) through (e) for other standard interfering-signal levels.

(5) Presentation of Test Data.—The ratio of the desired signal level to the sensitivity level obtained at the beginning of the test (P_d/P_{do}, in db) is calculated for each test point. Then the ratio P_d/P_{do} is plotted as the ordinate, and the difference between interfering signal frequency and tuned frequency (Δf, in kc) is plotted as the abscissa. The interfering signal level, P_i, is the fixed parameter for each curve. The curves are best plotted with the abscissa as a logarithmic scale and the ordinate as a linear scale. The effective attenuation caused by the large resistor in the desired signal lead is calculated as in step (f) of the test procedure for the co-channel test. The initial measurement of this attenuation at the beginning of the test is adequate for all the data at that particular receiver tuned frequency, provided that the setup is not changed during the test. However, it should be measured again if the test is to be performed at another tuned frequency.

e. Intermodulation.

(1) Background. — The intermodulation characteristics of a receiver are of primary importance because they give an indication of the interference possibilities when the receiver is used in the presence of two off-channel signals. Assuming that

these signals have not been mixed before arriving at the receiver, some mixing may be expected in the r-f amplifier tubes and/or the first mixer. If one of the extraneous signals generated in this manner happens to fall at the tuned frequency and is of sufficient amplitude, interference of a co-channel nature is the result.

(a) Third-Order Product.—Usually it is assumed that the third order mix is potentially the most serious type of intermodulation because both signals may be within the passband of the input circuit. The frequency relationships for this type of mix are given by

$$f_o = 2f_a - f_b, \qquad (49)$$

where f_o is the receiver tuned frequency and f_a and f_b are the interfering signal frequencies.

(b) Products Higher than Third Order. —It is also possible that higher order intermodulation products caused by two interfering signals near the tuned frequency could produce interference. An example of a higher order mix is the fifth order, defined by

$$f_o = 3f_a - 2f_b. \qquad (50)$$

These high order mixes, however, are not usually sufficiently strong to cause appreciable interference.

(c) Second-Order Product.—The second order, or primary, mix cannot be neglected as a possible cause of interference. This mix is defined by

$$f_o = f_b - f_a. \qquad (51)$$

Although one or both interfering signals must be far removed from the passband, they may still develop enough voltage at the grid of the first tube to produce strong interference.

(d) Precautions. — Care must be taken in conducting this test to insure that intermodulation does not occur within the signal generators themselves. If the signal generators are of a type such that generator intermodulation is a possibility, it is essential that a device be used to couple the generator outputs to the receiver which will provide considerable isolation between the generators.

(2) Required Equipment. — The required equipment is the same as for the true selectivity test, CED 3512.3d(2), except that an isolation network is substituted for the resistive pads.

(3) Test Setup. — The setup should be in a shielded room with the apparatus on a grounded metal (copper-clad) bench top (see block diagram, Figure 35-161). The receiver audio output should be terminated in the specified load impedance.

(4) Test Procedure.

(a) Set receiver controls to same positions as for the i-f, image, and spurious responses test, CED 3512.3b(4)(a).

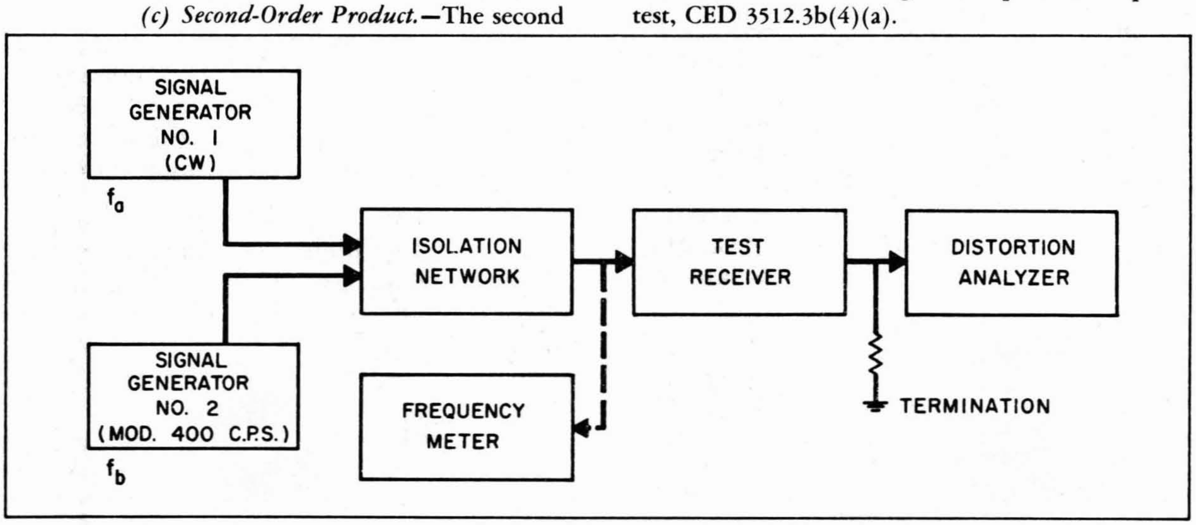


Figure 35-161.—*Block Diagram of Intermodulation Test Setup for AM Receivers.*

(b) Tune signal generator No. 2 to the receiver tuned frequency. Measure the sensitivity for a 6-decibel (S + N)/N ratio. This sensitivity level should then be corrected by subtracting the attenuation (in db) of the isolation network.

(c) If primary mixing is to be observed, set signal generator No. 1 to f_a and signal generator No. 2 to $f_b = f_a + f_o$.

(d) Keeping the output levels of both signal generators equal, vary the outputs until a 6-decibel (S + N)/N ratio is obtained. It may be necessary here to retune one signal generator very slightly to maximize the (S + N)/N ratio and then readjust levels to regain the 6 db ratio. Correct the generator outputs for the attenuation of the isolation network. Record the difference frequency, Δf, between f_a and the receiver tuned frequency, and record the *corrected* power levels, $P_a = P_b$.

(e) Repeat steps (c) and (d) for various frequencies f_a and f_b.

(f) To observe third-order intermodulation, repeat steps (c) through (e) for various positive and negative values of Δf. For each Δf, $f_a = f_o + \Delta f$ and $f_b = f_o + 2\Delta f$.

(g) Equivalent signal generator settings may be found if it is desired to test for higher-order intermodulation products.

(5) *Presentation of Test Data.* — For each test point, the intermodulation rejection ratio may be found. This is the difference between the corrected power levels, $P_a = P_b$ in dbm, and the corrected sensitivity, P_{do}, also in dbm. The ratio is thus obtained in decibels. A curve may now be plotted relating the intermodulation rejection ratio to the difference frequency, Δf. The intermodulation rejection ratio is plotted as the ordinate on a linear scale, and Δf is plotted as the abscissa on a logarithmic scale.

f. Impulse Response.

(1) *Background.* — For all practical purposes, broad band interference, *i.e.*, interference that covers a frequency spectrum much wider than the bandwidth of the system, can be considered as impulsive in nature. The energy which such interference injects into the receiver is directly proportional to the bandwidths of the input circuits. The test to evaluate the impulse response of a receiver is analogous to the co-channel test, CED 3512.3c, the difference being that in this test a calibrated impulse generator is substituted for the interfering signal generator. The response of the receiver to a desired signal is measured in terms of the level of impulse interference injected into the receiver.

(2) *Required Equipment.* — The required equipment is the same as for the co-channel test, CED 3512.3c(1), except that signal generator No. 2 is replaced by an impulse generator.

(3) *Test Setup.* — The test setup is the same as for the co-channel test, CED 3512.3c(2), except for the substitution of the impulse generator.

(4) *Test Procedure.*

(a) Set the receiver controls to the same positions as in the spurious response test, CED 3512.3b(4)(a).

(b) Tune the receiver to a standard test frequency.

(c) Connect the signal generator to the receiver through the 50-ohm pad. Tune the signal generator to the receiver tuned frequency and apply 30-percent, 400- cps modulation. Connect the impulse generator to the receiver through the large resistive pad, but do not turn on the impulses. Measure the sensitivity of the receiver for a 6-decibel (S + N)/N ratio.

(d) Reverse the connection of the signal generator and impulse generator. Measure the receiver sensitivity for a 6-decibel (S + N)/N ratio with the equipment connected in this manner. Leave the equipment connected this way for the remainder of the test.

(e) Calculate the difference between the sensitivity readings measured in (c) and (d) above. This difference, in db, must be subtracted from all subsequently measured desired signal levels to compensate for the pad attenuation.

(f) Turn on the impulse generator and set the PRF to 60 pulses per second. Set the impulse level to minimum. Increase the desired signal level, if necessary, to restore a 6-decibel (S+N)/N ratio. Record the impulse and desired signal levels.

(g) Increase the impulse level in steps of about 10 db to the maximum impulse generator output, each time increasing the desired signal to restore the 6-decibel (S + N)/N ratio. Record the impulse level and desired signal level P_d for each step.

(h) Repeat steps (f) and (g) for a PRF of 1000 pulses per second.

(i) Turn the impulse level back to the minimum. Set the desired signal level to a value 12 db above the measured sensitivity of the receiver. Turn the impulse PRF back to 60 pulses per second. Measure the (S + N)/N ratio. Record the impulse level, desired signal level, and (S + N)/N ratio.

(j) Increase the impulse level in steps of about 10 db to the maximum impulse generator output, each time measuring the (S + N)/N ratio. (The desired signal level is not varied.) Record the impulse level and (S + N)/N ratio for each step.

(k) Repeat (i) and (j) for a PRF of 1000 pulses per second.

(5) Presentation of Test Data. — The data should be presented in graphical form. For the first test, the impulse level, in db above one microvolt per megacycle, is plotted as the abscissa, and the desired-signal level, in dbm, is plotted as the ordinate. One curve is plotted for each of the two PRFs used. For the second test, the abscissa is the impulse level, and the ordinate is the (S + N)/N ratio in db. One curve is plotted for each PRF.

g. Power Line Susceptibility.

(1) Background.—Interference to a radio receiver by other electronic equipment in the immediate neighborhood may be caused by coupling into the receiver through the power leads. In the evaluation of this leakage, a stabilization network is needed to stabilize the impedance seen by the receiver and to provide a convenient point for attaching a signal generator or other measuring equipment. The line stabilization network used for this test is as specified in Military Specification MIL-I-26600. It is very similar to the IRE standard network. This unit is limited to the frequency range from 150 kc to 30 mc due to the components used in its construction.

(2) Required Equipment.

(a) Shielded test location.

(b) RF signal generator with provisions for amplitude modulation of 30 percent at 400 cps.

(c) Distortion analyzer.

(d) Frequency meter.

(e) Line stabilization network.

(f) Short connecting cables.

(3) Test Setup.—The setup should be in a shielded room with apparatus on a grounded metal (copper-clad) bench top. See Figure 35-162 for connection of the equipment. The repeatability of this test will be extremely poor if precautions are not taken to insure that the power cord is always dressed in the same manner each time the test is performed. The excess power cord should always be wound about the two posts provided on the line stabilization network in a figure-eight manner. A straight section, about one foot in length, should be left between the stabilization network and the receiver. This one-foot length should be dressed perpendicular to the set and about two inches above the ground plane.

(4) Test Procedure.

(a) Set the receiver controls to the same positions as for the spurious response test, CED 3512.3b(4)(a).

(b) Tune the receiver to one of the standard test frequencies.

(c) Set the signal generator for 30-percent, 400-cps amplitude modulation, and for full output.

(d) Slowly tune the generator over the range from 150 kc to 30 mc. Each time a response is noted, adjust the signal generator to give a 6-decibel (S + N)/N ratio at the receiver output. Record the frequency and signal generator output level, P_i.

(5) Presentation of Test Data.—The test data should be presented in tabular form, as shown below.

Frequency (mc)	*Sign*	*p*	*q*	P_i *(dbm)*

h. Case Susceptibility. — The object of this test is to determine the susceptibility of the receiver to case-penetrating radiation.

(1) Required Equipment

(a) Shielded test location.

(b) RF signal generator with provisions for amplitude modulation of 30 percent at 400 cps.

(c) 50-ohm resistive pad.

(d) 50-ohm shielded antenna termination.

(e) 3-inch magnetic loop probe with calibrated connecting cable.

(f) Distortion analyzer.

(g) Other short connecting cables.

(2) Test Setup.—The setup should be in a shielded room with the apparatus on a grounded metal (copper-clad) bench top. The connection of the equipment is as shown in Figure 35-163.

(3) Test Procedure.

(a) Set the receiver controls to the same positions as for the spurious response test, CED 3512.3b(4)(a).

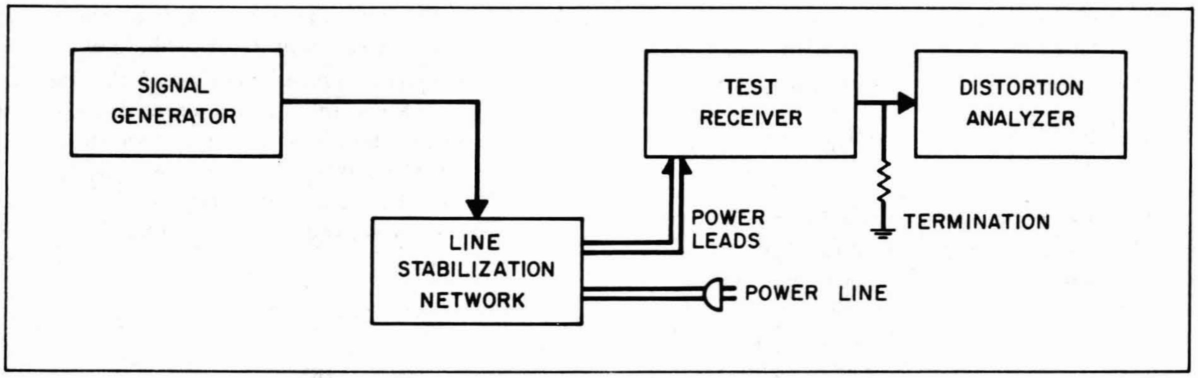


Figure 35-162.—*Block Diagram of Power-Line Susceptibility Test Setup for AM Receivers.*

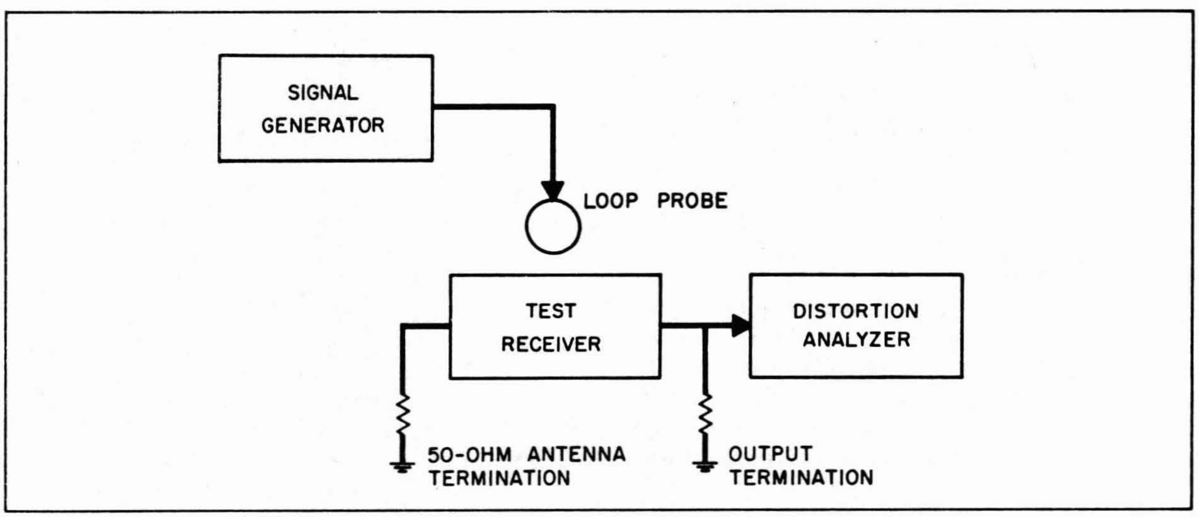


Figure 35-163.—*Block Diagram of Case Susceptibility Test Setup for AM Receivers.*

(b) Tune the receiver to a standard test frequency.

(c) Set the signal generator for 30-percent, 400-cps modulation.

(d) Measure the sensitivity of the receiver for a 6-decibel $(S + N)/N$ ratio, using the 50-ohm pad as a dummy antenna.

(e) Connect the loop probe antenna to the signal generator by means of the calibrated cable. Connect the 50-ohm shielded termination to the receiver antenna terminals.

(f) Set the signal generator for maximum output.

(g) With the signal generator tuned to the receiver tuned frequency, move the probe across the case of the receiver until the maximum output indication is obtained at the distortion analyzer. Then rotate the probe until this indication is further maximized. Adjust the signal generator output level for a 6-decibel $(S + N)/N$ ratio. Record the frequency, signal level P_i, and area of maximum susceptibility.

(h) Repeat the last step and measure all responses of the receiver over the range from 150 kc to 1000 mc. (Note: The area of maximum susceptibility may not be the same for all responses. Therefore, each time a response is discovered, the position of the probe should be adjusted for maximum response, and the area of maximum susceptibility should be recorded.

(4) Presentation of Test Data.—For each response, the "shielding-effectiveness" ratio, in db, should be calculated. The ratio is defined for this test as the difference between P_i and the measured sensitivity, P_{do}, as measured in paragraph CED 3512.3h(3)(d) of the test procedure above. The data are presented in tabular form, as shown below:

Frequency (mc)	*Sign*	*p*	*q*	P_i *(dbm)*	*Shielding Effectiveness (db)*	*Maximum Susceptibility Area*

.4 Emanation Tests on AM Receivers. — This section describes tests for determining the extent to which an AM communications receiver behaves as a source of r-f signals. Test results are used in a manner similar to those for any other r-f source, such as a radio transmitter, except that the less powerful nature of the source generally limits its effect to local or on-site situations.

a. Spurious Emissions.

(1) Background. — Any signal generated in a superheterodyne receiver, such as signals generated by local oscillators, calibration oscillators, beat frequency oscillators, and mixers, may radiate sufficient power to cause interference in adjacent communications equipment. Interference from these sources is usually caused by coupling to the adjacent equipment through the antenna terminals, receiver case, and power leads. The test described here is the measurement of power coupled through the antenna terminals into a 50-ohm resistive load.

(2) Required Equipment.

(a) Shielded test location.

(b) RF signal generator with provisions for amplitude modulation of 30 percent at 400 cps.

(c) Dummy antenna, consisting of 50-ohm series resistor.

(d) Distortion analyzer.

(e) RI/FI meter.

(f) Short connecting cables.

(3) Test Setup.—The setup should be in a shielded room with apparatus on a grounded metal (copper-clad) bench top. For initial tuning of the receiver, the test setup is the same as the co-channel test, CED 3512.3c (see Figure 35-160). The setup for the remainder of the test is shown in Figure 35-164.

(4) Test Procedure.

(a) Set the receiver controls to the same positions as in the spurious response test, CED 3512.3b(4)(a).

(b) Tune the receiver to a standard test frequency. *Be sure that the antenna trimmer is peaked for maximum output (S+N)/N ratio.*

(c) Disconnect the signal generator, dummy antenna, and distortion analyzer. Connect the RI/FI meter to the antenna terminals.

(d) Calibrate the RI/FI meter as a two-terminal VTVM.

(e) Set the meter to its most sensitive range.

(f) Tune until an indication is obtained. Record the frequency setting and the rms level in db above one microvolt. Convert this level, P_0, to dbm. In some cases, a frequency meter may be needed for accurate frequency identification.

(g) Repeat the last step for the complete frequency range from 150 kc to 1000 mc.

(5) Presentation of Test Data.—The test data are presented in tabular form, as shown below:

Frequency (mc)	*P_0 (dbm)*	*Frequency Identification*

The frequencies are identified according to their sources and harmonic order, *e.g.*, f_{lo_1}, $3f_{lo_1}$,$3f_{lo_2}$, etc. The levels of the emissions should be compared to the limit set by Military Specifications MIL-I-26600 and MIL-I-6181D. If the acceptable limit is exceeded by the levels of any measured emissions, this fact should be noted.

b. Power-Line Conducted Interference.

(1) Background.—Any large signal voltages that exist in a radio receiver, such as signals generated by local oscillators, calibration oscillators, beat frequency oscillators, and mixers, may couple into adjacent communications equipment through the power line and cause interference. This type of interference is evaluated by the following test, which is similar to the EIA Standard in that a signal is used in the receiver passband.

(2) Required Equipment.

(a) Shielded test location.

(b) RF signal generator with provisions for amplitude modulation of 30 percent at 400 cps.

(c) RI/FI meter.

(d) Line stabilization network.

(e) Short connecting cables.

(3) Test Setup.—The setup should be in a shielded room with the apparatus on a grounded metal (copper-clad) bench top. See Figure 35-165 for connection of the equipment. The same precautions with regard to power lead dress should be observed here as in the power-line susceptibility test, CED 3512.3g(3).

(4) Test Procedure.

(a) Set the receiver controls to the same positions as for the spurious response test, CED 3512.3b(4)(a).

(b) Tune the receiver to a standard test frequency.

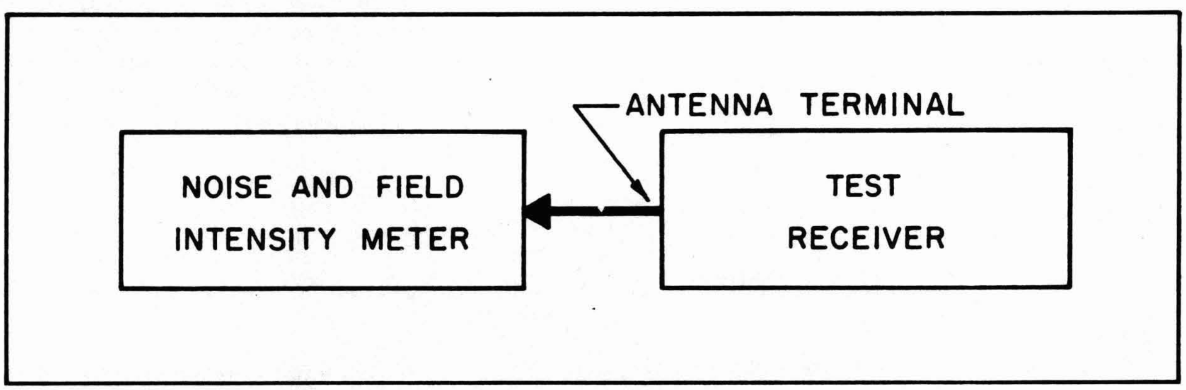


Figure 35-164.—*Block Diagram of Spurious Emissions Test Setup for AM Receivers.*

(c) Set the signal generator output level to −39 dbm and the modulation to 30 percent, 400 cps.

(d) Calibrate the RI/FI meter as a two-terminal VTVM.

(e) Set the RI/FI meter to its most sensitive range.

(f) Slowly tune the meter over the range from 150 kc to 30 mc. Each time a response is detected, read and record its frequency and amplitude. The amplitude of narrow-band signals should be measured in db above one microvolt, rms. Amplitudes of noise signals should be measured in db above one microvolt, *peak.*

(g) Convert the narrow band readings to dbm. Convert the noise readings to db above one μv/mc by means of the conversion charts supplied with the RI/FI meter.

(5) Presentation of Test Data.—The data for discrete frequencies should be tabulated in the same manner as that of the spurious emissions test, CED 3512.4a(5). Data for noise interference may also be presented in tabular form, as shown below, or they may be plotted to show the envelope of noise spectrum.

Frequency (mc)	E_0 *(db above 1 μv/mc)*

If any of the measured interference exceeds Military Specifications MIL-I-26600 and MIL-I-6181D, this fact should be noted.

c. Case Radiation, Probing Test.

(1) Background.—The object of the case radiation test is to determine the frequency, source, and field strength of radiation from the receiver case and the receiver cables, such as the power cord, the headphone cord, and remote cables. The probing test is designed to discover the frequency and source of each signal radiated from the receiver case and cables, whereas the field intensity test is a measurement of the actual field strengths of these signals.

(2) Required Equipment.

(a) Shielded test location.

(b) RI/FI meter.

(c) 50-ohm shielded antenna termination.

(d) 3-inch magnetic loop probe with calibrated connecting cable.

(3) Test Setup.—The setup should be in a shielded room with the apparatus on a grounded metal (copper-clad) bench top. The loop probe is connected to RI/FI meter and the antenna termination (50-ohm resistor) is connected to the receiver antenna terminals.

(4) Test Procedure.

(a) Set the receiver controls to the same positions as for the spurious response test, CED 3512.3b(4)(a).

(b) Tune the receiver to a standard test frequency.

(c) Calibrate the RI/FI meter as a two-terminal VTVM and set it to its most sensitive range.

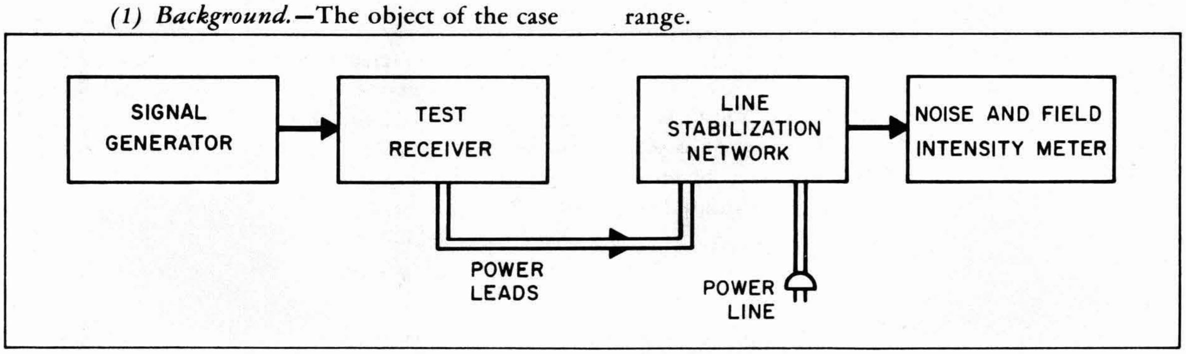


Figure 35-165.—*Block Diagram of Conducted Interference Test Setup for AM Receivers.*

(d) Place the loop probe near, or on, the receiver case, and tune the RI/FI meter until an indication is obtained. Move the position of the probe until a point or general area is found on the receiver case at which the radiation is maximum. Record the frequency, the level as measured in db above one microvolt, rms, and the point of maximum leakage. Convert the measured level, P_0, to dbm.

(e) Repeat the last step to measure all detectable leakage in the range from 150 kc to 1000 mc.

(5) Presentation of Test Data.—The test data are presented in tabular form, as shown below.

Frequency (mc)	*P_0 (dbm)*	*Frequency Identification*	*Leakage Source*

d. Case Radiation, Field Intensity Test.

(1) Background.—The purpose of this test is to measure at a distance one foot from the receiver case, the field strength of each leakage signal detected in the probing test.

(2) Required Equipment.

(a) Copper ground plane, approximately 6 by 8-feet.

(b) RI/FI meter.

(c) 50-ohm shielded antenna termination.

(d) Calibrated loop antenna and connecting cable.

(e) Adjustable dipole antenna and connecting cable.

(3) Test Setup.—The receiver under test is placed on the ground plane. The antenna is set up, also on the ground plane, at a distance one foot from the receiver case. The RI/FI meter is grounded to the ground plane.

(4) Test Procedure.

(a) Set the receiver controls to the same positions as for the spurious response test, CED 3512.3b(4)(a).

(b) Tune the receiver to a standard test frequency.

(c) Calibrate the RI/FI meter as a two-terminal VTVM. Set the attenuator to the most sensitive range.

(d) Tune the meter to a frequency at which leakage radiation was measured in the probing test.

(e) Orient the antenna so that it is centered one foot from the point of maximum leakage measured in the probing test.

(f) The loop antenna is used below 30 mc and dipoles are used above 30 mc. When a dipole is used, adjust the lengths of the dipole elements such that the dipole is one-half wavelength at the particular frequency measured.

(g) Measure the rms level, P_0, of the signal. Record this level and the frequency.

(h) Repeat steps (d) through (g) for frequency measured in the probing test.

(5) Presentation of Test Data.—Calibration curves or tables should be used to convert the signal levels measured in this test to units of field intensity *e.g.*, db above one microvolt per meter. Then the data, including field strengths, should be presented in tabular form, as shown below.

Frequency (mc)	*P_0 (dbm)*	*Field Strength (db above 1 μv per meter)*	*Frequency Identification*

.5 Susceptibility Tests on FM Receivers.—This section describes tests for determining the interference susceptibility of FM communications receivers required for interference-prediction data. As in tests on AM receivers, conventional sensitivity tests should be performed according to Military Specifications MIL-STD-449—not repeated here. All others should be performed in accordance with the following instructions.

a. General Considerations.—The following list of considerations is understood in the description of FM receiver tests:

(1) The desired signal standard test modulation is 1000 cps with rated frequency deviation as specified in the *Final Testing* section of the technical manual of the receiver under test. The interfering signal is always unmodulated.

(2) Unless otherwise specified, the standard output (S+N)/N ratios in db are 6, 10, 20 and the maximum that can be obtained. The ratios are obtained at the sensitivity audio output power of the receiver, as defined in the technical manual of the receiver under test. If the receiver has a stepped volume control, the setting which gives an audio output nearest to the rated audio output power should be used.

(3) The dummy antenna is such that its impedance plus the generator impedance is equal to the receiver input impedance.

(4) For 50-ohm generators used with 50-ohm receivers, no dummy antenna is used.

(5) When two signal generators are used, a large isolating resistor is used in the lead to the desired signal generator.

(6) The line stabilization network is the IRE standard network.

(7) Standard test frequencies are three points on each band, *i.e.*, low, mid and high. See CED 3512.3a(11) for the definition of a receiver band.

(8) "Mean-signal input" is taken as −60 dbm available power.

(9) Standard interfering voltage levels at the antenna terminals are +13, +7, −7, −13 and −27 dbm available power.

(10) A receiver is *tuned approximately* to a desired signal by adjusting the tuning control until the desired a-f output power is obtained either with the least possible r-f input or with the lowest possible setting of the volume control.

(11) A receiver for frequency-modulated waves is *tuned accurately* to a desired signal by first tuning it approximately and then adjusting the tuning controls until either the undesired noise is a minimum or the harmonic distortion of the demodulated desired signal is a minimum, *i.e.*, the (S+N)/N ratio is a maximum. When they do not coincide, it should be stated whether the tuning is for minimum noise or for minimum distortion.

(12) To tune a receiver to the position of *minimum noise*, the receiver is tuned approximately as described above. A mean-signal input of the desired frequency is amplitude modulated 30 percent at 1000 cps and is fed to the input terminals of the receiver. The tuning controls are then adjusted until the audio output of the receiver is a minimum. It is important to insure that the input signal has a negligible degree of frequency modulation.

(13) To tune a receiver to the position of *minimum distortion*, the receiver is first tuned approximately as described in paragraph CED 3512.5a(10) above. A mean-signal input of the desired frequency, modulated at 1000 cps with rated system deviation, is then fed to the input terminals of the receiver. The tuning controls are then adjusted until the rms level of the harmonic components of the 1000 cps sine wave in the output of the receiver is a minimum. In many receivers, the minimum distortion tuning point may be readily located by observing the audio waveform on a cathode-ray oscilloscope while increasing the deviation slightly above 100 percent.

(14) Because of the limitations on available signal generator outputs, the largest interfering signal amplitudes used are +13.0 dbm in 50-ohm systems and +5.4 dbm for 300-ohm systems, calculated on an available power basis.

b. Co-Channel Response.

(1) Background.—This test is intended to show the effect of an interfering signal of the same frequency as the desired signal, and includes the inherent effect of the detector, the limiter, and the automatic volume control. Two signal generators are required, only one of which need be capable of frequency modulation. The output of both are applied simultaneously to the receiver under test at one standard test frequency. The masking effect of the unmodulated interfering signal is obtained with

the desired signal modulated and with standard input levels of the desired signal; the output (S+N)/N ratio is noted as the level of the interfering signal is increased from zero. The interfering signal is unmodulated, because of the (S+N)/N depression effect in FM due to an interfering co-channel signal is a function of the relative level of the interfering carrier to the desired carrier and is essentially independent of the modulation on the interfering signal.

(2) Required Equipment.

(a) Shielded test location.

(b) RF signal generator with provisions for FM.

(c) RF signal generator (no modulation required).

(d) Distortion analyzer.

(e) Short connecting cables.

(f) Isolating resistor in a coaxial holder.

(g) Frequency measuring equipment.

(3) Test Setup.—(See Figure 35-166).

(4) Test Procedure.—With generator No. 2 adjusted to the tuned frequency of the receiver and its output level adjusted to the minimum possible, perform step (a) through (b) below. Record the output level of generator No. 1 in dbm available power.

(a) Set the receiver controls as follows:

RF gain	Maximum
Audio gain	For sensitivity audio output power
Squelch	Off
AFC	Disabled

(b) Set the receiver to the low-frequency band.

(c) Set the signal generator to rated frequency deviation at a 1000-cps rate.

(d) Set the signal generator near the center frequency of one band and adjust its output to −113 dbm, for some receiver types a greater output must be used.

(e) Tune the receiver for minimum distortion according to CED 3512.5(a)(13).

(f) Adjust the antenna trimmer for maximum output.

(g) Adjust the generator output so that the distortion analyzer shows a 6-decibel (S + N)/N ratio. Record the generator frequency and output P in dbm available power.

(h) The attenuation of the isolating resistor and the loading effects of signal generator No. 2 can be obtained from

$$\text{Attenuation (db)} = 20 \log_{10} \frac{P}{P_o} \qquad (52)$$

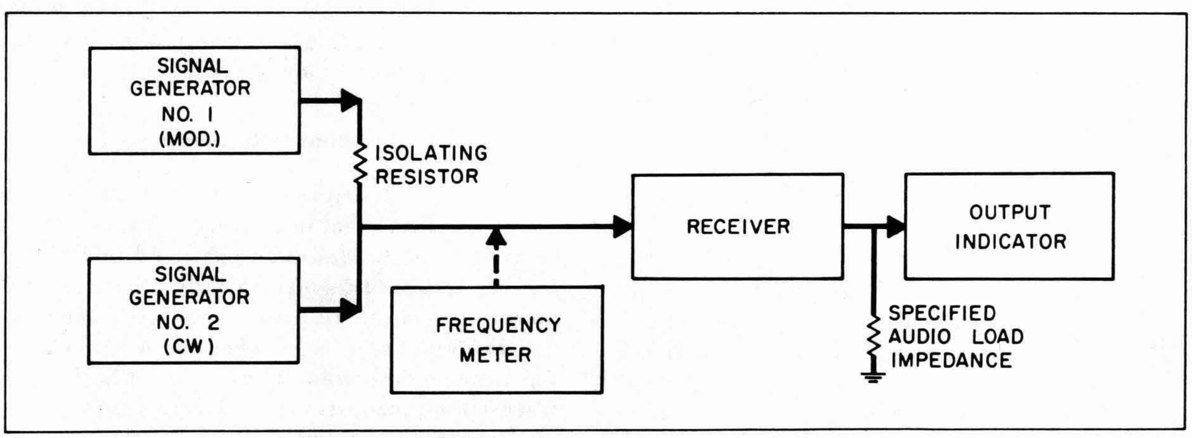


Figure 35-166.—*Block Diagram of Co-Channel Interference Test Setup for FM Receivers.*

where P = value of generator No. 1 output level obtained in step (g) above; and P_o = value of generator No. 1 output level obtained in the sensitivity test. This attenuation factor must be subtracted from all subsequently measured desired signal levels to correct them for pad attenuation and loading effects.

(i) Increase the output of the unmodulated interfering signal generator until the output (S + N)/N ratio is reduced approximately one db. Record the generator setting P_i and the output (S + N)/N ratio. It may be necessary to adjust the frequency of the interfering signal very slightly to give the *worst possible interference.*

(j) Repeat step (i) above, increasing the interfering signal level P_i in approximately 3 db increments until the desired signal is captured, *i.e.,* a 0 db ratio is obtained. At each setting of the interfering signal level, record the (S + N)/N ratio as well as the interfering signal level P_i.

(k) Increase the desired signal level P_d in 20 db increments and repeat steps (i) and (j) above.

(5) Presentation of Test Data. — These data should be presented in graphical form. The abscissa is the interfering signal level P_i in dbm and the ordinate is the (S + N)/N ratio in db.

c. Close-Channel Response.

(1) Background.—This test is intended to show the effect of an interfering signal whose frequency is inside the r-f passband but is outside the i-f passband. It is also a measure of true receiver selectivity since it shows the inherent effect of the selective circuits, limiter, AVC and the detector in the presence of interference. The test is performed at various P_i and P_d levels in order to show the selectivity at several different P_i/P_d ratios.

(2) Required Equipment.—Same as for the co-channel test, CED 3512.5b(2).

(3) Test Setup.—Same as for the co-channel test, CED 3512.5b(3). (See Figure 35-166.)

(4) Test Procedure.

(a) With the output of signal generator No. 2 turned down, perform steps CED 3512.-5b(4)(a) through (g) of the co-channel test. Record the corrected output level P_d of generator No. 1.

(b) Adjust the unmodulated output P_i of generator No. 2 to one of the standard interfering voltage levels.

(c) Set the frequency of generator No. 2 to approximately 10 mc above or below f_o.

(d) Slowly tune generator No. 2 toward f_o and record the depression of the (S + N)/N ratio as a function of frequency. The (S + N)/N depressions noted should be 75 percent, 50 percent, 25 percent and 10 percent of the initial (S + N)/N ratio. Spurious responses are omitted from this test.

(e) Repeat steps (a) through (d) above for values of desired signal P_d of −107, −87, −67, and −47 dbm and other standard interfering voltage levels.

(5) Presentation of Test Data.—For a fixed interfering and desired signal level, a curve of audio output (S + N)/N ratio versus frequency deviation Δf from f_o is plotted with the ordinate linear in decibels and the abscissa linear in frequency; or, at fixed interfering (P_i) and desired (P_d) signal levels, the data are recorded in the following tabular form.

Δf (mc)	(S + N)/N (db)

d. True Selectivity.

(1) Background.—The two-signal true selectivity test is a measure of the receiver response to weak and strong desired signals in the presence of weak and strong undesired signals. In FM receivers, interference to the desired signal is caused by increases in noise, desensitization, and capture. A two-signal test is the only test that will correctly show the selectivity curve, at reduced sensitivity, of an FM receiver having automatic gain control. The discussion under the true selectivity of AM Receivers, CED 3512.3d(1), also applies to FM receivers.

(2) Required Equipment.—Same as for the co-channel test, CED 3512.5b(2).

(3) *Test Setup.*—Same as for the co-channel test, CED 3512.5b(3) (see Figure 35-166).

(4) *Test Procedure.*

(a) With the output of generator No. 2 adjusted for the minimum possible output, perform steps CED 3512.5b(4)(a) through (g) of the co-channel test. Record the corrected output level P_{do} of generator No. 1.

(b) Set the output of generator No. 2 to + 13 dbm.

(c) Tune signal generator No. 2 ten mc below f_0, and then slowly tune toward f_0.

(d) When the 6-decibel $(S + N)/N$ output ratio is reduced to approximately a 0-decibel $(S + N)/N$ ratio, increase the output of signal generator No. 1 until the 6-decibel $(S + N)/N$ ratio is re-established.

(e) Record the new output of signal generator No. 1 as P_d in dbm.

(f) Increase the desired signal level 10 db tune the interfering signal toward f_0 until the audio output is reduced to a 6-decibel $(S + N)/N$ ratio (spurious response frequencies are excluded). Record the new output P_d of signal generator No. 1 and the frequency of the interfering signal.

(g) Repeat (e) above until the maximum output power capability of the desired signal generator is reached.

(h) Tune signal generator No. 2 ten mc above f_0 and then slowly tune toward f_0. Repeat steps (b) through (g) above.

(i) Repeat steps (b) through (h) above for other standard levels of interfering signal and standard test frequencies.

(5) *Presentation of Test Data.* — A curve of P_d/P_{do} in db, versus Δf is plotted with the interfering signal level P_i as a fixed parameter. Δf is f_0 minus the frequency of the interfering signal. P_{do} is the sensitivity test input level with the true selectivity test setup. The ordinate should be linear in db and the abscissa should be a logarithmic frequency scale; or, for a fixed P_i, the data are presented in the following tabular form:

Δf *(mc)*	P_d/P_{do} *(db)*

e. Spurious Responses — Two Signal Method.

(1) *Background.*—Spurious response magnitudes may also be evaluated by the two-signal method, CED 3512.5d. In this test, two values of desired signal are recorded, one which represents an interference-free condition and the other which indicates the intelligence "capture" point. This method of recording data for FM receivers was adopted because it is difficult to maintain a small $(S + N)/N$ ratio, *e.g.*, 6 db in the presence of interference. A combination of receiver and signal-generator frequency drift and the high FM "capture" slope creates an unstable audio output ratio when P_d is approximately equal to P_i. Due to the characteristics of FM receiver circuitry, the noise and interference effects are rapidly negated once P_d is approximately 6 db greater than the noise and interference level at the output of the last i-f stage. Therefore, once the $(S + N)/N$ audio output ratio is approximately 0 db, a very small percentage change in P_d is required to establish a 6 decibel $(S + N)/N$ audio output level. Hence, for all practical purposes, a 6 decibel $(S + N)/N$ audio output occurs at the same input value of P_d as the approximate 0 decibel $(S + N)/N$ ratio.

(2) *Required Equipment.*—Same as for the co-channel test, CED 3512.5b(2).

(3) *Test Setup.*—Same as for the co-channel test, CED 3512.5b(3) (See Figure 35-166).

(4) *Test Procedure.*

(a) With the output of generator No. 2 adjusted to the minimum possible output, perform steps CED 3512.5b(4)(a) through (g) of the co-channel test. Record the corrected output level of generator No. 1.

(b) Set the output of generator No. 2 to + 13 dbm.

(c) Slowly tune signal generator No. 2 over the frequency range from slightly above $f_0/2$ to 1000 mc.

(d) Each time a spurious response is found, the desired signal level is increased until the output (S + N)/N ratio is just noticeably reduced compared to step CED 3512.5d(4)(a). (The test indication is 0.5 db reduction in the (S + N)/N ratio). The distortion analyzer function switch is in the "set level" position. Record the desired generator level as P_{dr} in dbm.

(e) Reduce the desired signal until the output is captured, *i.e.*, until a 0-decibel (S + N)/N ratio occurs. Record the value of desired signal as P_{dc} in dbm.

(f) Repeat steps (d) and (e) above for all spurious responses.

(5) Presentation of Test Data.—For spurious responses, at a fixed P_i, the data are presented in the following tabular form.

Frequency, f_{sr} *(mc)*	*Sign*	*p*	*q*	P_{dr} *(dbm)*	P_{dc} *(dbm)*	*Spurious Response Rejection (db)*

f. Spurious Response Tests—Single-Signal Method.

(1) Background.—The single-signal method of measuring spurious responses is a composite of two tests. The first test evaluates the rejection ratios of spurious responses at and below $f_0/2$ and the second test measures the rejection ratios of spurious responses at frequencies between $f_0/2$ and 1000 mc.

(a) Whenever the interfering signal generator is tuned below f_0, harmonics of the signal generator must be attenuated well below the threshold sensitivity of the receiver in order to remove cochannel interference effects due to harmonics of the signal generator occurring at f_0.

(b) The spurious response rejection ratios of spurious responses occurring at frequencies greater than $f_0/2$ and less than 1000 mc are evaluated by the same method that is used for AM receivers. The test procedure and presentation of the test data are the same, except the interfering signal generator is unmodulated, and the audio output indication is 6 db of noise quieting.

(c) The procedure for measuring spurious responses at frequencies between $f_0/2$ and 150 kc is described below.

(2) Required Equipment.

(a) Shielded test location.

(b) RF signal generator, no modulation required.

(c) Low-pass filter with 50-ohm input and output impedance. The filter cutoff frequency should be between $f_0/2$ and f_0.

(d) Attenuator, 20-decibel L-pad.

(e) RI/FI meter.

(f) Distortion analyzer.

(3) Test Setup.—(See Figure 35-167).

(4) Test Procedure.

(a) First measure the attenuation of the filter at the receiver tuned frequency. This is done

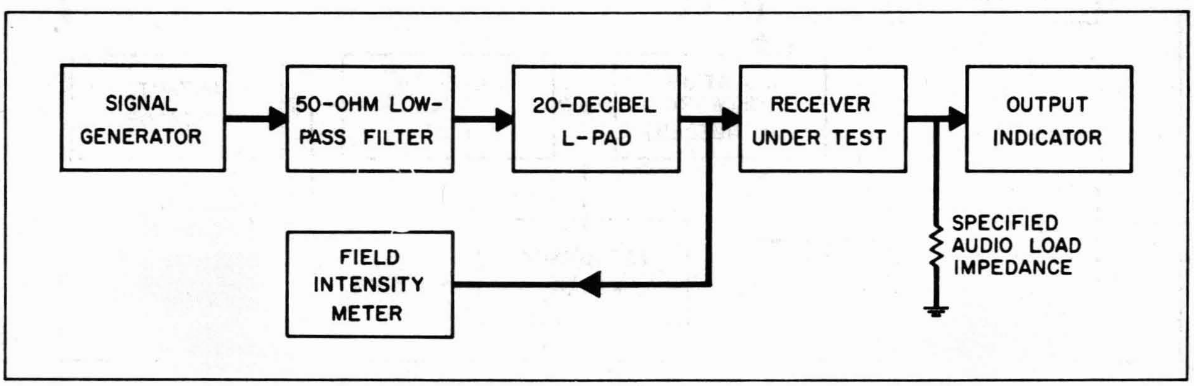


Figure 35-167.—*Block Diagram of Spurious Response Test Setup for FM Receivers.*

by setting the signal generator to the tuned frequency, measuring its output with the field intensity meter, then re-assembling the entire test setup and measuring the output at the RI/FI-meter jack on the attenuator pad box. The filter attenuation is equal to the db difference between these two readings, minus the 20 db drop in the RI/FI-meter arm of the pad.

(b) The signal generator is tuned over the test frequency range and, at each spurious response, the signal level P_i is adjusted to give 6 db of quieting. Here, however, the signal level is not read from the signal generator attenuator dial but is read on the RI/FI meter. The reading is then converted to dbm.

(c) There is still the possibility that an apparent spurious response may be detected which is due to the harmonic content of the generator even with the precaution of using the low-pass filter. If this seems to be a possibility, the actual voltage at the antenna terminal of the harmonic in question should be estimated. This voltage is the voltage of the fundamental, as measured by the RI/FI meter, corrected by the sum of the filter attenuation and the generator harmonic attenuation. The spurious response is true if the estimated harmonic voltage is much less than the receiver sensitivity. If the estimated harmonic voltage is approximately the same as the receiver sensitivity, it is possible that the harmonic of the generator is responsible for the response.

(5) Presentation of Test Data. — The test data are presented in the following tabular form.

Frequency, f_{sr} (mc)	*P_i (dbm)*	*Spurious Response Rejection (db)*	*Frequency Identification*

g. Intermodulation. — See discussion under intermodulation of AM receivers, CED 3512.3e(1).

(1) Required Equipment.

(a) Shielded test location.

(b) Two r-f signal generators, no modulation required.

(c) Distortion analyzer of rms voltmeter.

(d) Short connecting cables.

(e) Frequency-measuring equipment.

(2) Test Setup.—See block diagram, Figure 35-168.

(3) Test Procedure. — Use the procedure described for AM receivers, CED 3512.3e(4), except the audio output indication is 6 db of noise quieting. No modulation is used on the signal generators.

(4) Presentation of Test Data. — Refer to the form as used for intermodulation data of AM receivers, CED 3512.3e(5).

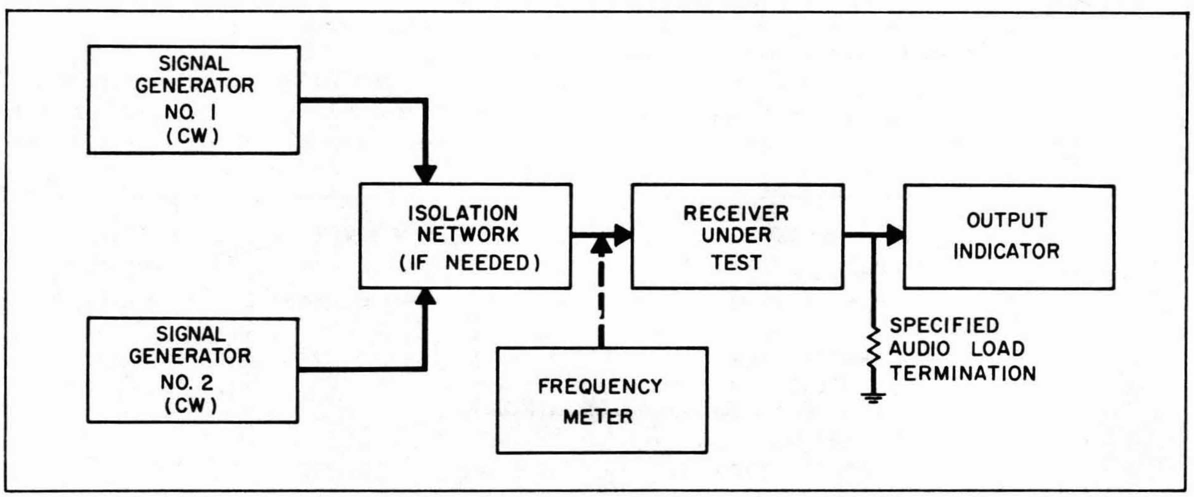


Figure 35-168.—*Block Diagram of Intermodulation Test Setup for FM Receivers.*

.6 Emanation Tests on FM Receivers. — This section describes tests for determining the extent to which an FM communications receiver behaves as a source of r-f signals in a manner parallel to that for an AM communications receiver in CED 3512.4.

a. Spurious Emissions.—This test is performed in the same manner as the test described for AM receivers, CED 3512.4a, except that the signal generator is modulated with the FM standard test modulation rather than the AM standard test modulation.

b. Case Radiation, Probing Test. — See case radiation, probing test, AM receivers in CED 3512.4c.

c. Case Radiation, Field Intensity Test.— See case radiation, field intensity test, AM receivers in CED 3512.4d.

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SECTION V — ADVANCED SYSTEMS

3513. RADIO-INTERFERENCE CONSIDERATIONS IN ADVANCED SYSTEMS.

.1 Communications Systems. — In addition to the HF, VHF, and microwave relay circuits that have been used in the past and will continue to be used, several new propagation modes offer considerable promise for future military radio communications. They are tropospheric scatter, ionospheric scatter, meteoric reflection, and satellite relay. The first two modes are already being used for military communications. The last two modes have thus far been used only for experimental purposes but will probably find application in the near future. Satellite communication appears to be especially attractive. These four new propagation modes are discussed below. Emphasis is placed upon the peculiarities of each mode which either make the communication system susceptible to interference or cause the system to produce interference in other systems. Since these modes are new, little or no quantitative information is presently available regarding their interference properties and, therefore, the discussion is qualitative only.

a. Tropospheric Scatter.—The theory and properties of tropospheric scatter propagation are discussed in Paragraphs 6-31 to 6-52 and 15-16 to 15-20 of TO. 31-3-25 dated 27 June 1958, and in CED 2900 *Electromagnetic Wave Propagation Planning.*

(1) Nominal Characteristics.

(a) Frequency.—The band from about 100 to 2000 mc is regarded as being the most suitable for tropospheric scatter propagation, although frequencies as low as 40 mc and as high as 10,000 mc have been used on a limited basis. The propagation loss in a tropospheric scatter system increases with frequency at a rate which is slightly greater than one which is proportional to the square of the frequency. Therefore, from this aspect, the lower portion of the usable band is preferred.

(b) Range.—A tropospheric scatter circuit may have a length of 60 miles up to perhaps 600 miles.

(c) Transmitter Power. — Transmitters for tropospheric scatter transmission usually have power outputs of 10 kw or more.

(d) Antennas.—Huge paraboloidal antennas—some as large as 60 feet or 120 feet in diameter—are used, providing gains of about 40 db. The antenna beam axis is directed at the horizon along the azimuth of the great-circle path between the two terminals of the circuit.

(e) Bandwidth. — The bandwidth of a tropospheric scatter system may range from a few tens of kilocycles in some systems to a few megacycles in others. The maximum usable bandwidth decreases with increasing range.

(f) Sensitivity Limitations. — Receiver thermal noise is usually the factor which limits the sensitivity of a tropospheric-scatter receiving system.

(2) Types of Interference.—Performance of a tropospheric-scatter circuit is limited by certain types of "self interference" as well as by interference from other sources.

(a) Multipath Transmission. — Self interference can occur when the transmitted signal arrives at the receiving end by more than one path. If the path lengths are different—as is usually the case —the signals will arrive at the receiver at slightly different times. As a result, if a pulse is transmitted, and the time difference for the different paths is great enough, the received signal may consist of more than one pulse. If the path length difference is smaller, only one pulse might be received, but it will be stretched or elongated beyond the width of the transmitted pulse. This stretching of a pulse into a broader pulse or into multiple pulses imposes a limit upon how narrow a pulse can be transmitted and upon how closely successive pulses can be spaced. Effectively, then, this "multipath" propagation limits the maximum useful bandwidth of the

tropospheric scatter system and hence limits the maximum rate of transmitting information.

(b) Tropospheric Scattering.—Some degree of multipath propagation is inherent in the tropospheric scattering process, since the scattering occurs from innumerable scattering "blobs" or reflecting layers in the atmosphere. This inherent multipath distortion becomes more serious as the path length increases. Narrow-beam antennas help to reduce the effects somewhat, but practical limits on antenna size restrict the improvement that can be gained by this means. Even if a CW signal is transmitted, self-interference is still encountered due to the inherent multipath characteristics of the tropospheric propagation medium. The effect is the rapid random fading or fluctuation of the signal envelope. Automatic-gain-control and diversity are universally used for minimizing such fading.

(c) Scattering From Aircraft.—Another reflector for self interference is aircraft flying through the effective scattering volume, resulting in broadened pulses or in multiple pulses. The only means for minimizing this effect is to select the scatter path so that the useful scattering volume will be comparatively free of aircraft intrusion.

(d) Tropospheric-Ionospheric Scattering.—It was mentioned earlier that frequencies as low as 40 mc might be used for tropospheric scatter. However, if frequencies below about 60 mc are used over path length of about 400 to 600 miles, another difficulty may be encountered. The received signals may be due not only to tropospheric scatter but also to ionospheric scatter since in that "transition zone" the signals from the two propagation modes can be of comparable strength. Due to the difference in lengths of the tropospheric and ionospheric paths the received signals will arrive at different times, again producing multiple signals. The path-length differences in this case are much greater than that encountered due to tropospheric multipath only. Hence the effects can be even more serious.

(e) External Sources.—Interference from external sources, if encountered, is almost certain to enter the system through the antenna. Due to the high-directivity antennas normally used (about 40-db gain, or about one-degree beamwidth) the system is obviously most susceptible to interference entering from the front of the antenna. Strong signals can still enter through side and back lobes, however.

b. Ionospheric Scatter.—The theory and properties of ionospheric scatter propagation are discussed in Paragraphs 6-13 to 6-30 and 15-10 to 15-15 of TO. 31-3-25 dated 27 June 1958, and in CED 2900, *Electromagnetic Wave Propagation Planning.*

(1) Nominal Characteristics.

(a) Frequency.—Ionospheric scatter can be used at frequencies above the minimum usable frequency (MUF) and below about 60 or 70 mc. The transmission loss increases greatly with increasing frequency, so that the lower frequencies provide the strongest signals. However, if the operating frequency is as low as the MUF, then both self-interference and interference from other radio circuits can occur.

(b) Range.—The most useful range of path lengths for an ionospheric scatter circuit is from about 500 miles to about 1300 miles.

(c) Power. — Transmitters for ionospheric scatter circuits require powers of the order of 10 kw or greater.

(d) Antennas. — The antennas usually have gains of about 20 db. The antenna is oriented so that the beam is directed at, or slightly above, the horizon and along the azimuth of the great-circle path between the terminal points of the circuit.

(e) Bandwidth.—The maximum bandwidth required for present equipments is approximately 40 kc.

(f) Sensitivity Limitations. — Cosmic noise is usually the basic limiting factor for sensitivity of an ionoscatter receiving system.

(2) Types of Interference.—As mentioned above, both self interference and interference from external sources can affect ionospheric scatter circuits.

(a) External Sources.—Interference from external sources is most likely to occur if the ionospheric scatter system operates at a frequency close to, or below, the MUF. Co-channel interference due to normal ionospheric reflection of signals originating even several thousand miles away can result.

Therefore, during periods of high sunspot activity, and hence high MUF, the use of the higher frequencies, such as 45 to 60 mc, is recommended to reduce interference from both atmospheric noise and signals propagating via ionospheric reflection.

(b) Multipath Transmissions. — Just as in the case of tropospheric scatter systems, ionospheric scatter systems are affected by a type of self-interference which is inherent in the propagation mode. Again, the result is the transmission of the signal along two or more paths of different lengths causing the arrival of multiple signals at slightly different times.

(c) Extraneous Transmission Modes. — A much more serious self-interference, however, is due to the reception of extraneous signals propagated by means of other modes in addition to the desired ionospheric scatter mode. Extraneous signals from the desired transmitter can be received in the following ways:

[1] Back-scattered energy propagated by F- or E-region reflection.

[2] Reflection from sporadic-E ionization.

[3] Reflection from auroral ionization.

[4] Reflection from meteoric ionization.

(d) Back Scattering.—The geometry of back-scatter is shown in Figure 35-169. The reception of relatively strong extraneous signals results when reflections from the F layer occur with relatively little loss as compared with the scattering loss experienced by the desired wave. Due to the relatively low path loss of the extraneous wave, the undesired signal can be appreciable even though it enters the receiving antenna through the back lobes.

(e) Sporadic-E Ionization.—Sporadic-E ionization can result in signal enhancements and also in multipath reception. However, the differential delay is much less than that due to F-layer back-scatter.

(f) Auroral Ionization.—Auroral ionization can cause signal enhancements and also multipath reception. Another characteristic due to auroras is the extremely rapid fading which can occur (200 to 300 cycles per second). This fading is called "sputter" because if the signal received in an AM receiver it sounds as if it were noise modulated.

(g) Meteoric Ionization. — Reflection from meteoric ionization results in one of the most serious multipath problems. Since the meteor ionization trails are within the same layer as that from which the desired scattering occurs, the multipath delays are not very great. However, the meteor-reflected signals may be 40- to 60-db stronger than

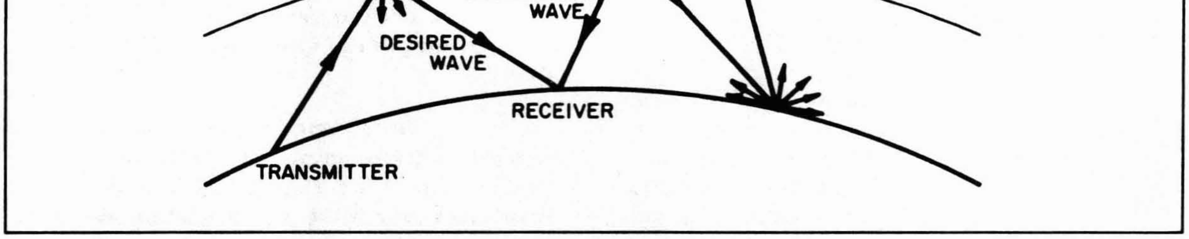

Figure 35-169.—*Geometry of Back Scatter in Ionospheric Multipath Propagation.*

the desired signal. Such reflections cannot be used effectively with ionospheric scatter communications equipment because of the intermittent nature of the meteor signals—individual signals lasting for only a few seconds or perhaps only a fraction of a second at a time. Hence one effect of the meteor signals is the transient increase in signal amplitude.

(h) Doppler-Shift.— Another effect is due to the fact that the meteor-reflected signals have their frequency changed slightly (up to a few kilocycles) due to the Doppler shift caused by the lengthening of the meteor ionization trail. This extraneous signal and the desired signal, when combined in the receiver, can heterodyne, resulting in a receiver output which contains short bursts of transient a-f signals. In a radio-teletype system using frequency-shift keying (FSK), the Doppler shift can be sufficiently great so that it may not be possible to determine at some instant whether a mark or a space has been transmitted. One means for overcoming this problem is the use of a large frequency difference between the mark and the space frequencies. A frequency shift of up to 18 kc has been used for this purpose.

(i) Multipath Delays.—Radio-teletype circuits employing ionospheric scatter are troubled, not only by the unpredictable Doppler frequency shifts, but also by multipath delays. Serious overlapping of symbols, *i.e.*, intersymbol interference, can result if the transmitted symbols have lengths comparable with the multipath delay times. Since many of the multipath delays (especially those due to back-scatter and F-layer propagation) can be as great as 10 to 50 milliseconds, these delays can cause a high error rate in teletype systems which may have symbol lengths of 7 to 22 milliseconds.

(j) Specialized Equipment. — Special stepped-frequency transmitter-receiver combination has been tried on ionospheric scatter circuits to combat reception. The equipment utilizes a transmitter and a receiver whose frequencies are stepped in synchronism at such a rate that the receiver will accept the desired pulse, *i.e.*, the direct signal, but will reject any later signals due to multipath reception because the receiver will already have been switched to another frequency by the time delayed (multipath) signal arrives. The transmitter and receiver are successively stepped to seven different frequencies in increments of 800 cps. For each of these seven nominal frequencies there are two slightly different frequencies, one representing a mark and the other a space. Hence the transmitted signal can occur at any of 14 frequencies, but only one at a time. Experimental results indicate that this type of anti-multipath equipment can reduce traffic outage due to back-scatter multipath by a factor of about 10.

c. Meteor Reflections.

(1) Theory of Operation.—Meteors falling into the earth's atmosphere form ionization columns as they pass through the E region of the ionosphere. These columns, if dense enough, can be effectively used as reflectors against which communications signals can be bounced in somewhat the same manner as in regular ionospheric propagation. The most distinctive feature of a communication system utilizing meteor reflections is that the communication must be carried on intermittently, *i.e.*, only when a suitable ionization column is present.

(a) Method of Operation.—A block diagram of a basic meteor-burst system for two-way communication is shown in Figure 35-170. The transmitters radiate continuous (unmodulated) signals on separate frequencies, with each receiver tuned to the frequency of the distant transmitter. When a suitable ionization trail occurs, each receiver detects the carrier from the distant transmitter. When the received carrier is sufficiently strong to assume an adequate signal-to-noise ratio, the transmitting gate is opened and the transmitting store begins to discharge information and modulate the transmitter at a high rate. Information is transmitted until, due to the fading of the ionization column, the received signal level drops below the level required for gating; then the transmitting gate is closed and modulation stopped. At the distant receiver, the signal is demodulated and fed to the receiving store from which it is discharged at conventional rates into the terminal equipment.

(b) Practical Considerations.—In a practical system, in which the noise levels in the two receivers are not identical, the gating must be performed in a manner somewhat different from that described for the basic system. Specifically, the gating must be controlled by the signal-to-noise ratio at the receiver to which the transmission is directed. The control signal from that receiver can be returned

in a reciprocal radio channel. The reciprocal channel could be used for control purposes only, or might also be used for transmitting information.

(2) Normal Characteristic.

(a) Frequency.—Meteor-burst communication is possible in the frequency band from about 6 mc to over 75 mc. but the most useful frequency range is 30 to 50 mc. The lower limit is introduced by excessive fading of the meteor signals and by competition from the regular ionospheric-reflection mode of propagation. The upper frequency is limited byt the fact that the meteor columns are less effective in providing good reflections at the higher frequencies.

(b) Range.—The optimum transmission distance for meteor-burst propagation is from 600 to 1200 miles, but the range can be varied somewhat outside these limits. Transmission over shorter ranges can be accomplished by using greater transmitter power than required normally (due to the greater reflection angle). The maximum range is about 1300 miles because of the limited height at which the ionization columns occur.

(c) Power.—Transmitter power might typically be 10 kw or more.

(d) Antennas.—Rhombic antennas or yagi arrays are typically used for meteor-burst propagation. The arrays are usually driven so as to produce a horizontal split-beam pattern with a null on the great circle between the stations, and with the main lobes lying about eight degrees to each side of the path.

(e) Bandwidth.—The bandwidth of each transmission channel range from a few kilocycles up to 50 kc, depending upon the type of communications service. Even for one voice channel, the bandwidth is much greater than the normal three or four kc voice spectrum, because the modulating signal is "speeded up" before modulating the carrier.

(f) Sensitivity Limitations.—Normally, the system sensitivity is limited by cosmic noise.

(3) Types of Interference.—One of the main sources of error in a meteor-burst communication system is the start-stop operation. For example, the transmission of information might erroneously begin before a suitable transmission path exists, or transmission might continue even after the signal-to-noise ratio has dropped below an acceptable value. It is possible for an interfering signal to cause the first difficulty — premature transmission — if the interfering signal is accepted by one of the receivers and activates the associated transmitter gate; information would then be lost from the transmitter store. Carrier identification is thus necessary in order to preclude this difficulty. Identification can be accomplished by means of a distinctive modulation continuously applied to the carrier or a brief identifying code transmitted at the start of each burst.

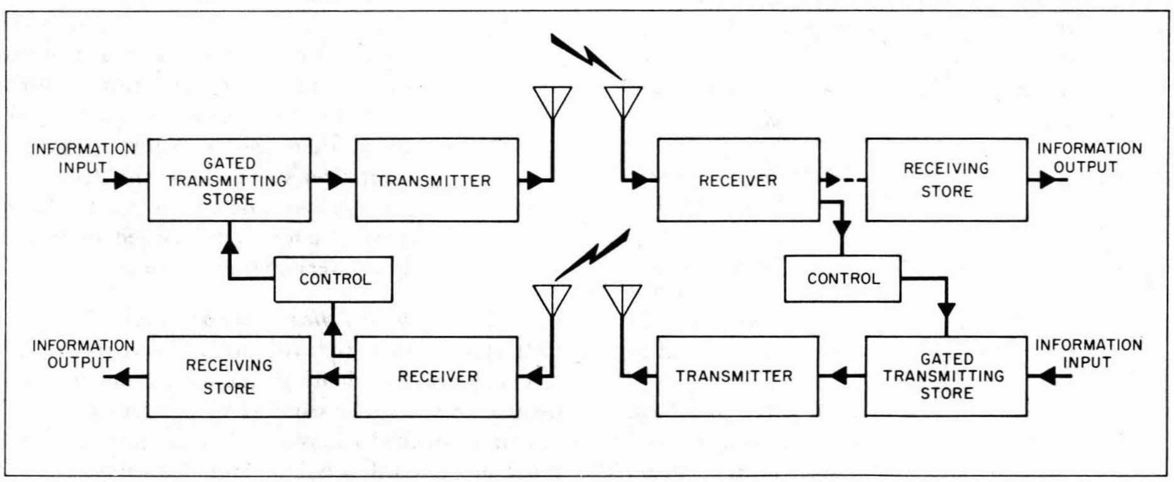

Figure 35-170.—*Meteor Burst System for Two-Way Communication.*

Acknowledgement of receipt of the identifying signal is required before information is transmitted.

(a) Point-To-Point Properties. — The directional characteristics of the meteor-reflection process inherently provide a meteor-burst communications system with a degree of protection from interference and also from signal interception. The directivity of the reflection process ensures that the signal reflected from a particular trail can be received within only a limited area on the ground. Figure 35-171 shows contours defining the percentage of information available at various ground locations. It is seen that, for ground locations more distant from the intended receiving point, comparatively little information is available. Similarly, the directivity of the meteor-reflection process provides a certain amount of protection against interference generated at some distance from either ground station and propagated via meteor reflection.

(b) Other Considerations.—The inherent security cited above allows two meteor-burst systems using identical frequencies to be located much closer to each other than can other systems operating over comparable distances. Different identifying signals for the two systems would still be desirable. Little if any difficulty seems to be caused by signal reflections from auroral or sporadic-E ionization. Such ionization, in fact, can provide useful signal enhancement.

d. Satellite Communications.

(1) Types of Systems.—Earth satellites are to be used to provide high-reliability, long-distance communications between fixed points widely separated on the surface of the earth. A satellite acts as a relay station in much the same manner as a conventional radio-relay system. However, the satellite's position high above the earth's surface will allow line-of-sight transmission to and from all points within very broad areas of the earth. Numerous types of satellite systems are under study and probably several of these types will eventually be used in military communications systems. At the time of writing, the following types are being considered:

(a) Hovering Satellite.—Three or more hovering satellites, each containing a receiver and a transmitter, could be used in orbits over the earth's equator. They would be equally spaced, as shown in Figure 35-172 and provide coverage as shown in Figure 35-173. To hover over fixed points on the earth's surface, they would have to be at a 22,300 mile altitude. Such satellites would transmit a message as it is received.

(b) Polar Orbiting Satellites.—As indicated in Figure 35-173 the high-altitude regions of the earth will not be covered by the hovering equatorial satellites. To provide this coverage four or more revolving satellites may be used in orbits over the poles. They would also transmit messages as they received them and would be used in conjunction with the hovering satellites.

(c) Courier.—The Courier is a satellite which is to orbit around the earth so that it successively passes over, or approximately over, the ground stations between which communication is

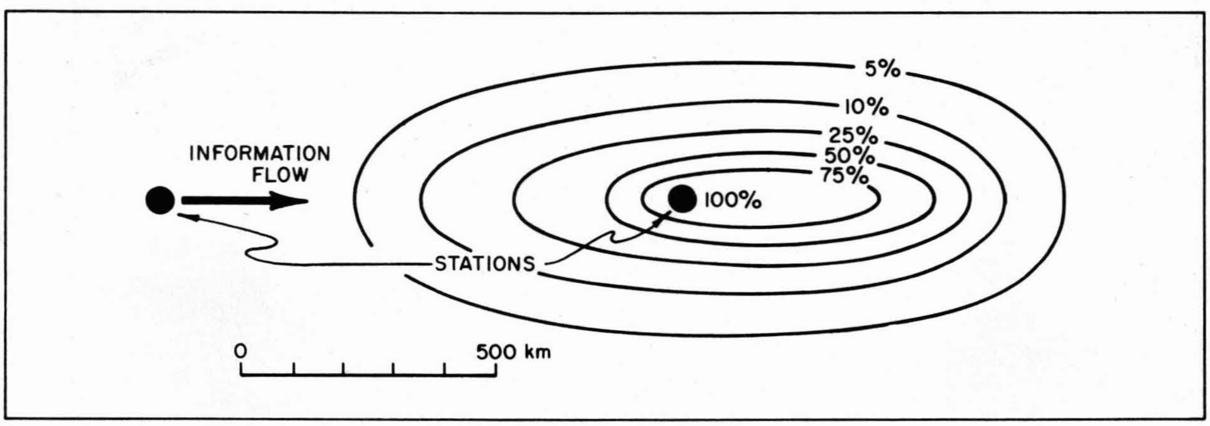

Figure 35-171.—*Percentage-of-Information Contours.*

required. The satellite system receives and records the message while passing over one station and then re-transmits the message when passing over the station to which the message is addressed. The altitude for such a satellite may be approximately 1000 miles.

(d) *Reflecting Satellites.*—Instead of utilizing a receiver and a transmitter, some types of satellites are to act only as passive reflectors. Energy beamed at the satellite from a ground station is reflected or scattered in various directions, and some of it is received by another ground station. Various types of reflectors are being considered:

[1] a large plastic sphere coated with a metallic film, such as Echo I;

[2] a flat plate, constituting a plane

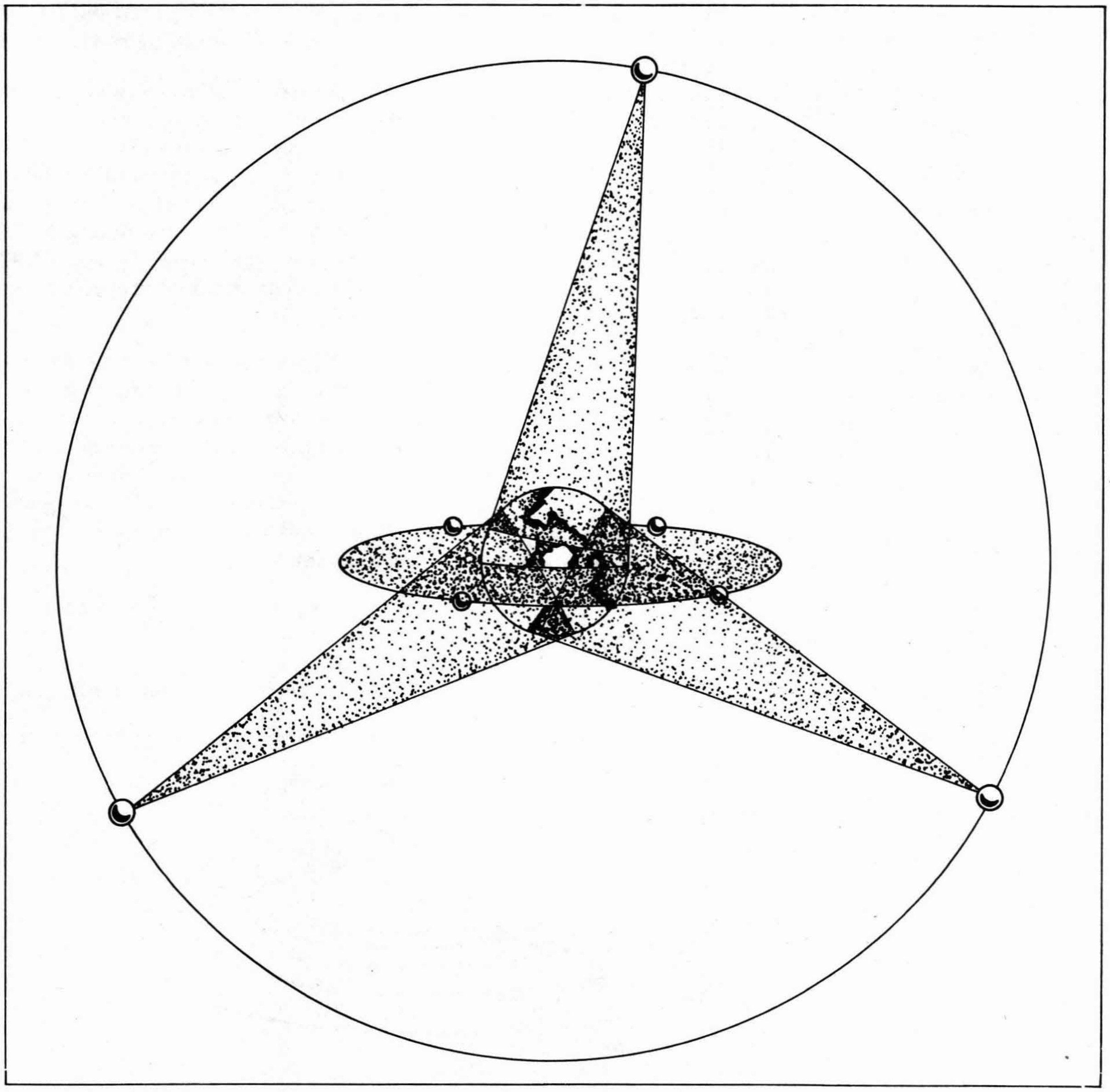

Figure 35-172.—*Three Hovering Satellites in Equatorial Orbit.*

mirror, properly oriented so as to maximize the received signal;

[3] a large cloud of small metallic particles or of ionized gas; or

[4] the earth's moon.

(2) Nominal Characteristics.

(a) Frequency.

[1] For "active" satellites (satellites containing a receiver and a transmitter) the frequency band 100 to 10,000 mc is considered suitable. Below 100 mc, the ionisphere can adversely affect the transmission characteristics. In the band indicated, the transmission can be considered to be essentially "free-space transmission." For "passive" (reflecting-type) satellites, the band 1000 to 10,000 mc will probably be the most useful. Due to the extremely weak signals which will be reflected back to earth. It is important that the system operate in a frequency band in which external noise is at a minimum. Since noise of a natural origin is at a minimum at about 2000 mc, use of the upper part of the VHF band or the lower part of the SHF band is most probable.

(b) Power.

[1] For systems employing active satellites, the power transmitted by the ground stations may be a kilowatt; the power transmitted by the satellite may be on the order of 10 watts.

[2] For systems using passive satellites the transmitted power will be as great as possible — probably 10 kw or greater.

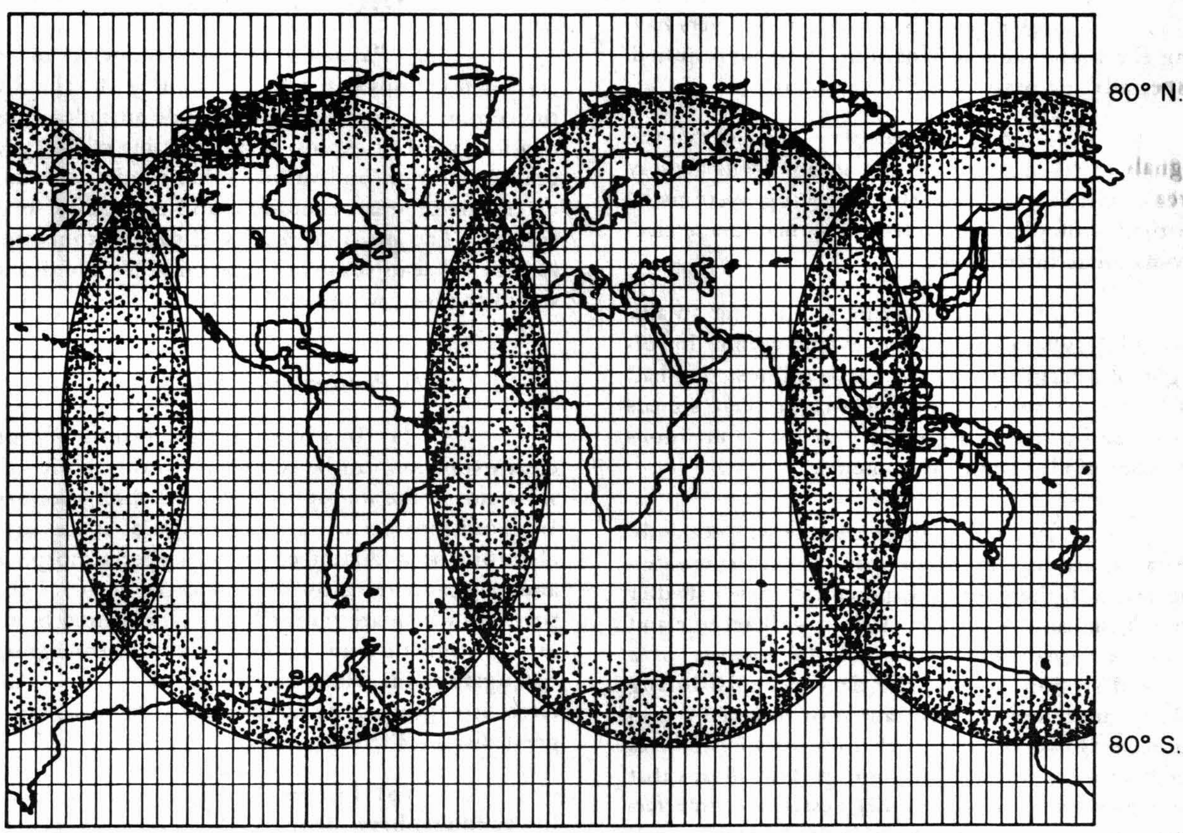

Figure 35-173.—*Coverage Area Obtainable from Three Hovering Satellites.*

(c) *Antennas.*

[1] All types of satellites systems will use ground-based antennas having fairly high gain (perhaps 25 to 45 db). Antennas of the satellites will be approximately isotropic (0-db gain).

[2] In systems using hovering satellites, the ground antennas will have stationary beams; in systems with revolving satellites the ground-based antennas will have to track the satellites over parts of their orbits.

(d) *Bandwidth.*—System bandwidths may range from a few kilocycles for passive-satellite systems to perhaps 10 mc for active-satellites systems. The weak received signal is the factor which limits the permissible bandwidth in passive-satellite systems.

(e) *Receiver Sensitivity.*—Receivers having the best available sensitivity will be required, especially for passive-satellite systems.

(3) *Interference Factors.*—The fact that the signals received at the ground stations will be very weak will require that the receiving systems be virtually completely free from any man-made electromagnetic interference.

(a) The hovering satellite (at an altitude of 22,300 miles) will always be within line-of-sight of a large area of the earth (almost one-half of the earth's surface), so that it can receive signals from, and transmit signals toward, a tremendous number of electronic equipments.

(b) The Courier satellite will normally be at a much lower altitude than the hovering satellite, and will therefore be exposed to a much smaller area of the earth's surface. Also, it will receive and transmit signals only when in the vicinity of a ground station, so that the time periods during which interference can be caused or received is also reduced. However, the fact that the satellite receives and transmits during only short periods means that the system must not encounter destructive interference during these short periods or the system will be useless.

(c) Satellite-relay communication systems must operate at frequencies sufficiently high to allow their signals to penetrate the ionosphere with practically no transmission loss. Therefore, all signals emanating from the satellites and also all signals emanating from the earth at frequencies in the same band as the satellite system — *i.e.,* those signals most likely to cause interference to the system — will pass through the ionosphere with practically no loss. Hence for calculation of interference signal levels under line-of-sight conditions, free-space propagation can be assumed for signals in this frequency band — greater than 100 mc.

.2 Nuclear Effects.—Although to date there are limited data available on effects of nuclear explosions on communication systems, it is evident that severe degradation of operation can occur. Before an attempt is made to consider possible suppression techniques, it is necessary to discuss some of the phenomena resulting from nuclear explosions.

a. Observed Phenomena.

(1) *Parameters.*—The parameters of nuclear detonations that are significant with regard to the communication situation include altitude of detonation, yield or explosive power, time of day, geographic location, and various other conditions which determine pre-blast conditions and effect after-blast results. The possible results of such detonations, as they relate to some of these variables, are discussed in the following paragraphs.

(2) *Post-Explosion Effects.*

(a) In some ways the results of a nuclear explosion can be compared to the results of a solar storm: the ionosphere becomes highly ionized. In explosions occuring on the edge of space, some electrons immediately enter the upper atmosphere and may cause the glow of an artificial aurora. Other particles which are released may be captured by the earth's magnetic field and carried to the geomagnetic conjugate point where aother aurora occurs. If this effect is exploited, disturbances can be observed at great distances from the blast.

(b) In explosions originating in the lower ionosphere, primary and secondary gamma radiation may result in changes in the magnetic field many hundred miles away, and the upper atmosphere may be ionized to nearly daytime intensity. Also effects may be observed for many hundreds of miles due to electrons following the magnetic lines of force to the magnetic conjugate point, as mentioned above. Generally, however, because the explosions at the lower levels are influenced by the pressure of the atmosphere, and because of the faster neutralization of the particles released in the blast, the effects of these blasts are not so far-reaching as detonations in space.

(c) In time, the condition of excessive free electrons is alleviated naturally. This comes about by recombination with positive ions and/or attachment to oxygen molecules. In the high altitudes (90 to 120 miles), recombination, rather than attachment, is the predominant process, but this process occurs slowly; at middle altitudes (approximately 60 miles), both recombination and attachment are common; and, at low altitudes (less than 40 miles), electron attachment is predominant.

(d) A phenomena of extreme importance to the communication picture is the thin sheet of radiation which often forms around the earth after a nuclear explosion. This results from the particles from the blast being directed by the magnetic lines of force into the Van Allen belt, where they cause a significant increase in the total radiation present. They form this sheet within approximately one hour after the blast. The radiation eventually leaks out of the magnetic field, but disruption of communications, particular ly in the HF range, has been observed to persist for as long as two weeks. This layer of radiation may also have practical significance as an electromagnetic shield against air-to-space communications and surface radio contact with ICBMs, or at least it may put limits on the useful ground-controlled and interrogated trajectories of these missiles.

b. Effects on Communications.—Effects on communications systems resulting from nuclear explosions have been varied. They have ranged from virtually no noticed effect to complete "blackout" over hundreds of miles for many hours. It should be pointed out that the data and equipment performances noted are limited to only a few nuclear tests, and it is reasonable to assume that the blackout distances and times encountered might be even longer under other circumstances.

(1) *Particle Density.*—The influence on communications arises chiefly from the increased particle density. Resulting critical frequencies of 10,000 mc are not unreasonable. This means that the new ionosphere is essentially opaque to frequencies of say 50 to 10,000 mc whereas, before the blast, it was transparent over most of this frequency range. The actual limits on frequencies affected, and degree of degradation is directly related to altitude and yield of the explosion.

(2) *Aurora.*—Articicial aurora, as previously mentioned, are common occurances after nuclear blasts. They, in themselves, do not cause communication difficulties; however, other phenomena that occur at the same time do affect communications, so that it is generally true that, during these aurora, impairment results.

c. Suppression techniques.

(1) *Channel Selection.* — One possible method of combatting the nuclear effects to an electronic missile-defense system might be to raise the frequencies of system operation above the new critical frequency. This is theoretically always possible, but practically is often not feasible for various reasons. The relationships between the nuclear phenomena and the usable communication frequencies is not completly know, and it may be that other portions of the spectrum might be acceptable under certain conditions.

(2) *Control of Particle Density.*—A more sophisticated technique aimed at minimizing the nuclear effect is to attempt to neutralize the excess charges. This might be accomplished by supplying a gas which would combine with the charges, or facilitate recombination. This approach is theoretically sound, but questionable from the practical aspect.

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SECTION VI — BIBLIOGRAPHY

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SECTION VII — CHARTS AND NOMOGRAMS

3515. REFERENCE CHARTS AND NOMOGRAMS. —This chapter consists of charts and nomograms (or nomographs) of a supplementary nature to the main text material. The following list of figures and titles is given to assist in finding the particular chart required:

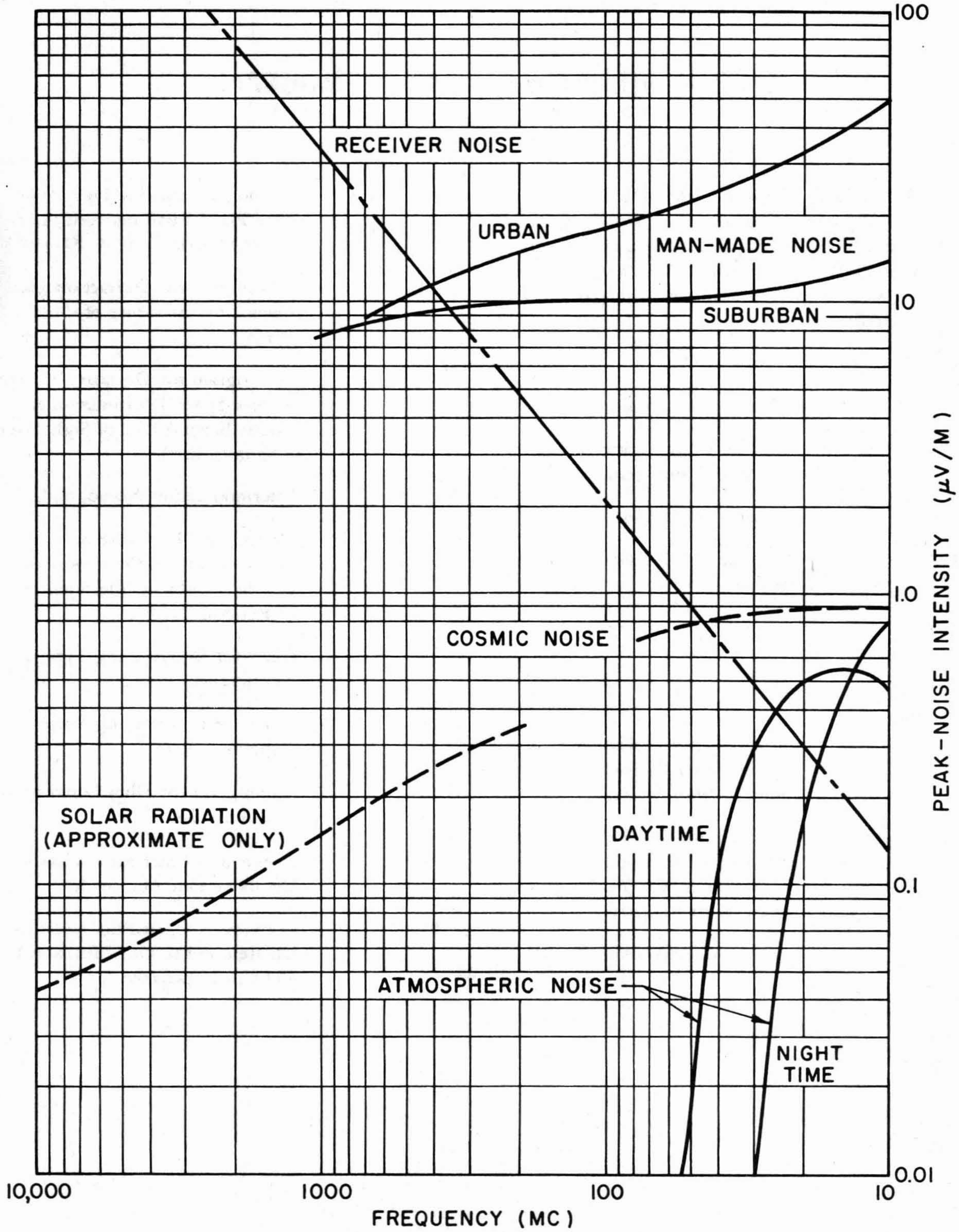


Figure 35-174.—*Sources of Radio Noise.*

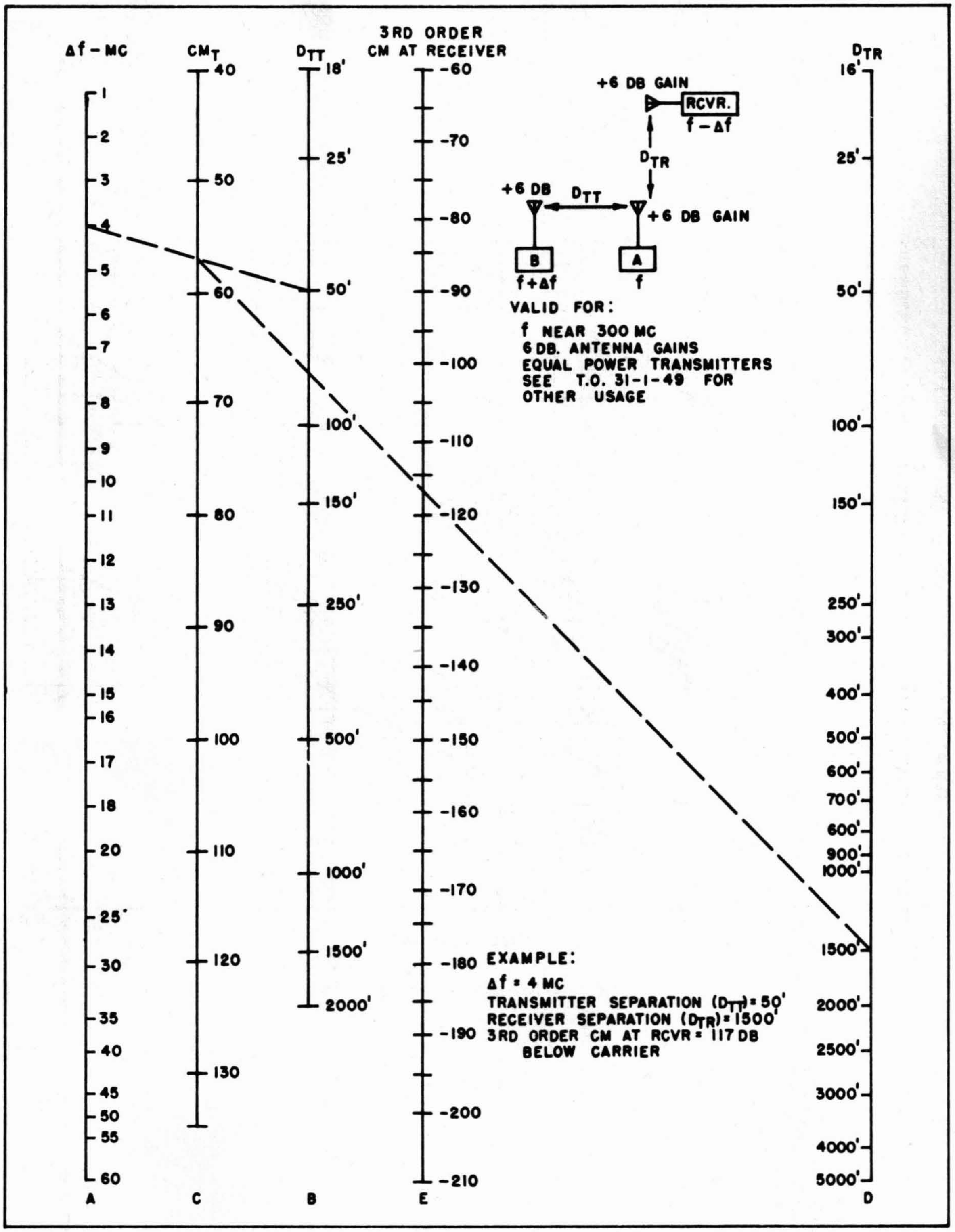


Figure 35-175.—*Third-Order Transmitter Cross-Modulation Nomogram.*

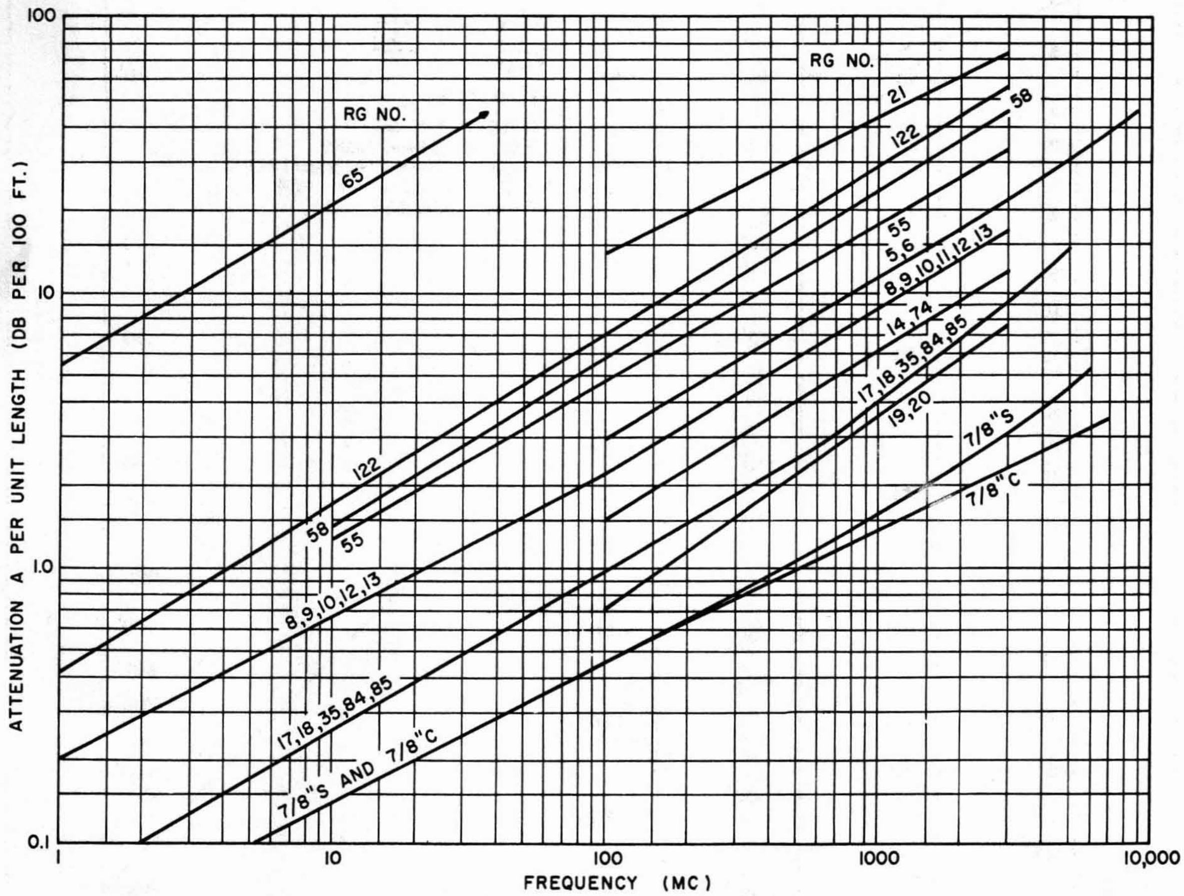


Figure 35-176.—*Attenuation of Cables.*

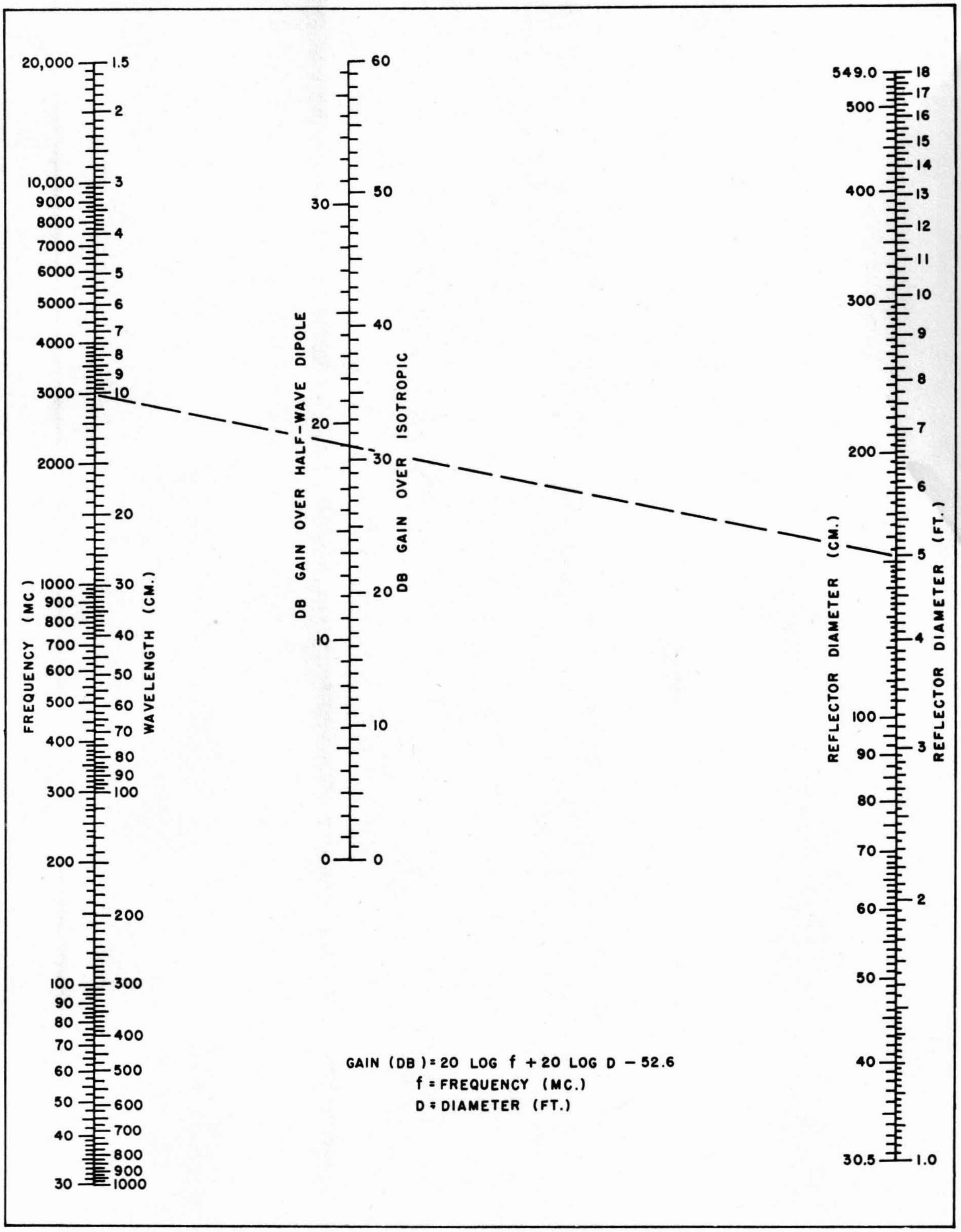
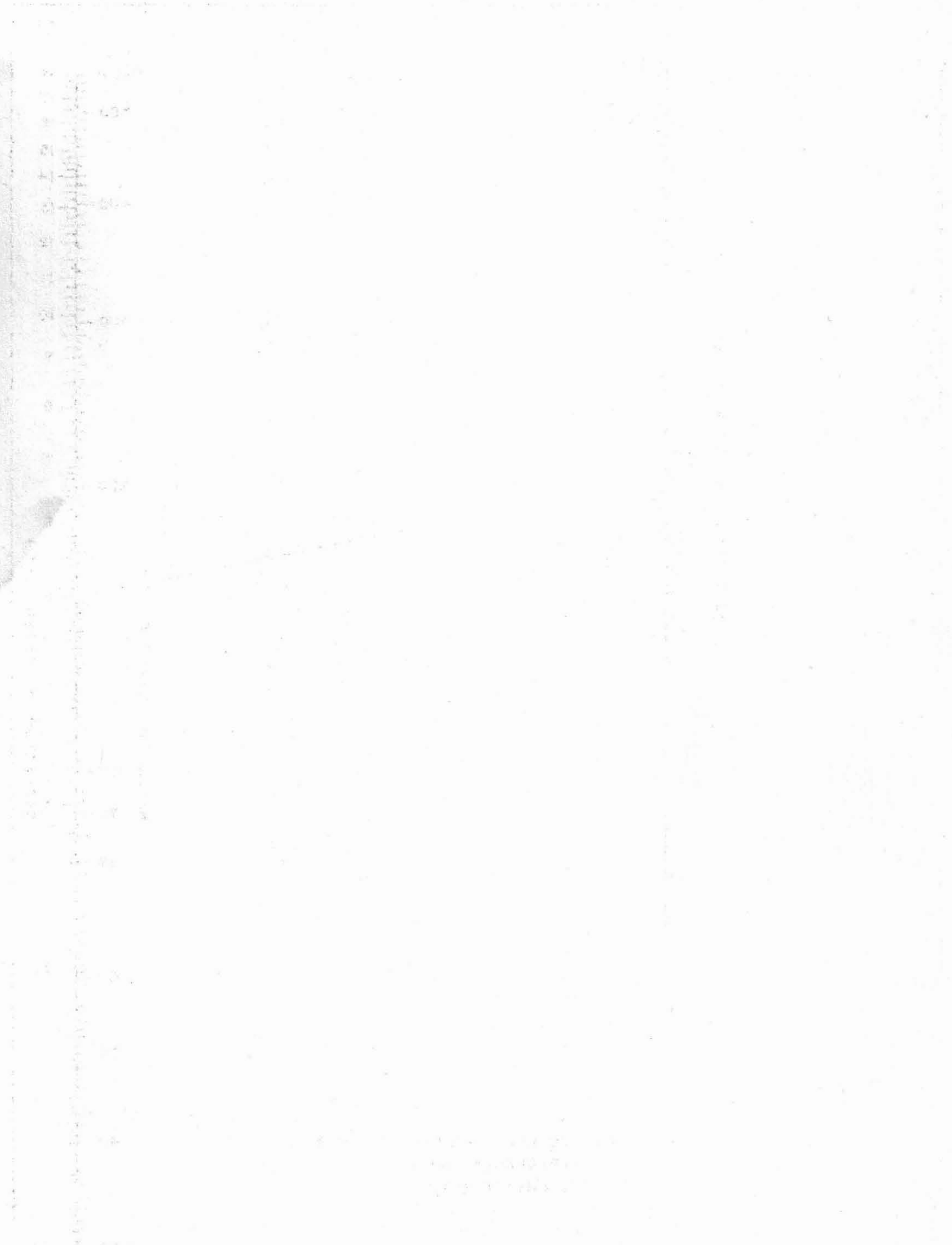


Figure 35-177.—*Nomogram for Gain of Parabolic Antennas.*



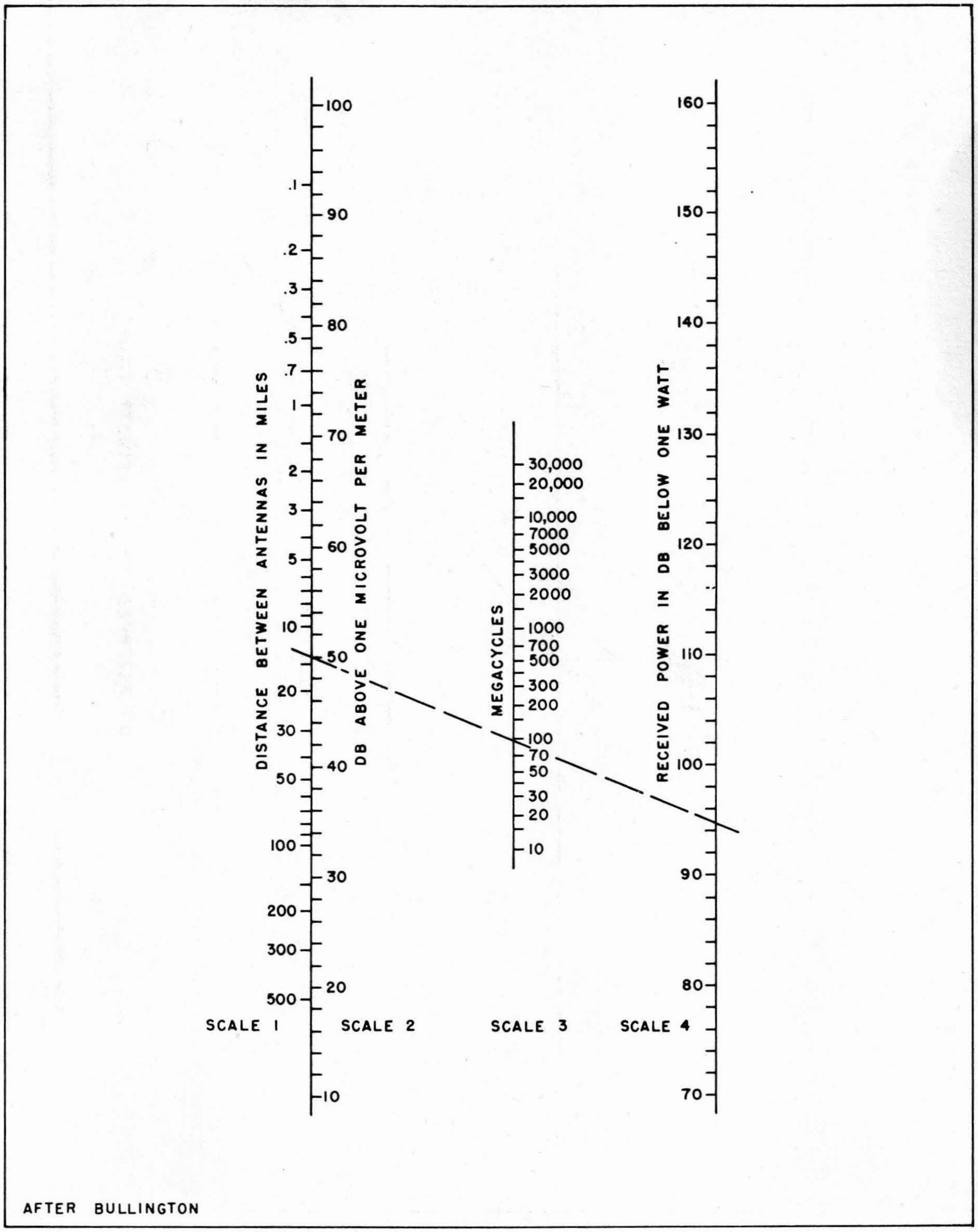


Figure 35-179.—*Nomogram for Free-Space Field Intensity and Receiver Power between Halfwave Dipoles, 1 Watt Radiated.*

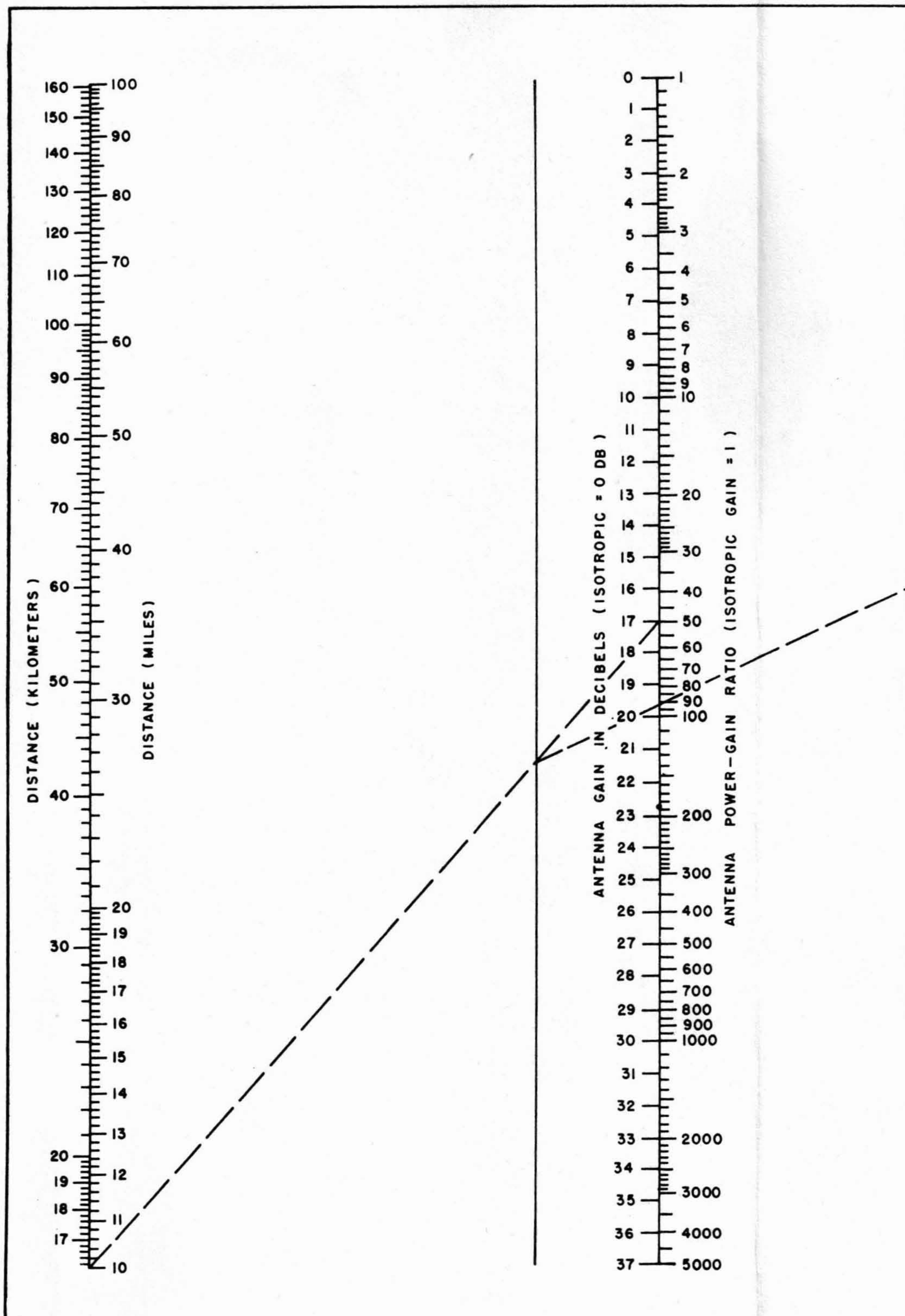
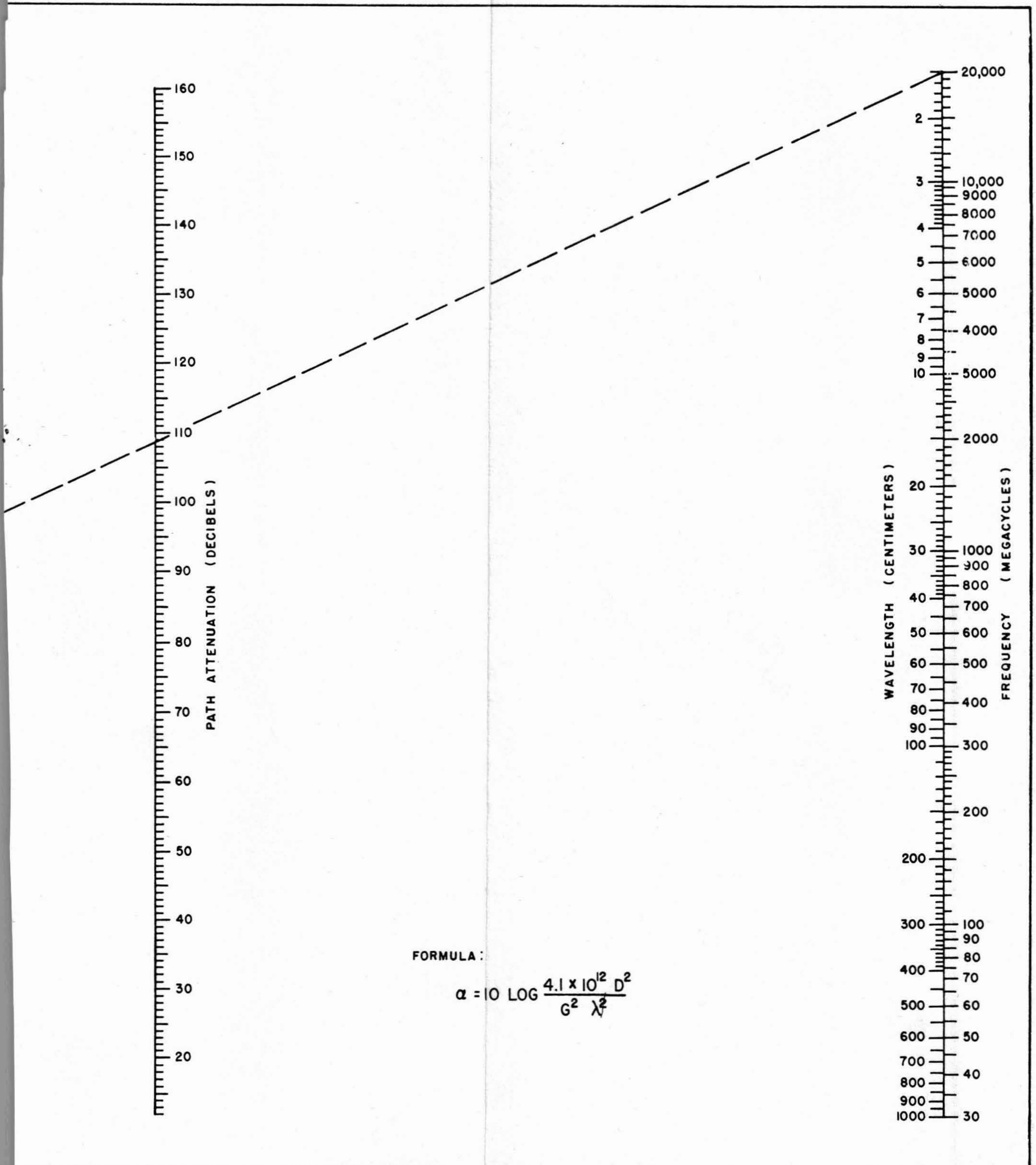


Figure 35-178.—*Nomogram fo*



Free-Space Attenuation between Identical Antennas.

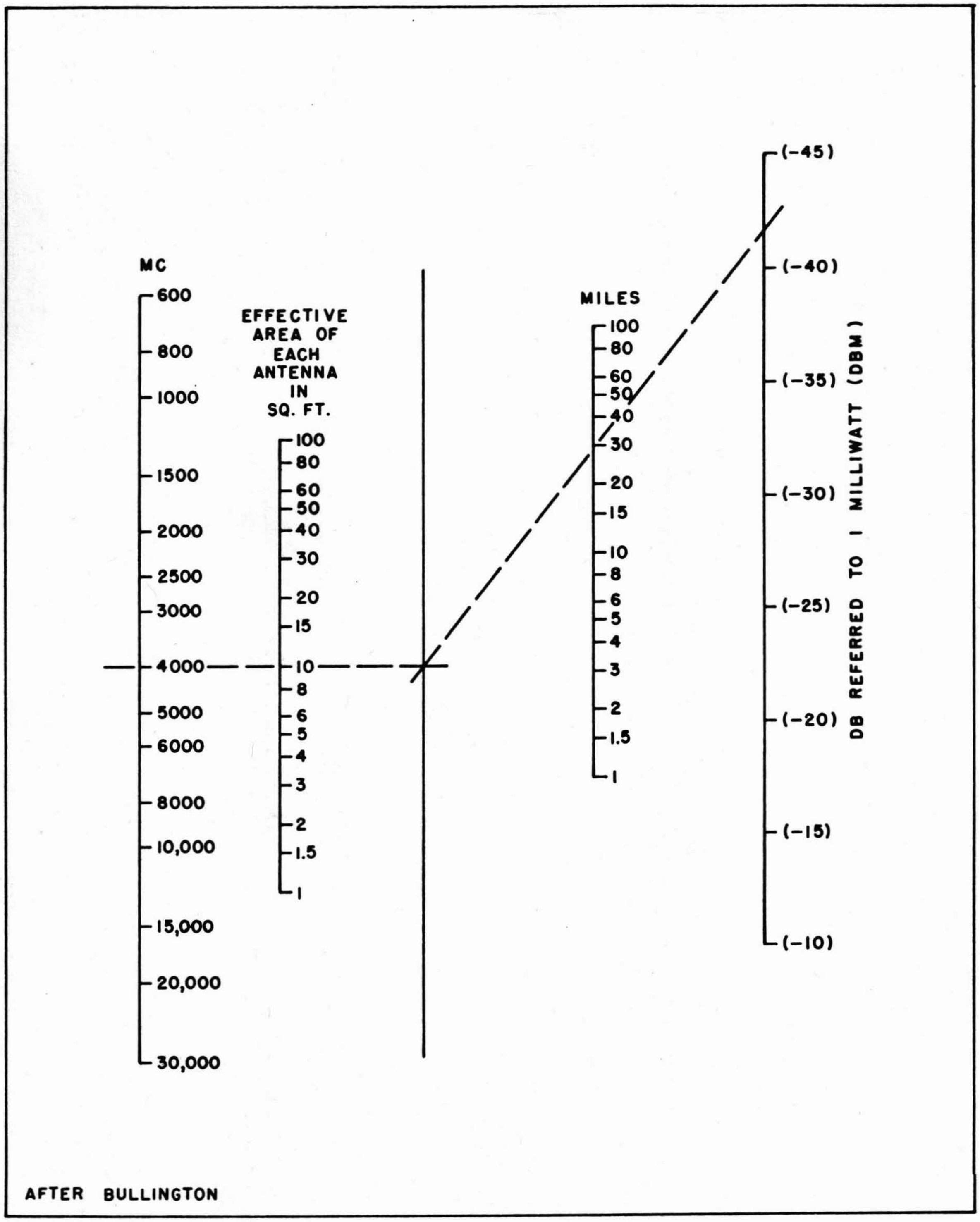


Figure 35-180.—*Nomogram for Received Power in Free Space between Two Antennas of Equal Effective Areas, 1 Watt Radiated.*

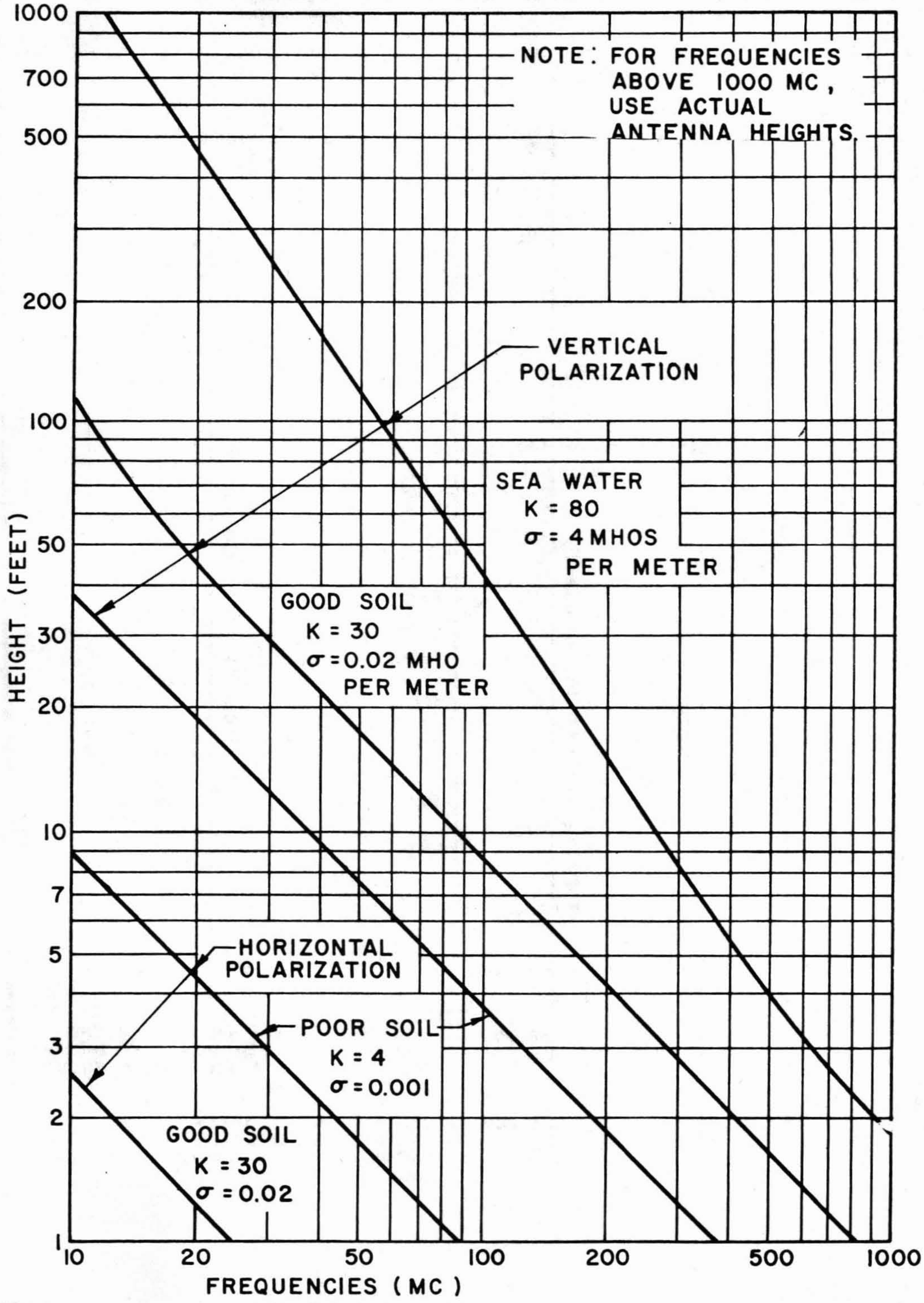


Figure 35-181.—*Minimum Effective Antenna Height.*

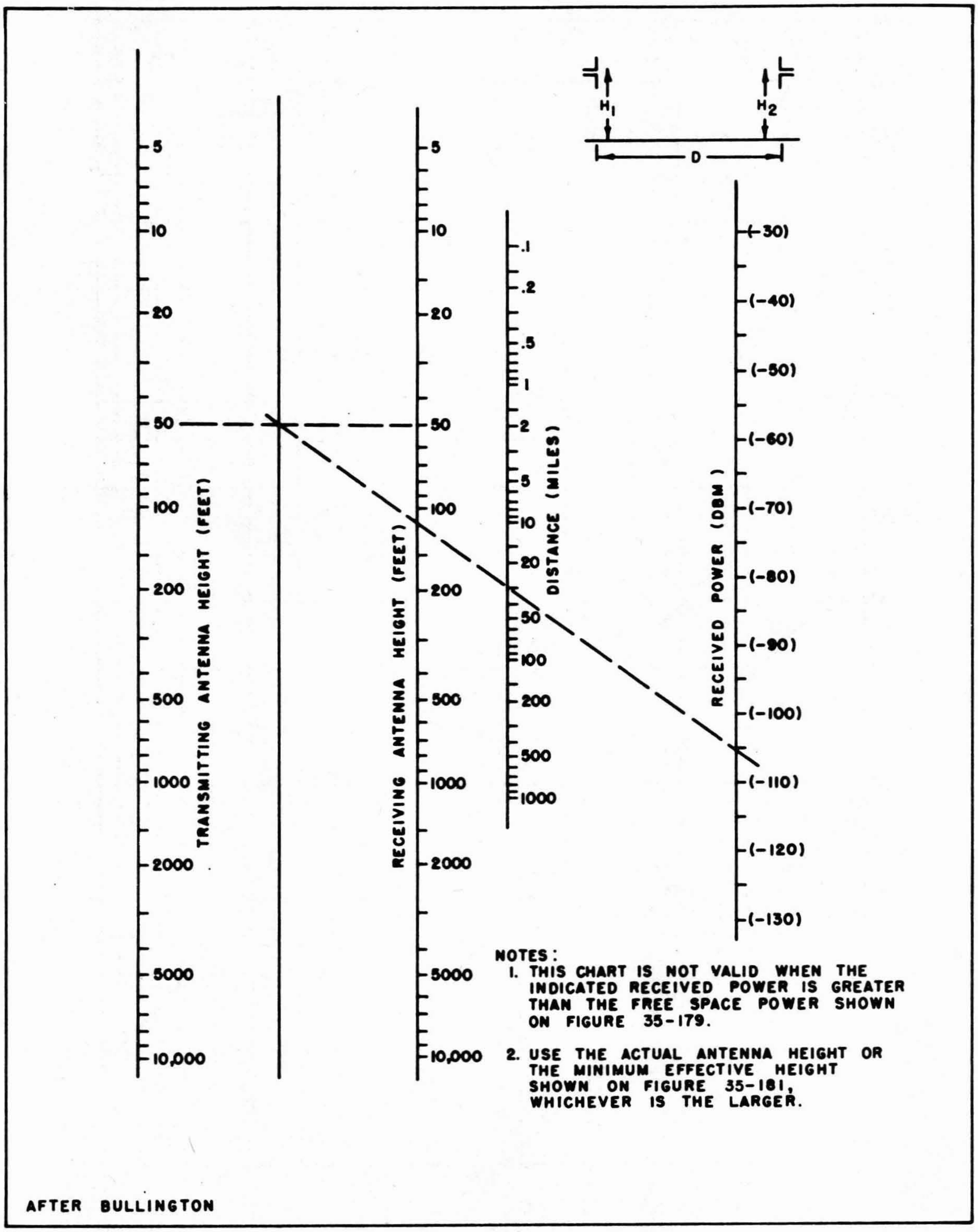


Figure 35-182.—*Nomogram for Received Power over Plane Earth between Half-Wave Dipoles, 1 Watt Radiated.*

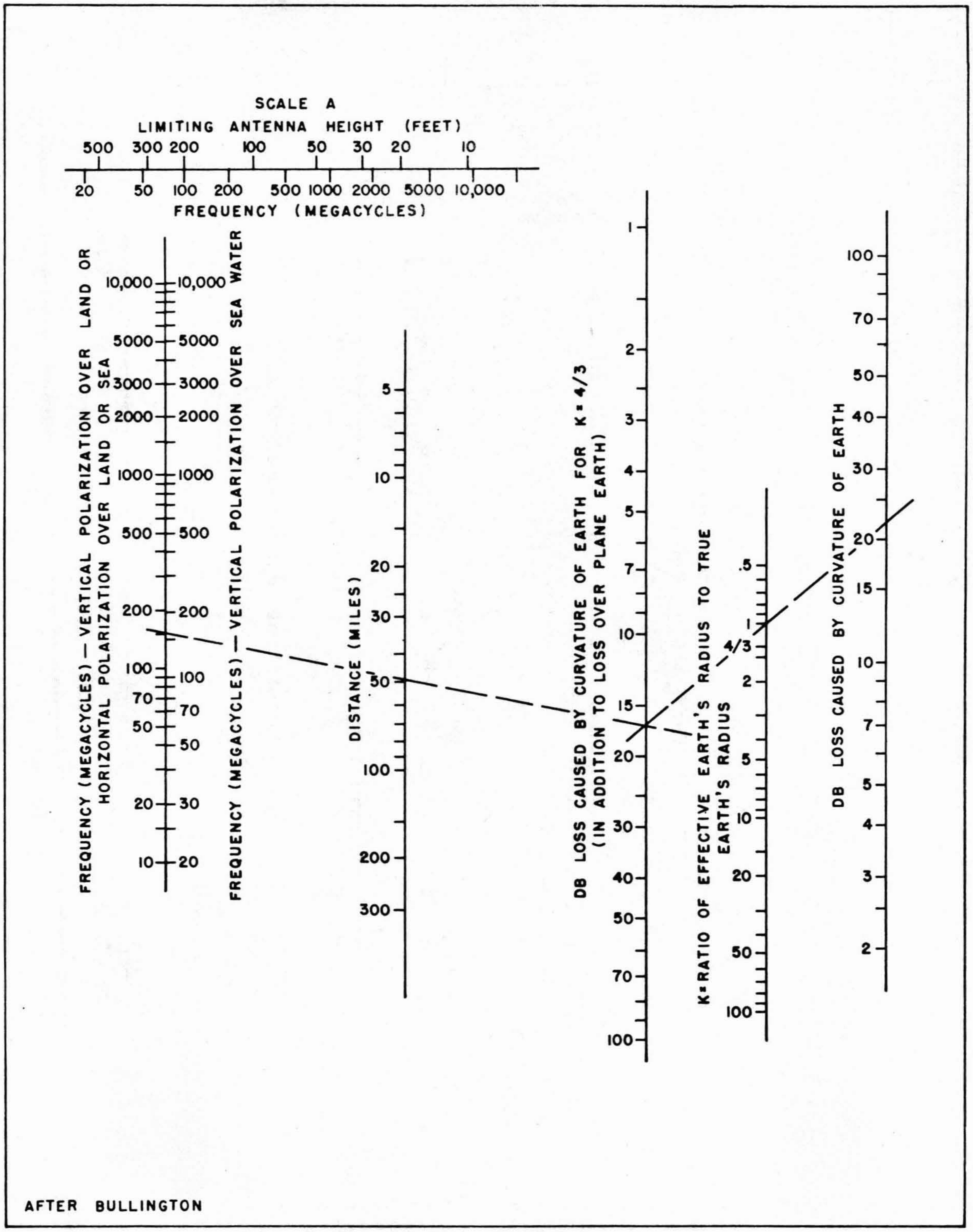


Figure 35-183.—*Nomogram for Diffraction Loss Caused by Curvature of the Earth.*

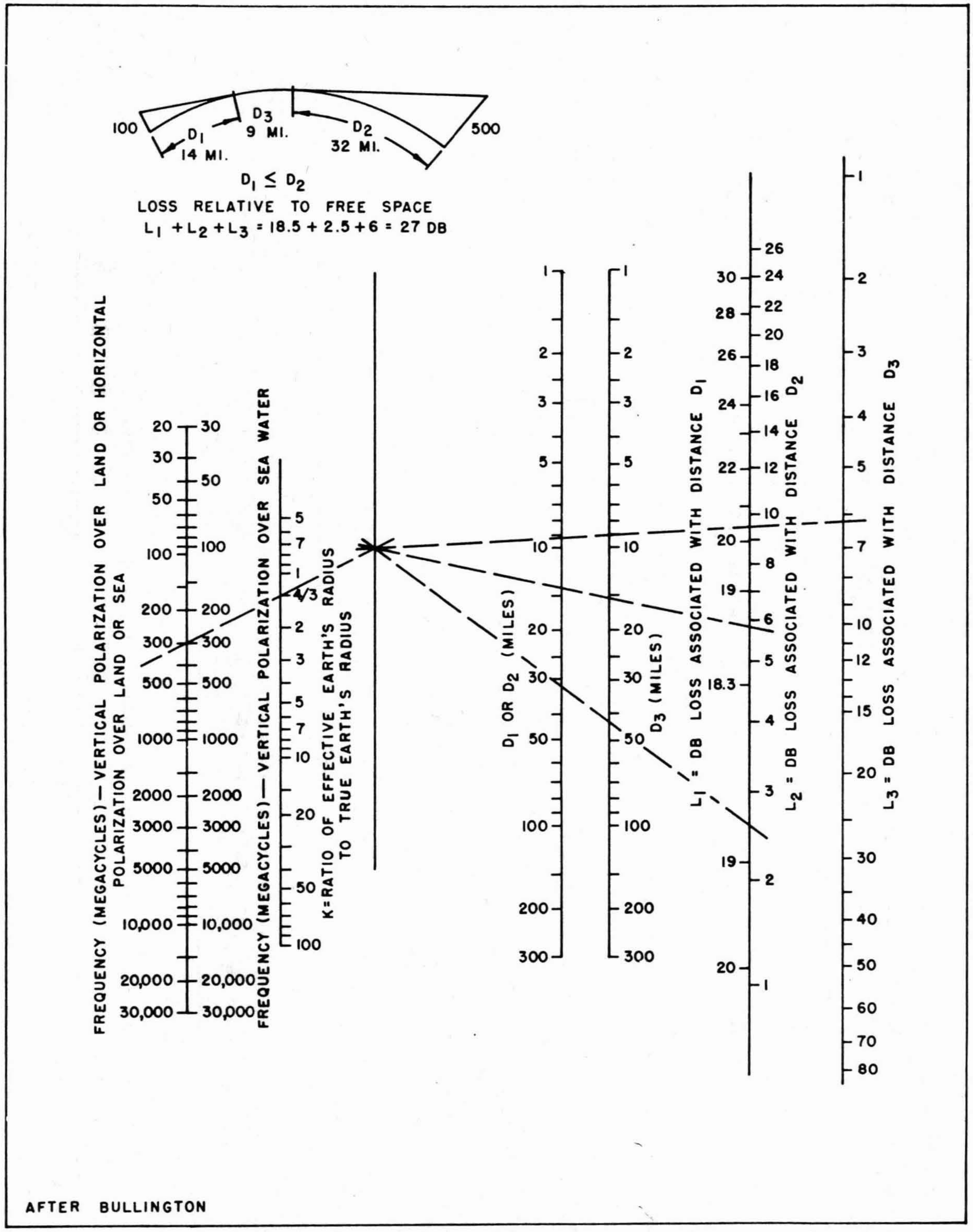


Figure 35-184.—*Nomogram for DB Loss Relative to Free-Space Transmission at Points beyond Line of Sight Over a Smooth Earth.*

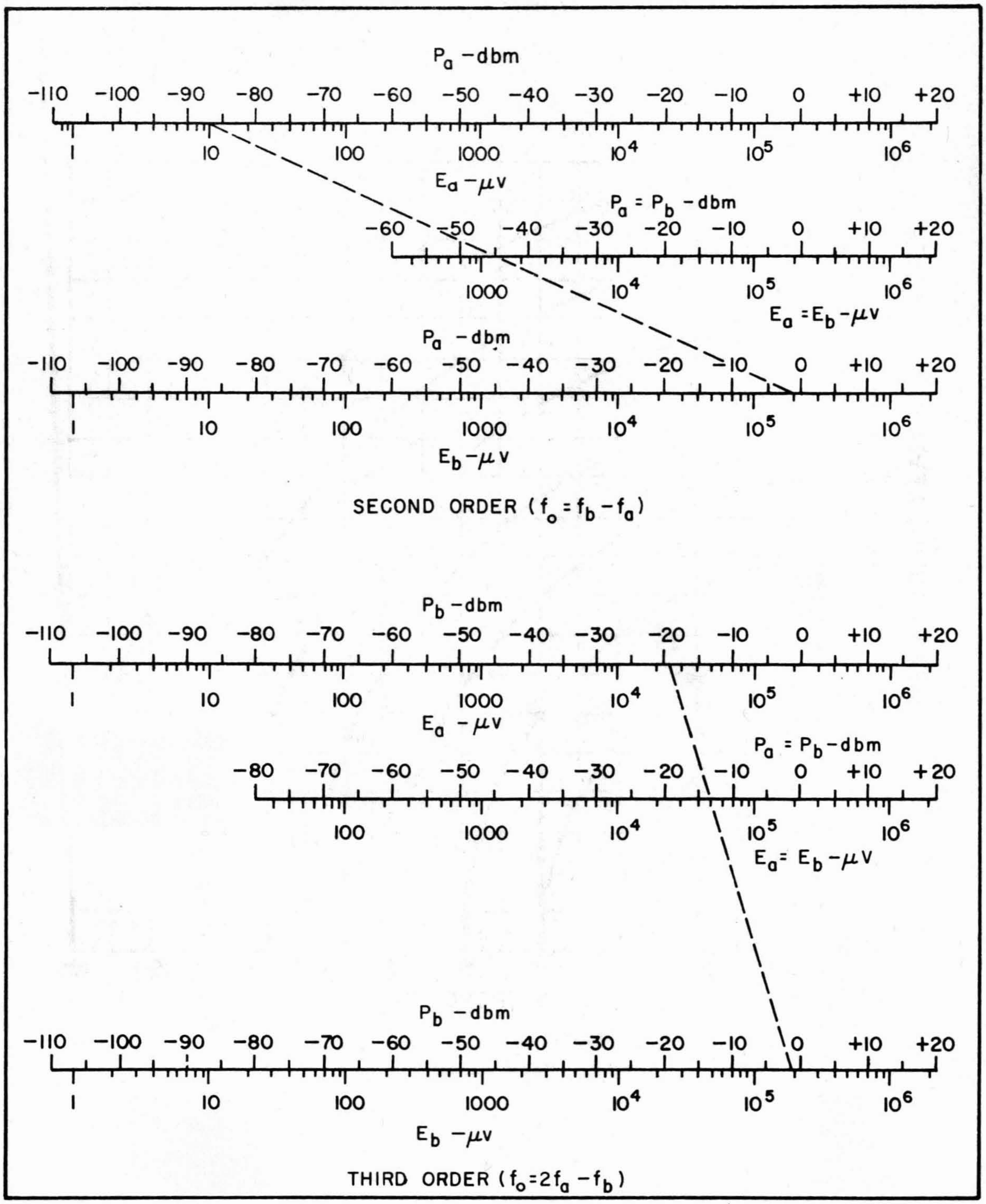


Figure 35-185.—*Intermodulation Nomograph.*

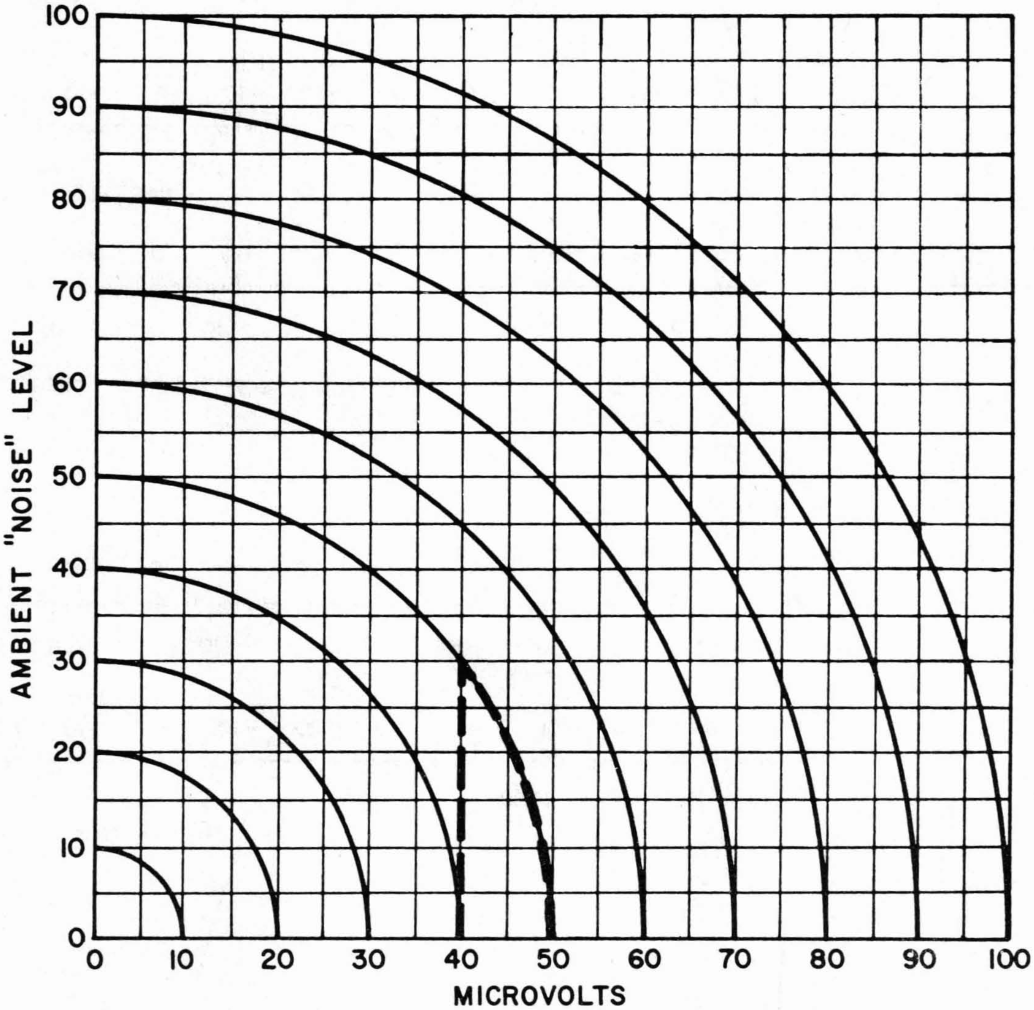


Figure 35-186.—*Correction Chart for Sine-Wave Signals in the Presence of High Ambient Interference of Random Nature.*

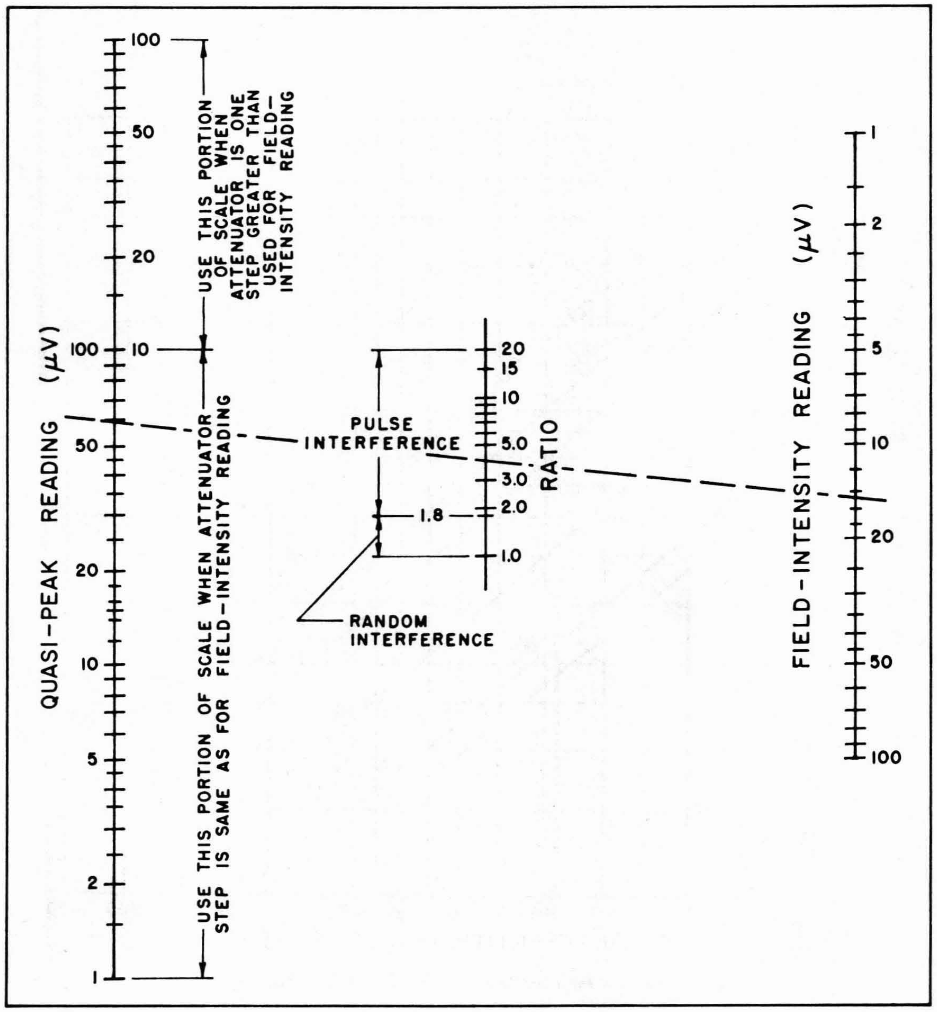


Figure 35-187.—*Chart for Determining Type of Interference.*

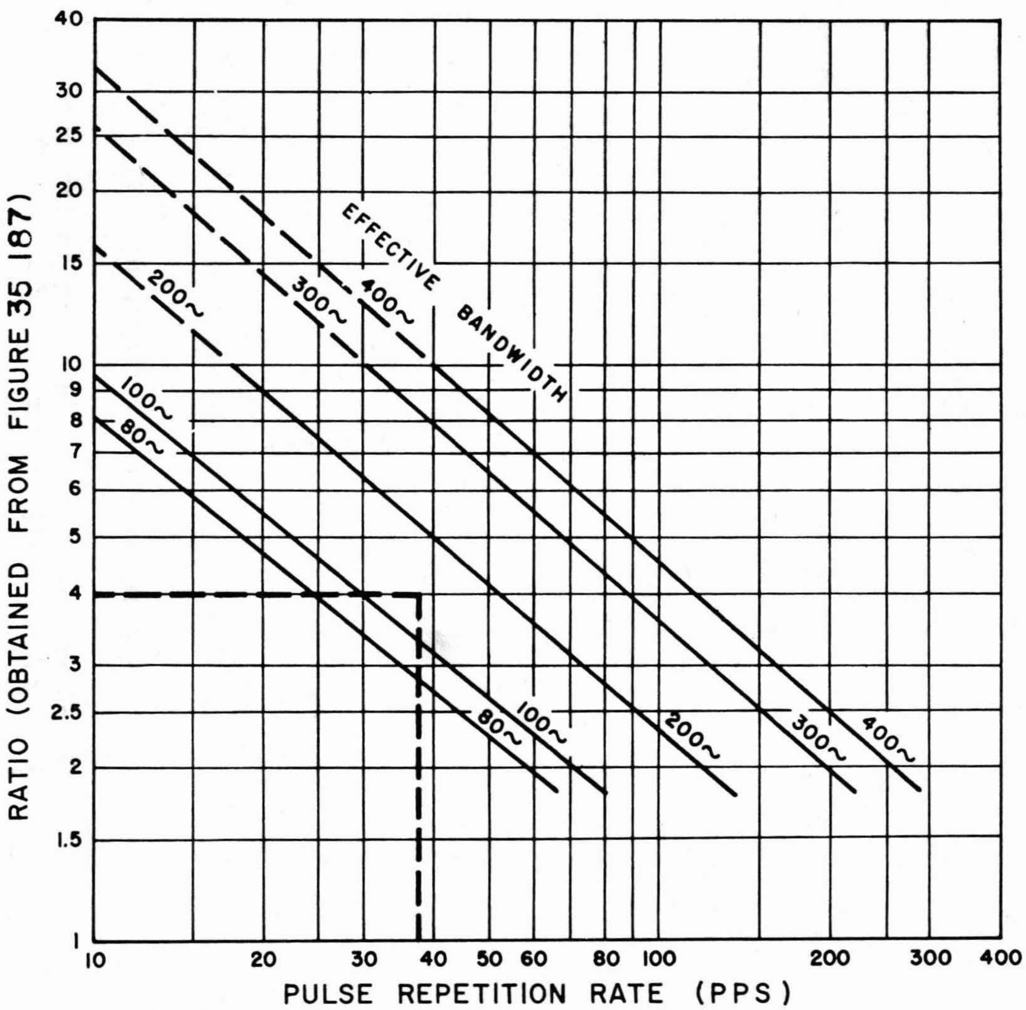


Figure 35-188.—*Chart for Determining Pulse Repetition Rate.*

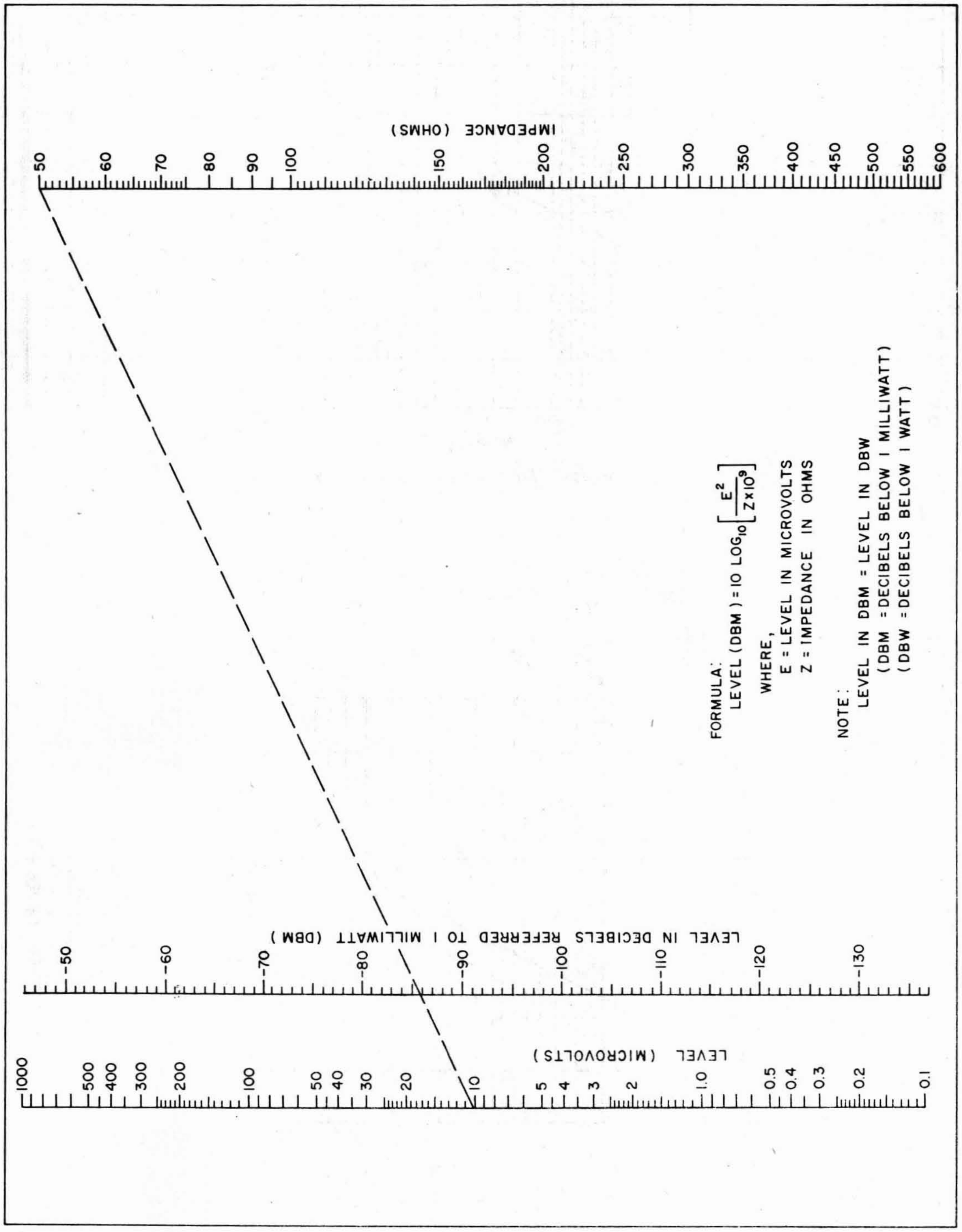


Figure 35-189.—*Nomogram for DBM Conversion to Microvolt.*

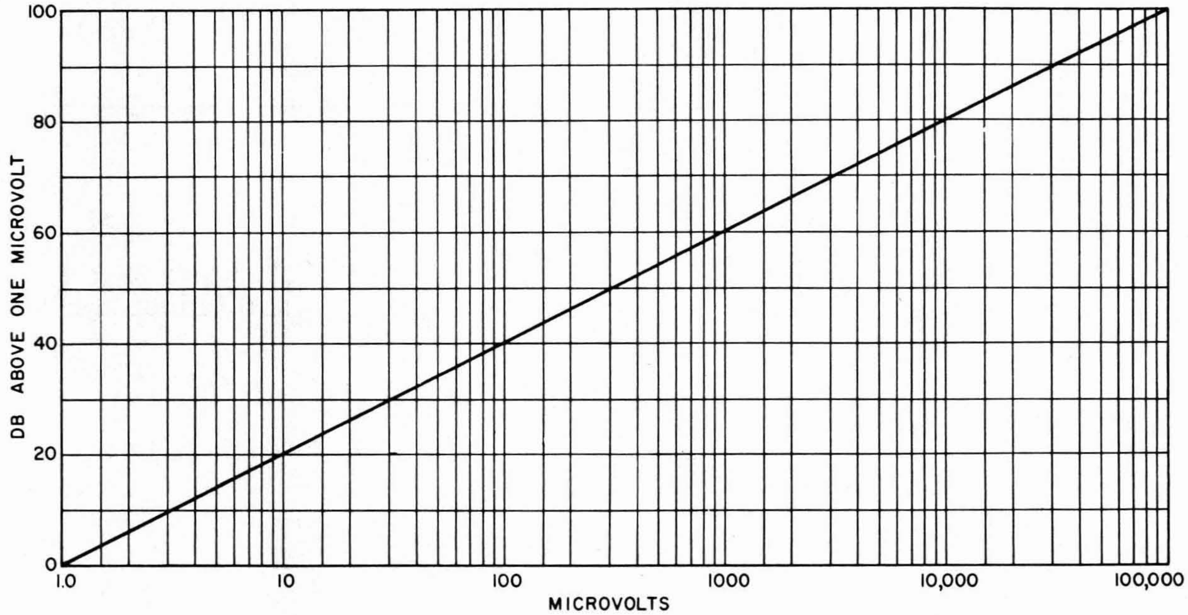


Figure 35-190.—*Conversion Chart-Microvolts to DB above One Microvolt.*

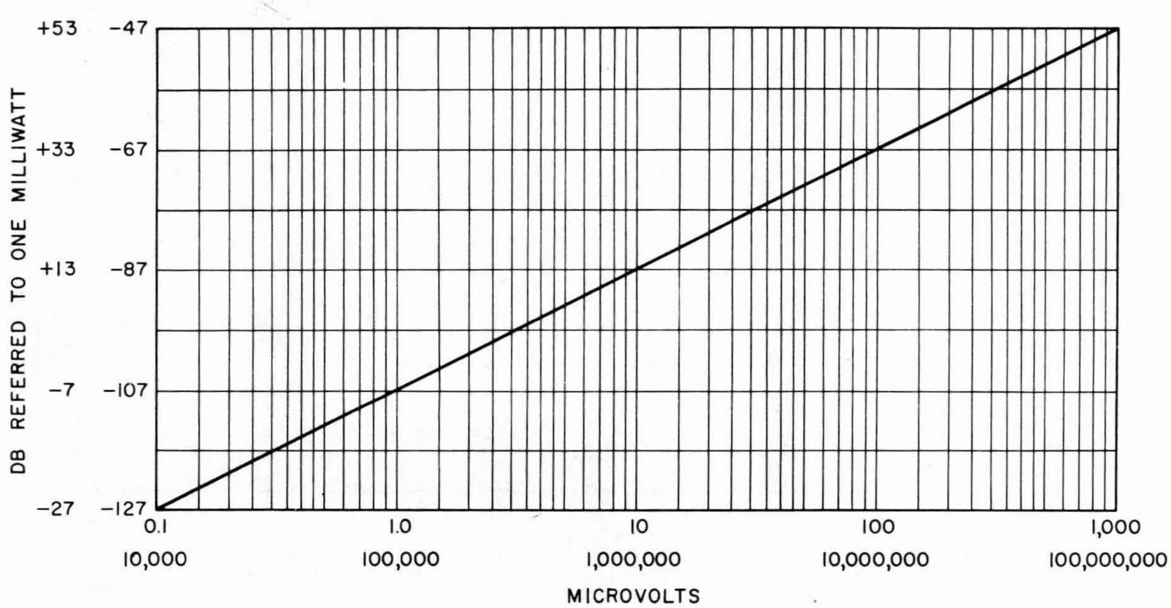


Figure 35-191.—*Conversion Chart-Microvolts to DB Referred to One Milliwatt for 50-Ohm Impedance.*

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