

CHAPTER 7

BASIC INSTALLATION CONSIDERATIONS

7.1 BASIC CONSIDERATIONS

The prevention or minimization of potential interference situations may be accomplished by various suppression techniques applied at either the source of the unwanted emissions, during the transmission stage, at the receiving (susceptible) equipments, or some combination of the three.

The ideal way of dealing with potential interference is by preventing or minimizing the generation of unwanted energy at the source; obviously if no potentially interfering emissions are generated, then no problem exists. Also, since an energy source can affect multiple equipments via a combination of radiated and conducted emissions, and because it is much more difficult (and costly) to suppress unwanted energy at susceptible equipments, suppression emphasis should be placed at the source.

Since it is not possible to prevent all potentially interfering signals from being generated or transmitted, the installation planner must sometimes devise measures to minimize the effects of undesired emissions that may gain entry into a device. Table 7-1 summarizes the areas which should be evaluated if an EMI problem is observed. Close attention to such factors as siting, grounding, bonding, shielding, and filtering during the installation planning stage will aid materially in achieving EMC and in reducing EMR hazards.

7.2 SITING

Siting is the term applied to the location of communications-electronics equipment within a given area to meet operational requirements. Implied within this definition is the achievement of optimum performance by siting to prevent or minimize the creation of potential interference situations.

In site planning, the individual equipment characteristic must be considered to obtain the optimum layout, i.e., is the equipment a fixed communications station? If so, is it a receiving facility or transmitting facility? What is the operating frequency, that is, is it UHF, VHF, etc.? Are transmitters and receivers to be located at the same site? Are rotating antennas used, as in search radars? What are the operational requirements? These, and many other factors will determine the final arrangement.

7.2.1 General Considerations

Surveys are made to determine suitability of a particular site for installation of electronic equipments. The following items are of interest from an EMC and hazards viewpoint, as well as an operational requirements viewpoint. Many other items are required for a complete survey.

a. Maps available of area showing general location of site (for example, state and county maps) attached to report.

b. Topographic maps of site area when available.

c. Site maps.

o A site map, to scale, showing the technical space requirements and proposed locations of antennas, transmission-line runs, electric and telephone outside-plant cable, and buildings.

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI

A. CIRCUITS TO BE SHIELDED AND FILTERED

- o Have the following EMI producing circuits been filtered in the EMI sources?
 - a. Chopper
 - b. Converters
 - c. Inverters
 - d. Relays
 - e. DC motors
 - f. Switches
 - g. Clock or timing circuits with fast rise time or high repetition circuits
 - h. Other circuits

- o Have transformer-rectifier (TR) outputs been filtered; was the transformer electrostatically shielded?

- o Has bandpass filtering been used on transmitter outputs or receiver inputs?

- o What type of electromagnetic field is being shielded against, E field or H field? Is the shielding material suitable for this type of field for the frequency range of interest?

- o Have decoupling capacitors been used on internal power connections?

- o Have any feed-through capacitors been used for internal connection of circuits? Or, as bulkheadmounted headers?

- o Have shielded subassemblies been used?

- o Have RF chokes and inductors been used to confine the RF energy to the desired circuits?

- o Were parts of internal chassis of equipment used to obtain shielding?

- o Have waveguide-below-cutoff techniques been used for chassis openings, such as tuning adjustments or air cooling?

- o Have low-level or susceptible circuits been physically separated from EMI producing circuits within an enclosure?

- o Have toroids been used to minimize the leakage field of inductors? Have inductors been cross-oriented to minimize coupling?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

B. METHODS OF ELIMINATING SPURIOUS EMANATIONS AND RESPONSES

- o Are components being operated in linear rather than nonlinear regions, if possible?
- o Are crystal-controlled circuits being used? Has the best choice of multiplier stages been made?
- o Have crystal filters, bandpass filters, tank circuits, tuned stages, and other narrowband devices been used?
- o Have RF trap circuits been used for known or expected spurious outputs or responses?
- o Have circuits been used which inherently discriminate against creation or passage of certain harmonics, such as push-pull outputs of amplifiers, balanced mixer-ring coupler combinations, or other hybrid circuits of a similar nature?
- o Have circuits of balanced or symmetrical design been used?
- o Have diodes or other biasing devices been used to establish definite minimum or maximum actuation levels for circuits?
- o Have coincidence circuits, time-delay circuits, or similar logic circuits been used ?
- o Have circuits using coded inputs or outputs been used ?
- o Has filtering been done at subsystem levels, especially multiplier stages?
- o Have RF circuits been decoupled from power supplies?
- o Have short-lead lengths been used in RF circuits? Has internal wire routing been controlled?
- o Has physical and electrical isolation of equipments and potentially capable of producing or of being susceptible to spurious energy been achieved?
- o Are internal subassemblies shielded and filtered to prevent undesired modulation?
- o Have components and devices been chosen to minimize frequency drift or random modulation due to temperature, aging, vibration, etc?
- o Are potentially susceptible equipment and circuits sufficiently shielded against external RF fields, including low-frequency magnetic fields?
- o Have special precautions been taken to prevent responses at receiver image frequencies?
- o Have shielded antenna inputs been used?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

- o Have operating frequencies been chosen to avoid conflicts with known existing frequencies or their harmonics?
- o Have the proper or excessive power levels of generated frequencies been used, such as the local oscillator stages or receivers or multiplier and output stages of transmitters?
- o Has circuitry (other than RF) of receivers and transmitters, such as power connections, telemetry connections, and monitoring points, been controlled to prevent RF coupling to other circuits?
- o Have any special methods been used to avoid spurious modes of operations of circuit elements, such as klystrons and oscillators?

C. METHODS OF ELIMINATING SPURIOUS RESONANCES

- o Have short-lead lengths been used where possible?
- o Has damping been used in circuits capable of oscillation?
- o Have feed-through capacitors been used for inter-stage coupling and isolation, and for power input connections to RF circuitry?
- o Have waveguide-below-cutoff techniques been used where possible?
- o Has the number of enclosures openings been minimized?
- o Have critical dimensions been avoided, considering the enclosure or subenclosure as an RF cavity?
- o Have tuning methods which minimize nodes or harmonic generation been used?
- o Have all feedback loops been designed to prevent oscillation under worst-case conditions?
- o Have high-power and low-power stage of units been isolated?
- o Is the bonding adequate at the known critical radio frequencies?
- o Have component tolerances been controlled to prevent frequency drift, mode switching, etc., due to temperature, aging, etc?
- o Have RF components been used throughout RF stages, (i.e., have components been used that are not self-resonant in the intended frequency range, unless desired)?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

C. METHODS OF ELIMINATING SPURIOUS RESONANCES

- o Have special circuits which discriminate against spurious resonance been used?

D. METHODS OF OBTAINING CONTINUOUS SHIELDING ON EQUIPMENT USING PRESSURE OR HERMETIC SEALS

- o Have the equipment enclosures been mechanically designed to assure sufficient pressure between mating parts?
- o Have the equipment chassis been mechanically designed to minimize the number of openings and open leakage?
- o Has each opening in equipment enclosure been analyzed to determine the need for gaskets, waveguide-below-cutoff techniques, screening, etc?
- o Has the minimum attenuation needed by the enclosure been evaluated?
- o Are openings and attenuation consistent? If not radiation through the metallic portion of the enclosure will occur, leakage will normally determine minimum overall enclosure leakage, except at low frequencies.
- o Do the mating surface pressure, area, finish, or tolerances degrade the expected attenuation of the enclosure seams?
- o Have dissimilar metals been used in the installation, is this compatible with the expected environment?
- o If RF gaskets have been used, is the design adequate to optimum pressure, class of joint, or seam, choice of gasket mounting, size of gasket, attenuation of gasket, etc?
- o What are the expected internal and external electromagnetic fields and frequencies?

E. THICKNESS OF CASE MATERIAL REQUIRED TO PROVIDE ADEQUATE SHIELDING IN HIGH POWER RF EQUIPMENT

- o Are there expected internal and external fields and frequencies? What is the physical location of the equipment to other equipments?
- o Is the enclosure thickness adequate to attenuate the expected fields to a tolerable level ? Is the thickness and weight excessive?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

E. THICKNESS OF CASE MATERIAL REQUIRED TO PROVIDE ADEQUATE SHIELDING IN HIGH POWER RF EQUIPMENT

- o How is the estimated additional attenuation to be provided?
- o Is composite shielding provided by enclosure, sub-enclosure, waveguide-below-cutoff openings, gasket seams, screened openings or normal making surfaces?
- o Does associated external cabling degrade the required attenuation levels?

F. SELECTION OF INTERFERENCE-FREE COMPONENTS TO BE USED WITH OTHER COMPONENTS

- o Are diodes or other suppression components being used across relay coils?
- o Are RC circuits being used across switch or relay contacts?
- o Are solid-state switches being used instead of mechanical switches?
- o Are capacitors being used directly across DC motor brushes?
- o Are electrostatically shielded transformers being used?
- o Are matched diodes being used in balanced mixers?
- o Are toroids or other low leakage field inductors being used?
- o Are nonself-resonant components, such as feed-through capacitors, being used?
- o Are bulkhead-mounted components being used?
- o Are crystal filters being used?
- o Are separate connectors being used for sensitive and EMI producing circuits?
- o Are twisted pair, twisted triad, or shielded wire being used?
- o Is balanced-circuit design being used?
- o Are diodes or other bias devices being used to establish definite maximum or minimum actuation levels?
- o Are connectors being used as inherent parts of filter?
- o Are crystals being used as frequency sources?
- o Are selective waveguide or coaxial components, such as diplexers, being used?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

F. SELECTION OF INTERFERENCE-FREE COMPONENTS TO BE USED WITH OTHER COMPONENTS

- o Are lossy line techniques being used to attenuate harmonics?
- o Are temperature-compensated components being used to minimize drift, etc?
- o Are components being operated in linear regions?
- o Are limiting devices, such as diodes, being used?
- o Are DC blocks being used?

G. OTHER PERTINENT INFORMATION

- o Are there any special type circuits which intentionally or unintentionally eliminate or minimize EMI? Examples might be blanking circuits, time-sequencing circuits, disabling circuits, bridge or differential type of circuits, balanced input circuits, possibly AGC,AFC, and AVC circuits.
- o Is there any bonding information that has not been previously covered?
- o Is there any circuit uniqueness due to special signal or modulation characteristics?
- o Is there any antenna data that could be included which could influence the EMI characteristics of transmitters or receivers?
- o Is there any sharing of antennas, or time sharing, or switching of antennas? If so, has it been proved feasible.
- o Are there any transmission line or antenna devices present, such as RF isolation, whose losses or bandwidth would be pertinent?
- o Have sources of primary power been fully covered? Are there any usual characteristics of primary or secondary power sources?
- o Is there any circuit redundancy which might affect EMI control?
- o Have the most susceptible equipments and circuits been identified? Have the greatest EMI producing equipment and circuits been identified?

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- o Additional maps as required showing locations of the transmitting and receiving antennas with respect to the reflection zones.
- d. Photographs of the site may be required to illustrate unusual features or special problems.
- e. Reflection terrain profiles, as may be indicated.
- f. Tidal or seasonal water-level data and analysis of its effect on site adequacy in the case of water reflection terrain.
- g. Horizon profiles taken from the antenna and from other locations as required to define situations where horizon- clearance angles may be a problem.
- h. Elevation angle of the horizon at design azimuth and an estimate of distance from site to the obstruction.
- i. Profiles and other data needed to establish suitability of local radio-relay paths.
- j. Ambient noise or interference estimate, or report of measurements.
- k. List of radio, radar, and television frequencies in use, or proposed for use, in the immediate area. Distances and antenna directivities, transmitting and receiving facilities, output-power levels.
- l. Interaction with radar, direction-finding equipment, VHF omnidirectional range, tactical air-navigation systems, or radio beacons.
- m. Estimate of seasonal influences likely to affect suitability of the site.
- n. Any problems of compatibility with existing facilities. Examples are:
 - o Noise, hum, and frequency response of telephone lines.
 - o Terminal facilities: teleprinter speeds, station battery voltage, and available capacity levels for voice inputs and outputs.
 - o Technical factors relating to the adequacy of the site, particularly with respect to sources of emissions and potential signals interference and, when appropriate, requirements for communications between sites and traffic control centers. This should summarize conclusions with respect to the overall technical adequacy of the proposed site.

7.2.2 Detailed Considerations

Detailed siting criteria for communications equipment may be found in Naval Shore Electronics Criteria Handbooks NAVELEX 0101,102; 0101,103; 0101,104; and 0101,105. Siting criteria for other electronic systems will appear in an appropriate volume of the Criteria Handbook Series when it is published.

7.3 GROUNDING ELECTRONIC SYSTEMS

The basic purpose of earth ground is, in general, to hold electrical and/or electronic equipment at or near earth potential. This in turn, provides for the required safety of personnel and, if properly designed, improves the operation and continuity of service of all electronic configurations. Considering all the variables, it is practically impossible to design an earth grounding system which can be used as a standard.

7.3.1 Requirements Of A Satisfactory Ground Connection

A ground connection, regardless of its application, must meet certain specifications. The electrodes, buried in the ground to form an electrical connection to earth must themselves be good electrical conductors and be capable of resisting corrosion while in contact with the soil. In addition, the electrodes must be capable of withstanding mechanical abrasion and have sufficient area in contact with the soil so that the ground resistance is within the rated limits. The resistance of this earth path must remain reasonably constant throughout the seasons of the year and must be unaffected by the circulating currents resulting from the equipment configuration to which the connection is made. In short, ground connections should be durable, have low DC resistance, low AC impedance, sufficient current carrying capacity, and of such design that provides for ease of installation and maintenance.

7.3.2 Factors Affecting Earth (Soil) Resistivity

The range of earth resistivity may vary from several ohms/cm³ to several million ohms/cm³. This variation is due to the electro-chemical action in the soil and is dependent upon the moisture and temperature, as well as the composition of the soil.

a. Effects of Soil Composition. The most general data on earth resistivity considers the type of soil and not the environmental conditions. Data collected by the National Bureau of Standards listed in Table 7-2 indicates a wide variation in soil resistivity dependent upon the composition of the soil. This table demonstrates that a ground connection that might be satisfactory in one type of soil would be totally inadequate in soil of another composition. Samples taken from different locations of similar soil composition, when measured, have sometimes varied by a factor of 200 to 300 percent.

Table 7-2. Resistivity of Different Soil Composition

SOIL	RESISTANCE (OHMS) 5/8 in. x 5 ft. RODS			RESISTIVITY ohms/cm ³		
	Avg.	Min.	Max.	Avg.	Min.	Max.
Fills, ashes, cinders, brine, waste	35	14	41	2370	590	7000
Clay, shale, gumbo, loam	24	2	98	4060	340	16300
Same-with varying proportion of sand and gravel	93	6	800	15800	1020	135000
Gravel, sand stones, with little clay or loam	554	35	2700	94000	59000	458000

b. Effects of Environmental Changes on Soil Resistivity. Variations of soil resistivity with moisture are important since what might have been considered an excellent ground connection might become, due to fluctuations of moisture content with the changing seasons, a high resistance ground connection that would compromise the ground system. Dry soil has such a high resistivity that it functions as an insulator. The effect of moisture upon soil resistivity is illustrated in figure 7-1. The resistivity increases abruptly between 10 and 20 percent with a slight decrease in moisture content. Table 7-3 illustrates the variations of resistivity in two dissimilar samples of soil as the moisture content is increased. The resistivity of the samples vary greatly until, with 30 percent moisture content, one sample measures 6,400 ohms/cm³ and the other 4,200 ohms/cm³. As important as moisture content is, it is not always the predominant factor in determining low resistivity of soil. A ground rod driven in the bed of a mountain stream in which the water is devoid of organic and inorganic impurities would not conduct readily and would introduce a high resistance connection between the electrode and earth. Unless the soil contains sufficient soluble mineral elements to form a conducting electrolyte, an abundance of moisture will not provide the soil with adequate conductivity.

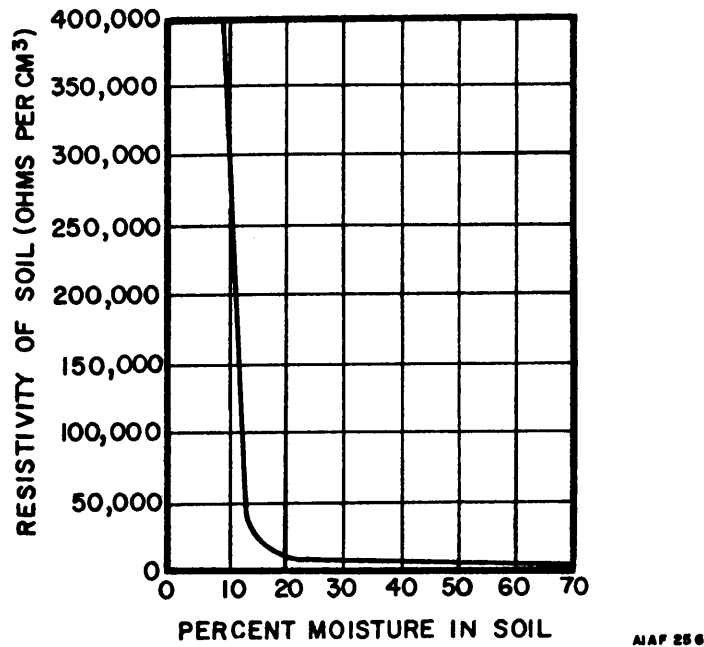


Figure 7 - 1. Resistivity vs. Moisture Content for Red Clay Soil

Table 7-3. Variations of Resistivity in Two Dissimilar Samples of Soil

PERCENT MOISTURE CONTENT (per cm by wt)	RESISTIVITY ohms /cm ³	
	Top Soil	Sandy Loam
0	Over 1 billion	Over 1 billion
2.5	250,000	150,000
5.0	165,000	43,000
10.0	53,000	18,500
15.0	19,000	10,500
20.0	12,000	6,300
30.0	6,400	4,200

Ambient temperature is another environmental change that will influence soil resistivity. This is graphically illustrated in figure 7-2. As the temperature approaches the freezing point of water, the resistivity of the soil increases sharply. Consequently, it would be suspected that soils with high moisture content would be particularly troublesome if the temperature falls below the freezing point for an extended period of time. These two variables - temperature and moisture are part of the seasonal environmental changes; their effects work simultaneously as the seasons change. Figure 7-3 relates these changes over a period of 18 months. Also note that these reactions are more prevalent on the surface of the soil.

7.3.3 Earth Connection Design Considerations

In order to provide a low impedance ground connection for any ground system, a study of local soil characteristics is mandatory. The standard equations used to determine the effectiveness of a ground electrode or the electrode resistance to earth assume a uniform soil structure in contact with the electrode to the depth driven. The resistance of an earth connection will be that offered to current flow within six to ten feet surrounding the electrode (see figure 7-4). Ninety percent of the current distribution into the soil is within this area. Tests conducted by the National Bureau of Standards have shown that the contact resistance between the electrode and the soil can be considered negligible when compared to the resistivity of the soil itself.

a. Current Loading Capacity. A ground connection is a resistance connection mainly confined to the volume of earth immediately surrounding the electrode. As ground current flows through the ground electrode, heat is generated that follows the I^2R heat loss pattern. Like all resistors, this ground connection can be damaged if excessive current is passed through it for an appreciable length of time. The heating effect causes the temperature of the soil surrounding the electrode to rise, drying out the soil. The loss of moisture causes the electrode contact resistance to rise and, consequently, there is a reduction in the current dissipation rating of the connection. When selecting a particular ground electrode configuration, it is important to achieve as low a contact resistance as cost factors will permit. For ground currents that will flow for a relatively long duration, soil conditions alone control the current capacity. When designing the ground configuration for employment of this type, it must be appraised only in terms of desired resistance.

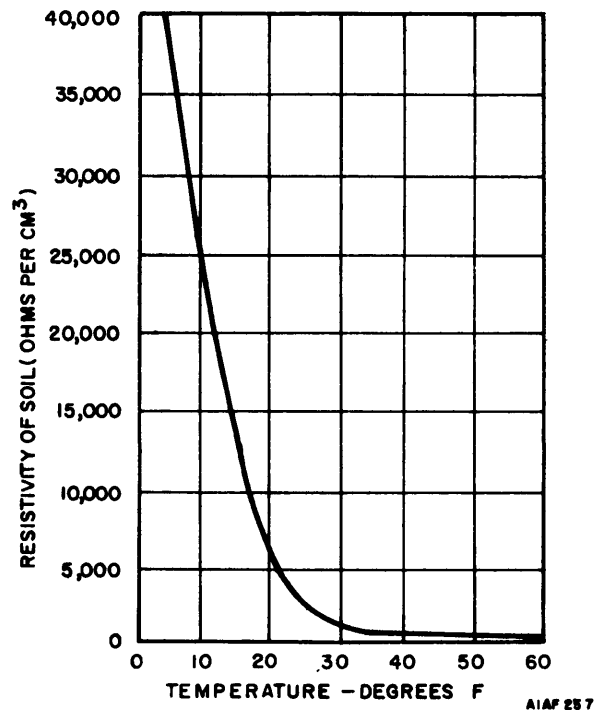


Figure 7 - 2. Variation of Soil Resistivity with Temperature

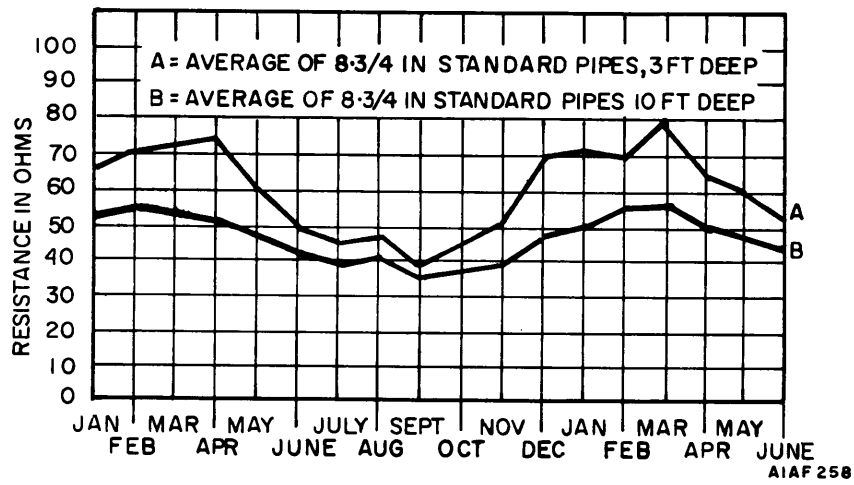


Figure 7 - 3. Variation in Resistance of Pipe Grounds with Months

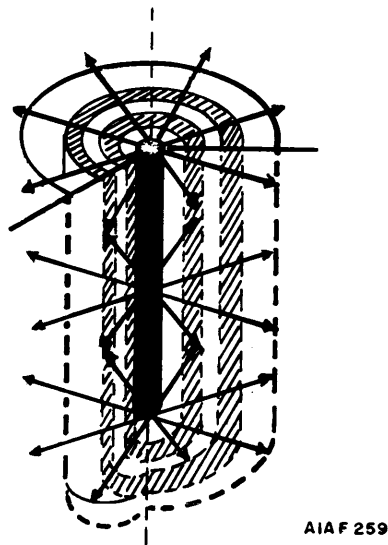


Figure 7 - 4. Current Distribution About a Ground Electrode in Earth

b. Variations of Ground Impedance with Frequency. Grounding systems are inherently dependent on the frequency of energy to be dissipated into the earth. At 60 hertz and low frequencies, the impedance is generally resistive and a good electrode to earth contact is all that is required to provide adequate grounding. As frequencies go higher the reactive term becomes the predominant and controlling factor. At frequencies below 5 kHz, capacitance exists between the buried ground electrode and the surrounding soil. If alternating current is impressed on the electrode, the resultant current will have a "leading" component whose contribution to impedance is slight at low frequencies. As the frequency increases, the leading component becomes of greater importance. The "leading" component of current will increase as the capacitance between the buried electrode and the surrounding soil increase; this capacitance is a function of the surface area of the electrode and the resistivity of the soil encompassing it. The curves of figure 7-5 disclose the inverse proportionality between impedance and frequency. In both configurations the slopes decrease to a point where no appreciable change in impedance with increase in frequency is evident. Additional investigations revealed that increasing the lengths of the ground rods did not produce any marked decrease in impedance.

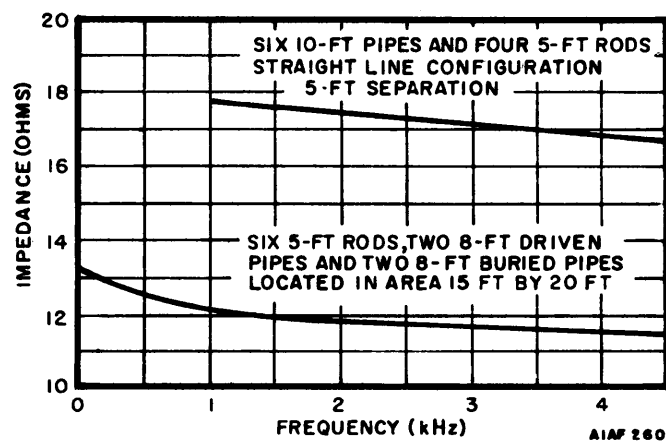


Figure 7 - 5. Relation Between Impedance to Ground and Frequency for Two Multiple Rod Connections

c. Soil Conductivity as a Function of Depth. In the design of a grounding system local soil characteristics must be considered. Empirical data shows that soil structure varies as a function of depth. The surface soil is usually dry and, more or less, nonconducting depending upon the amount of precipitation for a given area. Below the topsoil there is a stratum of semi-moist soil of a different texture, and finally, at some depth, a lower level of permanent moisture known as the water table. In many localities not only does the moisture vary at these levels but the texture of the soil changes radically. Figure 7-6 depicts the relationship of conductance to resistance as a function of depth. The resistivity of the soil varies with a change in depth below the surface because of the two variables previously discussed, (temperature and moisture) as well as the composition and the physical position of the soil in the various layers. The conductance (reciprocal of resistance) is plotted to show a more meaningful relationship as the depth of the ground rod is measured. It will be noted from these curves that the sharp increase in conductance, after 30 feet, is attributed to ambient climatic conditions no longer affecting this parameter. It can readily be seen that many of the factors that affect soil conductivity are directly related

and dependent upon each other. Some adverse characteristics can be overcome simply by increasing the depth to which the electrode is driven. This, in turn, will improve the contact resistance for the following reasons:

- (1) The area of contact between the electrode and soil increases in proportion to the length of the electrode below terrain surface.
- (2) Soil resistivity stabilizes with depth when the permanent moisture content is increased.
- (3) The changes in resistance resulting from temperature variations are less likely with increased depth.

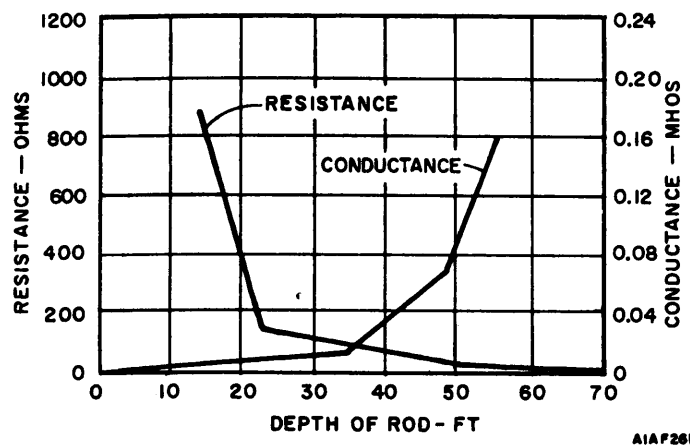


Figure 7 - 6. Resistance and Conductance Curves as a Function of Rod Depth

7.3.4 Types and Characteristics of Ground Electrodes

Ground electrodes are basically divided into two general categories. The first comprises water pipes, water well casings, metal framework of buildings and other metal embedded in, and in contact with the earth. This group provides a possible means of obtaining a convenient low resistance ground for equipment, facility or system. The second category is commonly referred to as the "ground electrodes" and are composed of buried interconnected ground rods, plates, strips of metal, wires, grids, and counterpoises. The "ground electrodes" provide a means of obtaining the lowest possible resistance contact with the earth. They are installed at, or as near as practical, to the electronic equipment, facility, or system that must be grounded for personnel safety. In addition they must dissipate the electrical charges detrimental to system operational quality and reliability.

a. Water Pipes. The National Electrical Code requires that any watering metering equipment shall be bypassed by a jumper of a size not less than that required for the grounding conductor. The grounding conductor shall bypass the meter and service unions. The water piping system must be made electrically continuous by bonding together all parts which may become disconnected. As with other ground connections, the resistance should be measured before deciding on this type of ground connection. It should be noted that where lead or screw-type joints are used for joining together lengths of pipe they usually provide joints of low resistance. However, if joints are made of "leadite" or similar types of cement, the resistance of these connections may be on the order

of several hundred ohms, rendering the water system useless as a suitable ground connection. Continuous metallic underground water systems generally provide a resistance to ground of less than 3 ohms.

b. Metal Framework. The National Electrical Code states that the metal framework of buildings can be expected to provide resistances to ground substantially below 25 ohms. The value of this resistance depends upon the size of the building, the type of footing, and the subsoil at a particular location. Resistances of several ohms are obtainable and compare favorably with water pipe ground connections. Measurement of resistance is mandatory in determining the suitability of this type of ground connection.

c. Well Casings. Although no specific data is available on the values of resistance of well casing installations, investigation has shown that measurements of less than 2 ohms are obtainable. In some areas, steel pipe employed as casings in wells is used for making ground connections. In any event, well casings located near equipment sites should be considered for their suitability as a ground connection.

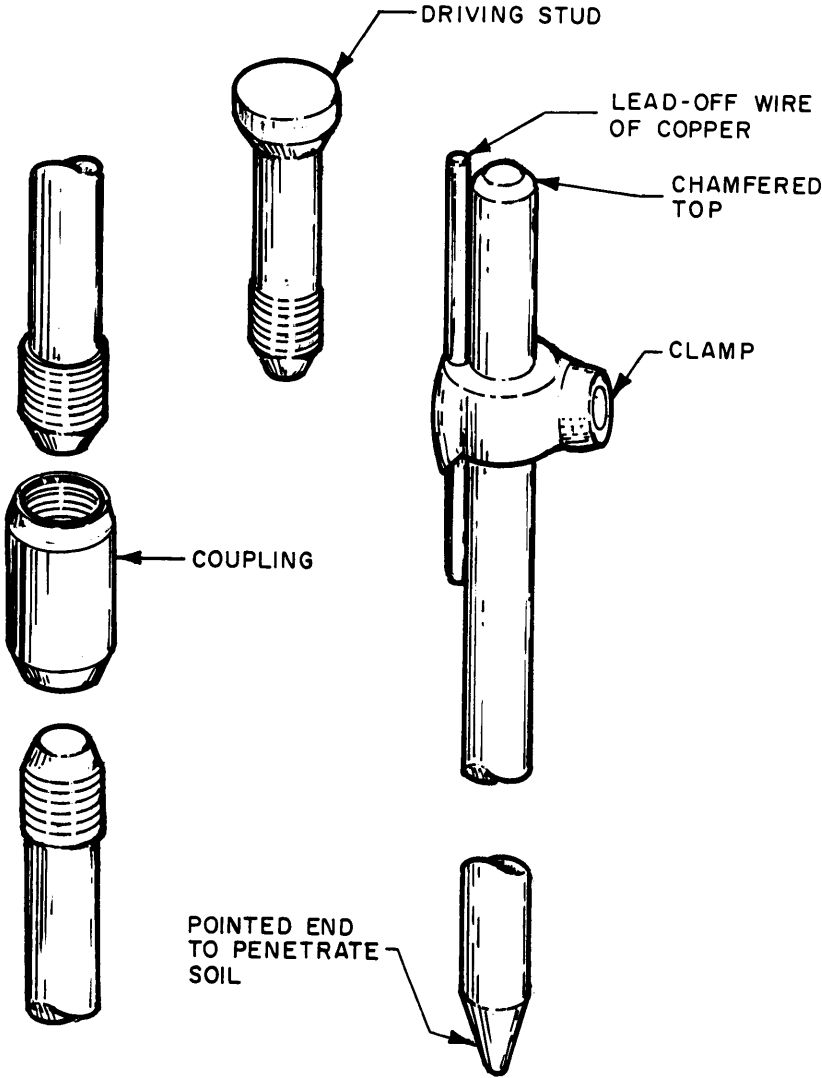
d. Driven Electrodes. Driven ground electrodes, more commonly referred to as ground rods or pipes, are used where bedrock is beyond a depth of 10 feet. Ground rods are commercially manufactured in 3/8, 1/2, 5/8, 3/4, and 1 inch diameters. For most applications the 1/2, 5/8, and 3/4 inch diameters in lengths of 8, 10, 12, and 16 feet are normally used. The National Electrical Code specifies that rods of steel or iron be at least 5/8 inch in diameter and rods of nonferrous materials not less than 1/2 inch in diameter. Copper clad steel, one of the most common types of rod, permits driving to a considerable depth without destruction of the rod itself. The copper coat provides direct copper-to-copper connection between the ground conductor and the rod. Galvanized steel rods, copper plated T, H, or channel iron also provide an excellent means of obtaining the lowest possible resistance.

For ease of driving, some rods are available in sections, threaded at both ends. (Figure 7-7). As the sections are driven, the rods are connected by couplings into a continuous conductor. A removable stud will take the driving blows and avoid damage to threads at the joint.

To obtain a specified ground resistance, multiple electrodes may prove of greater practicability than increasing the depth of the grounding rod. Figure 7-8 graphically presents the resistance of multiple driven electrodes at various spacings compared to a single electrode. The direct reciprocal relationship (i.e., the inverse of the number of electrodes is equivalent to the percent reduction in resistance) is not reached in practice because the spacing is limited and the area of influence for each electrode tends to overlap. It should be noted that at 100 feet this reciprocal relationship does equal the inverse proportion. Spacing electrodes at this distance, however, is impractical. The more practical limits for spacing multiple electrodes is usually 10 to 20 feet. At this distance, the optimum reciprocal relationship is approached while practical considerations are satisfied.

The minimum diameter of a driven electrode is limited by mechanical rather than electrical criteria. The usual practice is to select an electrode with a diameter large enough and strong enough to be driven into the soil at a given location. This factor is emphasized in figure 7-9. Curve A is plotted for homogeneous soil. Curves B and C represent the average of hundreds of actual measurements in two different cities. From Curve A, the calculated difference when doubling the diameter of the 1/2 inch rod is a decrease in resistance of only 9.5 percent.

e. Buried Strips, Wire or Cable. Where bedrock is near the surface of the earth or sand is encountered, the soil may be very dry and of high resistivity making it necessary to have an earth connection that extends over a considerable area. Under such conditions the use of buried metal strips, wire, or cables offer the most economical solution. Figure 7-10 illustrates the need for extensive length in this type of installation. Although this is a theoretical curve based on soil of uniform resistivity, actual measurements have been made and are in substantial agreement. From the curve it may seem that if the length is doubled the resistance is approximately halved. This ratio assumes that the strips, wires, or cables are buried in a straight line. If the conductors were curved or coiled, the resistance would tend to be higher because the cross sectional area of the soil would be less. With longer conductors, reactance increases as a factor of the length. Consequently, the use of a number of well spaced, shorted conductors, in parallel, is preferable to one long conductor. The depth to which such a network



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Figure 7 - 7. Physical Characteristics of Typical Ground Rods

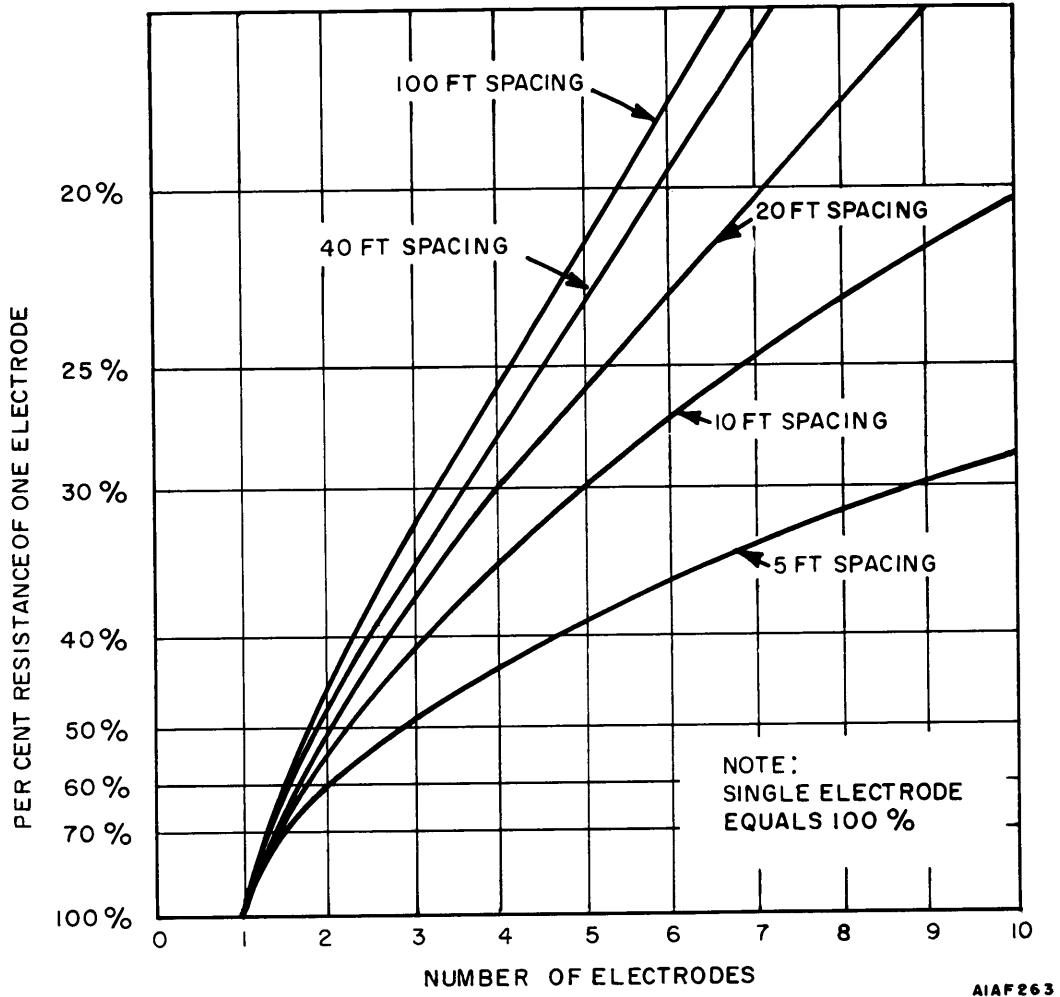
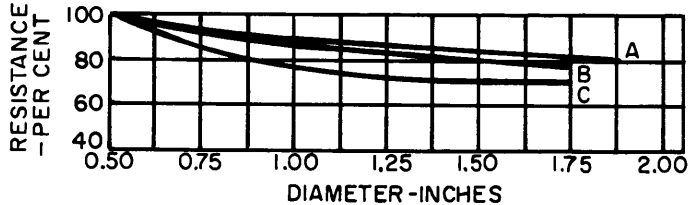


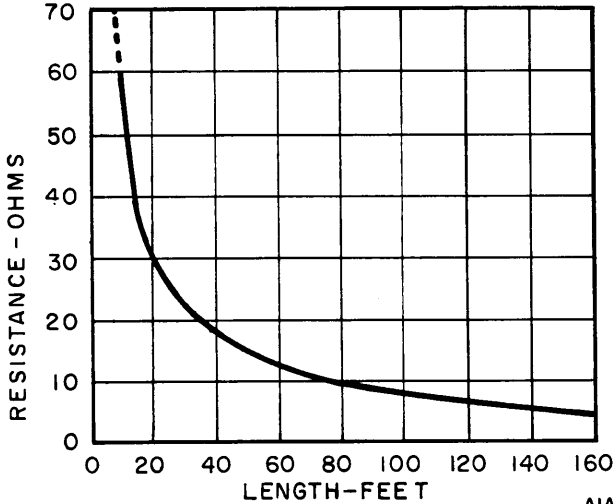
Figure 7-8. Comparative Resistance of Multiple Grounds



A. FROM BUREAU OF STANDARDS TECHNOLOGIC PAPER 108.
B. AVERAGE OF UNDERWRITERS LAB TESTS AT CHICAGO.
C. AVERAGE OF UNDERWRITERS LAB TESTS AT PITTSBURGH.

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Figure 7 - 9. Effect of Electrode Diameter



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Figure 7 - 10. Resistance as a Factor of Length for Strip Electrode

is buried is not critical. Tests conducted by the Bureau of Standards indicate that a decrease in resistance from the minimum to the maximum practical depth (approximately 18 to 36 inches) is about 5 percent. Similarly, the effect of conductor size is extremely small.

f. Grids. Grid systems usually extend over entire system installations, and may also extend some distance beyond. They consist of conductors buried a minimum of 6 inches in the ground, or stone fill, to form a network of squares. The sizes of the squares will vary with the particular installation, but cable spacings of 10 to 12 feet are commonly used. All cable crossings should be securely bonded and the system connected to the station ground system, as well as all equipment and structural steel work. In rocky ground, where driven electrodes are impractical, it is sometimes more economical and desirable to use a grid system in place of buried strips. In this use, the cables are usually buried at a depth of one or two feet.

To attach ground rods to the ground grid simply to obtain a lower resistance to earth, would not be economically feasible. However, ground rods assist in other ways that make them useful. Under certain climatic changes, the soils resistivity around the grid may increase beyond the stated limit. If ground rods are attached to the grid, contact is with the deeper layer of strata that is probably not affected by such climatic conditions.

g. Buried Plates. The resistance of a plate ground is dependent upon the area of the plate or, more correctly stated, on the overall dimension of the plate. The variation of resistance with respect to area is illustrated in figure 7-11. This curve is calculated for a circular plate in soil having a uniform resistivity. It should be noted that quadrupling the size of the plate approximately halves the resistance. The curve also shows that increasing the area beyond 25 to 30 square feet does not result in an appreciable decrease in resistance. Generally, to facilitate installation, two or more plates connected in parallel are recommended. This same relationship holds for a rectangular plate, although the curve illustrated in the figure should be taken as an indication of relationship and not as a check upon it. The National Electrical Code recommends plate electrodes that present not less than two (2) square feet of surface to earth contact. Ferrous electrodes (iron or steel) should be at least 1/4 inch thick while non-ferrous metals should be a minimum of 0.06 inches in thickness. A burial depth of 5 to 8 feet below grade should be maintained.

h. Counterpoise. The counterpoise is used to reduce the grounding network around a building, tower, or facility in an effort to acquire acceptable ground test readings. Normally it consists of a continuous ring of No. 1/0 AWG bare copper wire bonded to driven electrodes spaced about 20 feet apart installed underground around the perimeter of the building. Grounding conductors from all types of protective systems within the facilities are extended beyond the building foundation and bonded to it. A variation of this is the radial counterpoise which consists of many wires extending radially from a central grounding point (wagon-wheel design) to an outer ring of buried copper. Both counterpoise systems are employed to reduce the impedance of the ground connection, at the same time increasing the capacity coupling between the conductors.

7.3.5 Corrosion and Protection

The choice of electrode metal for ground connections is not important from the standpoint of resistance since almost all the voltage drop is in the surrounding earth. Under ordinary conditions, iron or mild steel is the most economical material. In many areas the effects of corrosion must be considered in the selection of compatible ground electrodes.

a. Factors Effecting Galvanic Corrosion. If large quantities of bare copper wire and plates are buried in the moist soil, good grounds can always be achieved. Such an approach makes a grounding system with excellent properties of conductivity and will last for many years. However, if there are other buried structures - underground pipe, buried cable, steel footings - a penalty is paid for this good ground by the problems that these structures create. If a steel pipe is buried in the earth, it will gradually develop a potential of approximately 0.7 volt negative with respect to a buried bare copper ground cable. If the pipe happens to be galvanized, the potential difference will be 1.1 volt. This difference in potential naturally causes a current to flow from the higher to the lower points. Such current is associated with the galvanic corrosion at the steel pipe, in this case,

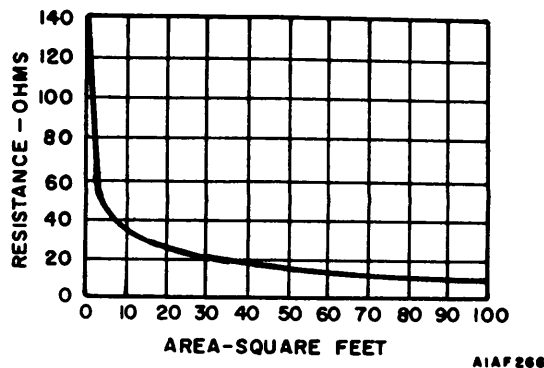


Figure 7 - 11. Resistance as a Factor of Contact Area for Circular Plate

the anodic surface. Effects at the copper ground wire tend to protect it against corrosion, and various salts may be precipitated out of the soil; this reaction is cathodic.

b. Corrosion Preventing Techniques. Corrosive action can be prevented in almost any situation, but the principal limiting factor is the cost. Techniques proven to be the most useful are:

(1) Insulation of Buried Steel. This is the only practical method for such uses as on power transmission lines. A highly satisfactory solution to the cathodic protection problem for new electric cable installations includes the following:

- o Use of recognized high resistance coatings on the sheath.
- o Insulation of the sheath from external grounds, etc.
- o Provision of special heavy-duty and reliable crossbond grounding connections to the sheaths at selected locations.
- o Provision of a special generating device (or devices) to provide adequate cathodic protection.
- o Provision of special grounding devices that will not appreciably increase or adversely interfere with the cathodic protection scheme.

(2) Replacement of Copper Ground Electrodes. Although copper is the most frequently used material for grounding systems, in many situations other materials can be used to advantage. Such is particularly true in cases where the facilities involved are relatively isolated with respect to other utility and industrial installations. The choice of materials will depend primarily upon soil resistivity and corrosive characteristics at each location. Before the selection of material and consideration of design, sufficient soil and corrosion surveys shall be made

to obtain all data required to support the necessary design decisions.

Adequate and reliable grounding systems have been installed using steel and combinations of steel conductors and zinc electrodes. Because of the difference in conductivity, the cross-sectional area of individual steel conductors must be larger than that for copper. The conductivity ratio of copper to steel is approximately eight to one, and for equal conductivity, the area ratio is approximately the inverse.

In cases where steel is the selected material, solid steel conductors not smaller than one inch diameter are recommended for ground grid meshes, ground rods, and interconnecting conductors. Larger shapes may be required in cases where gradual sacrifice of steel is intentionally planned. Rails salvaged from street railway systems are a typical example of economical, suitable, and sturdy material which has been used successfully for conductors on steel grounding systems. Two promising groups of alloys which may be valuable in the prevention of galvanic corrosion, are the austenitic irons (STDMA-439 Type D-2) and austenitic stainless steel of the 18% chromium and 8% nickel variety. Although these materials are presently in use by some utility companies, much additional research is required to evaluate the effectiveness of such materials for economical use in conjunction with grounding electronic shore facilities.

(3) Sacrificial Anodes for Cathodes Protection. Sacrificial anodes have been successfully employed to provide sufficient potential and current to protect the steel ground rods as well as for building substructures within the environment of the anodes. In addition, grid system resistance has been lowered by the anodes being connected in parallel with the rods. Based on data of previous experiments, the steel ground rods with cathodic protection would last indefinitely and assure adequate ground protection.

The cathodic protected grounding systems described, not only provide the necessary low resistance to earth, but offer cathodic protection to adjacent metallic substructures.

7.3.6 Treating Soil Artificially

Multiple electrodes will not always provide an adequate low resistance to earth. In such instances, it is generally possible to reduce the resistivity of the soil immediately surrounding the electrode by treating the soil with a substance which, when in solution, is highly conductive. There are several substances; however, the better known, in the order of preference are:

Magnesium sulphate ($MgSO_4$) - epsom salts.

Copper sulphate ($CuSO_4$) - blue vitriol.

Calcium chloride ($CaCl_2$).

Sodium chloride ($NaCl$) - common salt.

Potassium nitrate (KNO_3) - saltpeter.

Preference is given to use of magnesium sulphate, which is the most common material used, as it combines low cost with high electrical conductivity and low corrosive effect on a ground electrode or plate. All electrodes used in the soil treatment methods noted above should be of copperweld type.

a. Chemical Treatment. Large reductions in the ground contact resistance of the individual ground electrodes may be expected after chemical treatment of the earth where low resistances are difficult to obtain without chemical treatment. The initial effectiveness of chemical treatment is greatest where the soil is somewhat porous because the solution permeates a considerable volume of earth, and ground contact thereby increases the effectiveness of the electrode. When soil of compact texture is encountered, the chemical treatment is not as

effective at first because the solution tends to remain in its original location for a longer period of time. Chemical treatment limits the seasonal variation of resistance and lowers the freezing point of the surrounding soil. Chemical treatment of the earth around a driven electrode using the magnesium sulphate and water solution is illustrated in figure 7-12 and described as follows:

(1) A 4-foot length (approximately) of 8-inch diameter tile pipe is buried in the ground, surrounding the ground electrode, and filled to within one foot of the ground level with the magnesium sulphate; water thoroughly after installation. The 8-inch tile pipe should have a wooden cover with holes and be located at ground level.

(2) Forty to ninety pounds of chemical will initially be required to retain its effectiveness for two or three years. Each replenishment of chemical will extend its effectiveness for a longer period so that future retreatment occurs less and less frequently.

7.4 BONDING

7.4.1 Basic Considerations

Bonding is essential to the prevention, control, and/or elimination of interference. Inadequate bonding frequently contributes to poor equipment performance; improved bonding almost always results in a reduction of interference. MIL-B-5087 (ASG) and MIL-STD-1310 (NAVY) outline preferred bonding methods.

A bond is an electrical union between two metallic structures used to provide a low-impedance circuit between them. Bonding is the procedure by which the housing or structure of a subassembly or component is electrically connected to another structure, such as the frame of an electrical machine, or chassis of an electronic assembly. Because the reason for bonding two or more units together is to simulate electrically a single homogeneous structure to prevent development of electrical potentials between individual metal structures and non-linear circuits which can produce intermodulation products, it is important that the bond present a low-impedance path to all frequencies of interest capable of causing interference.

The effectiveness of a bond at radio frequencies is neither fully dependent upon nor measureable in terms of its DC electrical resistance; especially at high frequencies, where lengths of bonding jumpers tend to approach the wavelengths of undesirable electromagnetic radiation. When this occurs, a bonding jumper becomes a high-impedance path, and there is a potential drop across the bond causing the metal structures connected by the bond to be at different potentials. As a result, the metal structures do not function effectively as shields and fail to limit interference radiation from and susceptibility to circuits within. Since it is more convenient to measure the DC resistance rather than the AC impedance of a bond, DC measurement is often employed as an indication of low-frequency bonding effectiveness. This should be accomplished with a low resistance bridge. At high frequencies, however, bond effectiveness is best determined by means of impedance measurements because bond capacitance and inductance become significant and may result in relatively high RF bond impedances, despite low DC resistance readings. The equivalent circuit of a bond strap and its impedance as a function of frequency are shown in figure 7-13. In practice, DC resistance measurements are utilized to detect grossly defective bonds, and to determine quickly, by comparison with manufacturer's test data, whether or not bonds on existing equipment have deteriorated in the field. The DC resistance of an adequate bond should be between 0.00025 and 0.0025 ohm. In addition to impairing shielding effectiveness, high-impedance bonding jumpers may re-radiate RF energy. Resonant frequencies of a bonded circuit can be determined by a "Grid-dip Meter," and will roughly indicate the quality of the bond.

In designing and establishing bonding criteria for specific applications, it is necessary to consider a variety of factors, such as interference frequency spectrum and maximum allowable bonding impedances for frequencies within a specific range. Of prime importance are such physical characteristics of the bonds selected as size, strength, fatigue resistance, corrosion resistance, resistivity, and temperature coefficients. It is the design engineer's responsibility to provide bonds that will not deteriorate appreciably even when equipment is subjected

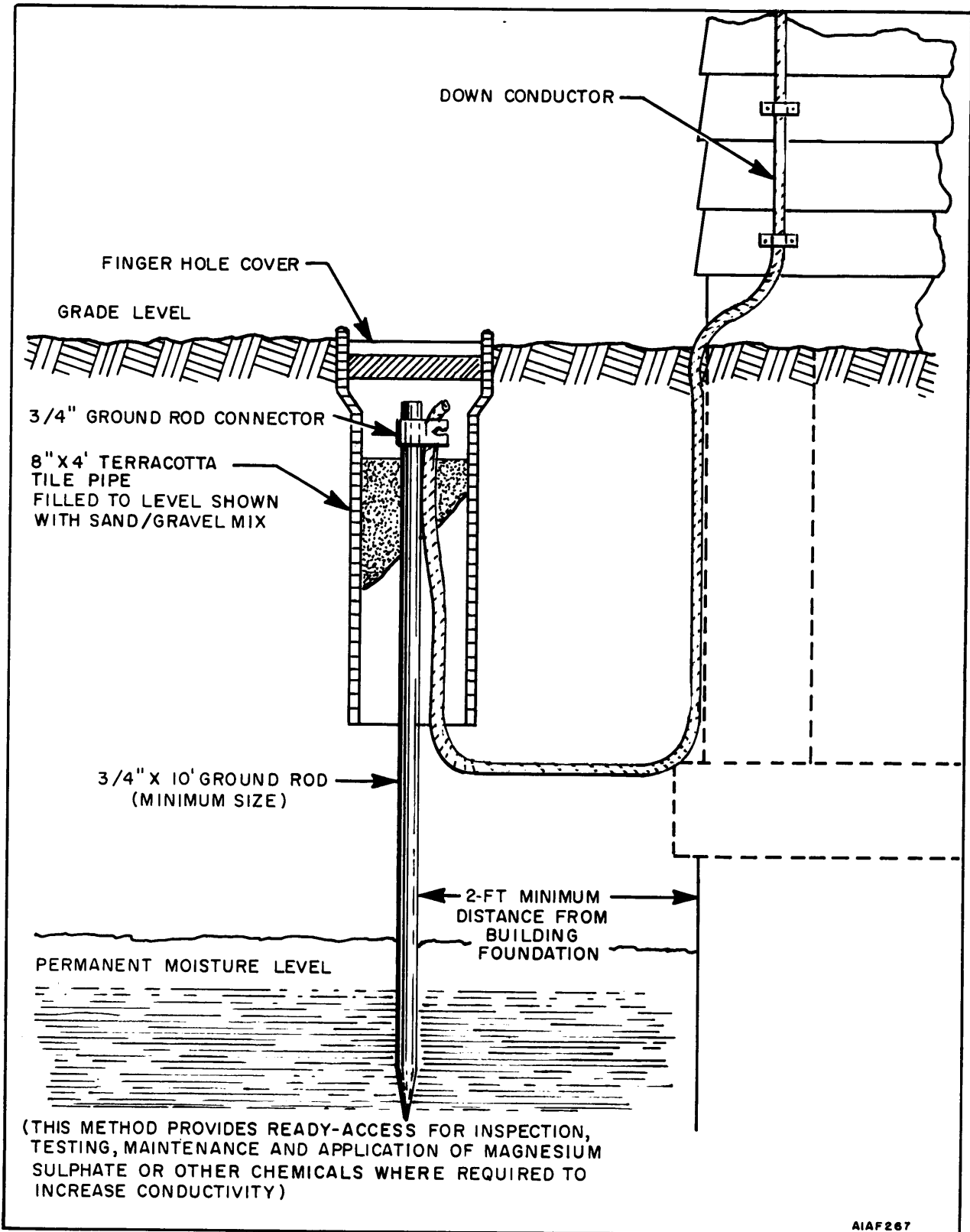


Figure 7 - 12. Typical Ground Rod Installation (Chemically Treated)

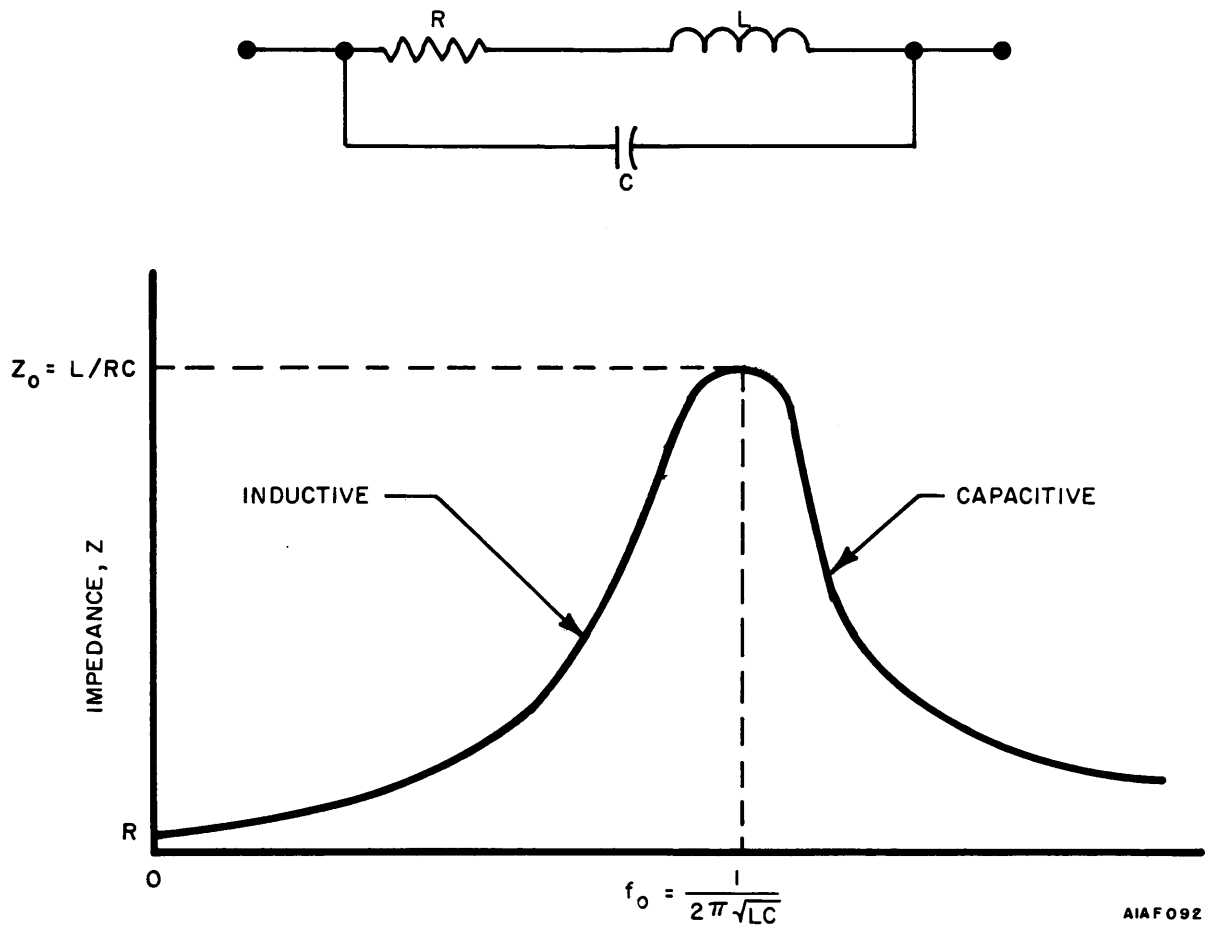


Figure 7 - 13. Bonding Strap Impedance Characteristics

to adverse environmental conditions. Bonds may be affected by electrolytic action between the metals used and their surroundings. An excellent bond at time of fabrication may actually become a serious interference source shortly afterwards if proper precautions described herein have not been taken.

Bonding jumpers should preferably be flat, thin, and short solid straps to provide large surface areas for low RF impedance (RF currents flow along conductor surfaces). The measured RF impedance of a typical flat bond strap at frequencies up to 30 MHz increases almost linearly with frequency; such impedance is due almost entirely to the self-inductance of the strap. The capacitance between the bonded members is in parallel with the inductance of the bond strap; and the bond strap has the characteristics of a parallel capacitance-inductance circuit operating far below its resonant frequency. At the frequency of self-resonance, the RF impedance of such a parallel capacitance-inductance circuit is very high compared to its DC resistance, and effectiveness of the bond strap is nil.

7.4.2 Types of Bonds

There are two classifications of bonds: direct and indirect. The most desirable of these is the direct bond. This term is applied to permanent, metal-to-metal joints such as are provided by welding or brazing. Indirect bonds, or flexible metal straps, are used when metals to be bonded cannot be placed in direct contact; for example, when there is a need for motion between bonded members.

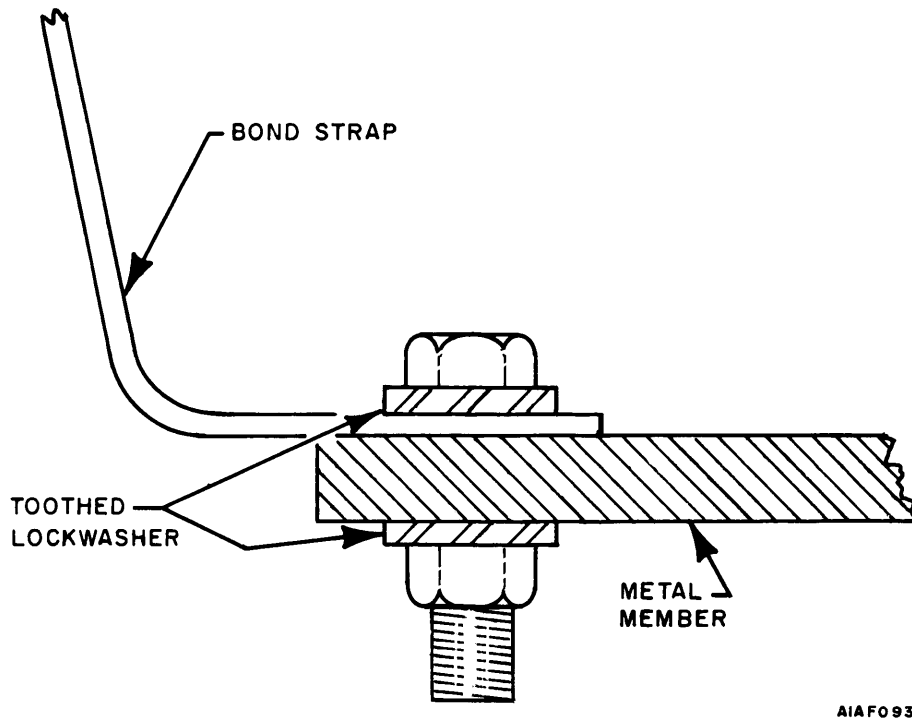
a. Direct Bonds. Direct bonds include permanent metal-to-metal joints formed of machined metal surfaces; or with conductive gaskets held together by lock-threaded devices, riveted joints, tie rods, or pinned fittings driven tight and not subject to wear or vibration. The best bonded joint is formed by welding, brazing, or sweating. Soldering is not a good method of direct bonding because soldered joints have appreciable contact resistance. Basic requirements for direct bonding are that good metal-to-metal contact be provided for the life of the joint, and that precautions be taken to seal the joint against moisture that would cause galvanic corrosion. Dissimilar metals in direct contact should be avoided. Screw threads are never considered adequate bonding surfaces. In particular, sheet-metal type screws are inadequate for use in bonding. If two structural members are held together by screws, the impedance between them is usually comparatively high unless very low ohmic contact is maintained.

b. Indirect Bonds. When a direct bond is not practical, the designer should select an indirect bond. A good indirect bond is one that presents a low impedance throughout the interference spectrum and retains its usefulness for an extended period of time. An indirect bond is usually a bond strap or jumper, mechanically held by means of bolts, rivets, welding, brazing, or sweating. Tooth-type lockwashers are used with bolt fasteners to ensure no deterioration of the metal-to-metal contact of bond strap connections. The most significant feature of a bond strap is its resiliency. When a solid strap is used, resiliency is determined by its material and thickness. Beryllium copper or phosphor bronze are often used and, under conditions of severe vibration, a corrugated strap often proves useful in preventing excessive damping and in achieving maximum service life. Figure 7-14 shows a typical bond strap bolted into position. Good metal-to-metal contact at the point of bonding is required for efficient operation, and any discussion of corrosion is not intended to compromise this requirement.

o Bonding Jumpers. Bonding jumpers are short, round, braid conductors for application where the interfering signal frequency is below a few megahertz. They are generally used in low-frequency devices, and where the development of static charges must be prevented.

o Bond Straps. Bond straps are either solid, flat, metallic conductors, or a woven braid configuration where many conductors are effectively in parallel. Solid metal straps are generally preferred for the majority of applications.

Braided or stranded bond straps are not generally recommended because of several undesirable characteristics. Oxides may form on each strand of non-protected wire and cause corrosion. Because such corrosion is not uniform, the cross-sectional area of each strand of wire will vary throughout its length. The nonuniform



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Figure 7 - 14. Recommended Bond Strap Bolting Installation

cross-sectional areas (and possible broken strands of wire) may lead to generation of unwanted signals within the cable or strap. Broken strands may act as efficient antennas at high frequencies, and emissions may be generated by intermittent contact between strands. In some cases solid straps may be preferable because of lower self-inductance. The direct influence of bond strap construction on RF impedance is shown on the graph of figure 7-15, where the impedances of two bonding straps and of No. 12 wire are plotted against frequency. The relatively high impedance at high frequencies illustrates that there is no adequate substitute for direct metal-to-metal contact. A rule of thumb for achieving minimum bond strap inductance is that the length-to-width ratio of the strap should be 5:1 or less. This ratio determines the inductance, the major factor in the high-frequency impedance of the strap.

c. Bonding Metal Selection and Bond Strap Finishes

The choice of material for a given bonding application is usually dictated by consideration of the metals being bonded and the environment within which the bond must exist. In bonding, the necessity for joining dissimilar metals is frequently unavoidable. In such cases, galvanic corrosion becomes an important consideration. Factors contributing to galvanic corrosion are the relative closeness of metals in the electromotive series and the amount of moisture present.

Several methods can be employed for minimizing or preventing corrosion and its adverse effects on bonding. One is to use metals low on the activity table, such as copper, lead or tin (table 7-4). Where members of the electrolytic couple are widely separated on the activity table, it is sometimes practical to use a plating such as cadmium or zinc, which helps to reconcile the dissimilarity. Thin, bimetallic plates, formed by mechanical bonding of dissimilar metals cold flowed together under high pressures, have been used to interconnect two structural units of dissimilar metals. Where bimetallic plates are to be used, the junctures of the two metals are normally covered with a protective coating, such as grease or polysulphate, to exclude moisture and retard corrosion. This coating reduces the area of metal exposed to an electrolyte, thus reducing corrosion. If bonding is such that corrosion is likely to occur, the bond should be designed as a replaceable element, such as a jumper, plate, separator, or washer.

Acceptable contact surface materials that may be used to fasten bonding jumpers to structures are indicated in table 7-5. Typical methods for fastening connection jumpers to the various case metal types are illustrated in figure 7-16. The arrangement of the metals listed in this table is in the order of their decreasing galvanic activity when exposed to an electrolyte. The screws, nuts, and washers to be used in making the connections are indicated as Type I, cadmium or zinc plated, or aluminum, and Type II, passivated stainless steel. Where neither type of securing hardware is indicated, Type II is preferred from a corrosion standpoint.

The possibility of galvanic and/or electrolytic action necessitates extreme care in assembling joints that serve as bonds. Surfaces should be absolutely dry before mating, and should be held together under high pressure to minimize the possibility of moisture entering joints. The use of number 7/0 garnet finishing paper or equivalent is recommended to remove paints, anodic films, and oxides from surfaces. Care must be taken not to remove excessive metal under the protective finish. Abrasives, such as emery cloth or sandpaper, cause corrosive action because their particles embed themselves in the metal and should not be used. The contact area should be wire brushed clean and should be about 1-1/2 times greater than the area necessary for actual mounting. After a joint (free of moisture) is assembled, the periphery of the exposed edge should be sealed with suitable grease or a polysulphate coating. See figure 7-14.

7.4.3 Bonding Applications

a. Shock Mounts. A frequent application for which indirect bonding is the only suitable type is that involving shock mounted equipment. The designer should consider the degree of relative motion to be expected between two surfaces to be bonded, the characteristics of the materials involved, and the frequency range over which the bonding is expected to be effective. A typical shock mount is shown on figure 7-17. The application of a bond strap to a vehicle engine is shown on figure 7-18.

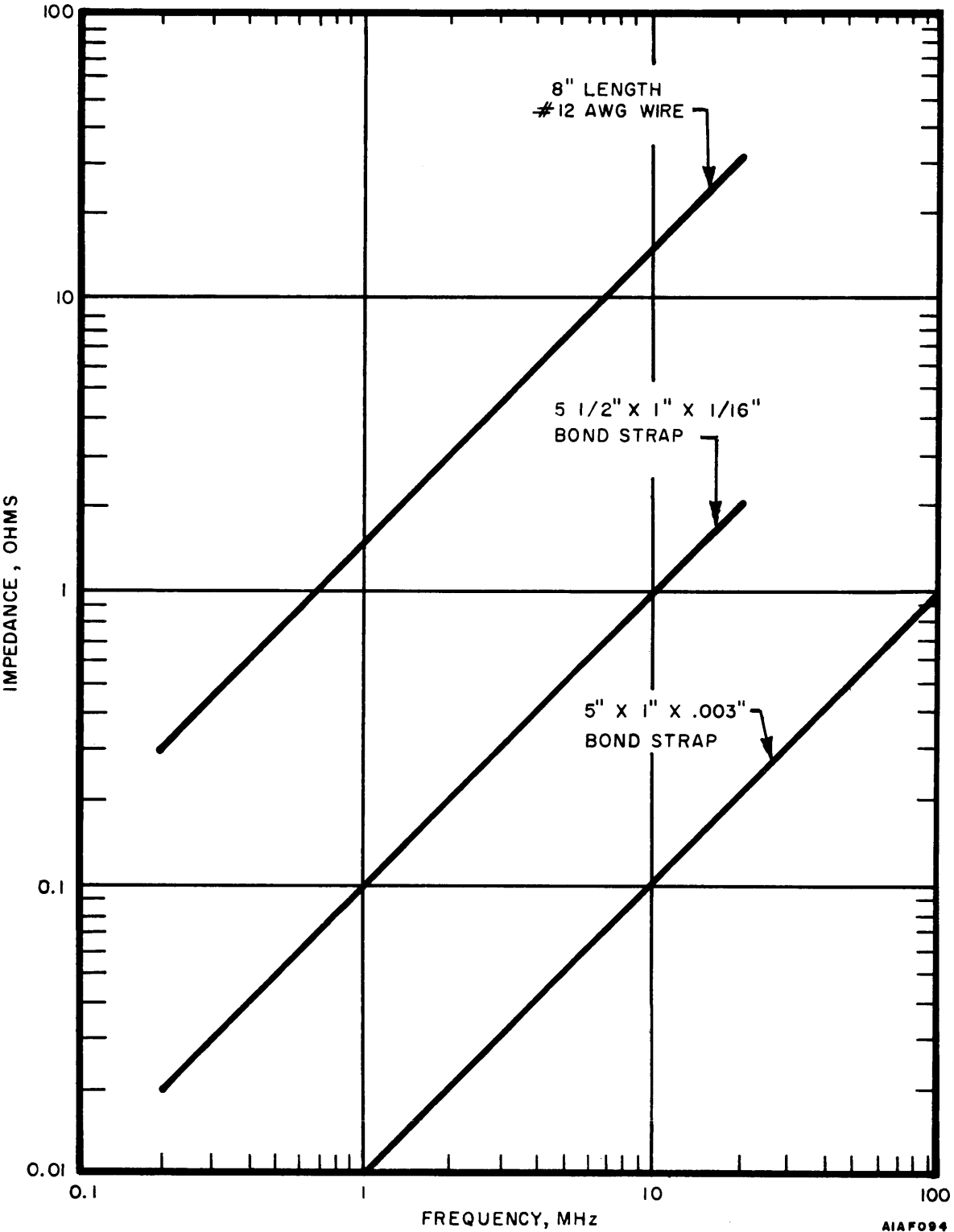


Figure 7 - 15. Impedances of Bond Straps and No. 12 AWG Wire

Table 7-4. Electromotive Force Series of Commonly Used Metals*

METAL	ELECTRODE POTENTIAL VOLTS
Magnesium	+2.40
Aluminum	+1.70
Zinc	+0.762
Chromium	+0.557
Iron	+0.0441
Cadmium	+0.401
Nickel	+0.231
Tin	+0.136
Lead	+0.122
Copper	-0.344
Silver	-0.798
Platinum	-0.863
Gold	-1.50

* Select dissimilar metals so that if corrosion occurs, it will be in the replaceable components, such as grounding jumpers, washers, bolts or clamps, rather than structural members or equipment enclosures. When two different metals are in contact, the one higher in the electromotive-force series will be more affected by corrosion than the other. The smaller mass (generally the more easily replaceable) should therefore be made of the higher metal; for example cadmium-plated washers are recommended for use with steel surfaces.

Table 7-5. Metal Connections

METAL STRUCTURE (OUTER FINISH METAL)	CONNECTION FOR ALUMINUM JUMPER	SCREW TYPE ^a	CONNECTION FOR TINNED COPPER JUMPER	SCREW TYPE ^a
Magnesium and magnesium alloys	Direct or magnesium washer	Type I	Aluminum or magnesium washer	Type I
Zinc, cadmium, aluminum and aluminum alloys	Direct	Type I	Aluminum washer	Type I
Steel (except stainless steel)	Direct	Type I	Direct	Type I
Tin, lead, and tin-lead solders	Direct	Type I	Direct	Type I or II
Copper and copper alloys	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II
Nickel and nickel alloys	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II
Stainless steel	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II
Silver, gold, and precious metals	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II

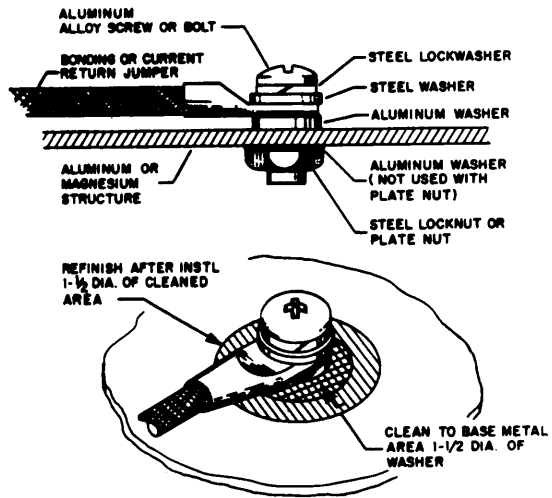
a - Type I is cadmium or zinc-plated, or aluminum; Type II is stainless steel. Where either type is indicated as acceptable, type II is preferred from a corrosion standpoint.

The resiliency of the bonded mount should be determined by characteristics of the mount, not of the bond strap. The strap should not significantly dampen the shock mount, and where necessary, it should be corrugated to withstand severe and continued vibration. Where interference suppression is desired in the VHF range and higher, two bond straps across each shock mount should be used. This arrangement reduces the inductance of the bond to half of its former inductance and increases the resonant frequency of the strap. The use of tooth-type lock washers is preferable so that perforation of any nonconductive coating (with improved electrical contact) is assured. Where severe environments are involved, joints should be protected after tightening with a suitable grease or polysulphate coating to preclude corrosion at contact surfaces.

b. Rotating Joints. It is often necessary to bond shafts of rotating machinery to prevent accumulation of static charges. Bonding is generally accomplished by use of a slip ring and brush assembly, or a phosphor-bronze finger riding directly on the shaft.

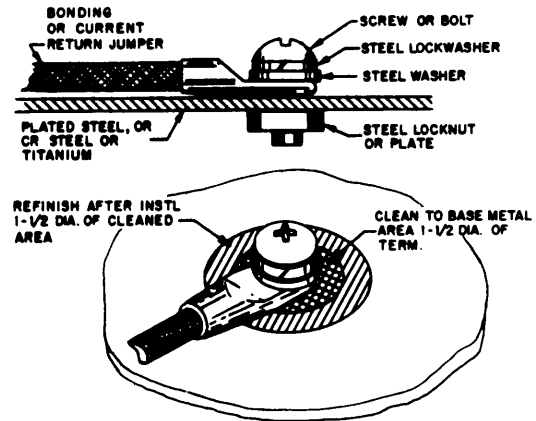
BOLT SIZE:
BONDING - NO. 6 & NO. 8 SCREW WHERE EDGE DISTANCE WILL NOT PERMIT NO. 10
 - 3/16-INCH DIA. MIN WHERE POSSIBLE
100-AMP RETURN-1/4-INCH DIA. MIN
200-AMP RETURN-3/8-INCH DIA. MIN

NOTE: Electrical bonding to magnesium structure for current return is prohibited



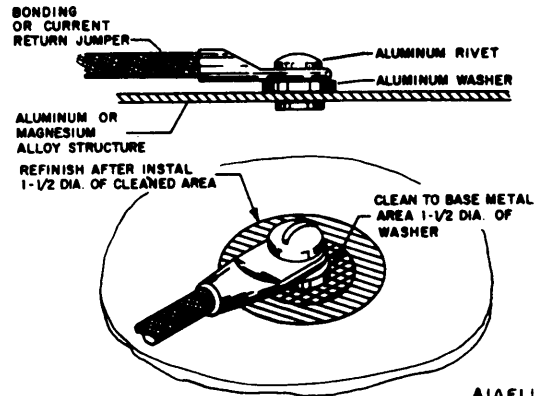
a. BOLTED TO ALUMINUM OR MAGNESIUM ALLOY STRUCTURE

BOLT SIZES:
BONDING - NO. 6 & NO. 8 SCREW WHERE EDGE DISTANCE WILL NOT PERMIT NO. 10 SCREW
 - 3/16 - INCH DIA. MIN WHERE POSSIBLE
100-AMP CURRENT RETURN: 1/4-INCH DIA. MIN
200-AMP CURRENT RETURN: 3/8-INCH DIA. MIN



b. BOLTED TO ALLOY STEEL, PLATED STEEL OR TITANIUM

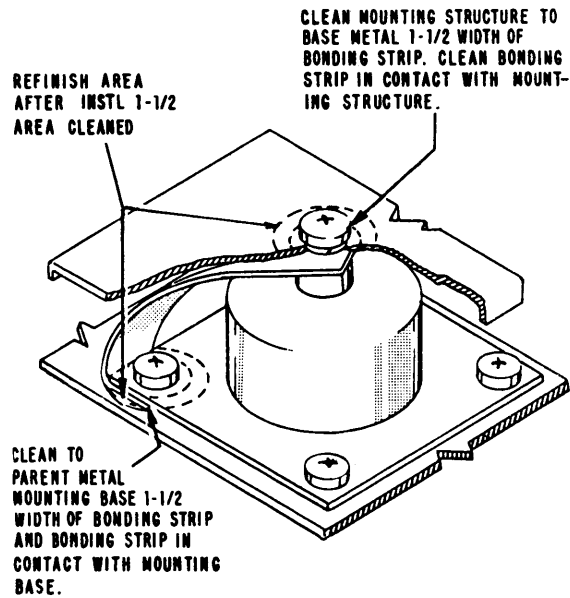
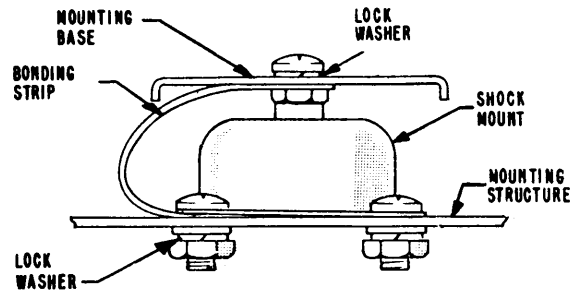
NOTES: 1. Not applicable to bonding jumpers used for current return
 2. Use bolted connections where jumper is used for current return
 3. Ensure that rivet size is equal to the equivalent bolt size



c. RIVETED TO ALUMINUM OR MAGNESIUM ALLOY

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Figure 7 - 16. Connection Jumpers



NOTE: INSTALL BONDING STRIP UNDER SHOCK MOUNT PAD IN SUCH A MANNER THAT THE STRIP DOES NOT ALTER SHOCK MOUNT FUNCTION.

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Figure 7 - 17. Typical Shock Mount Bond

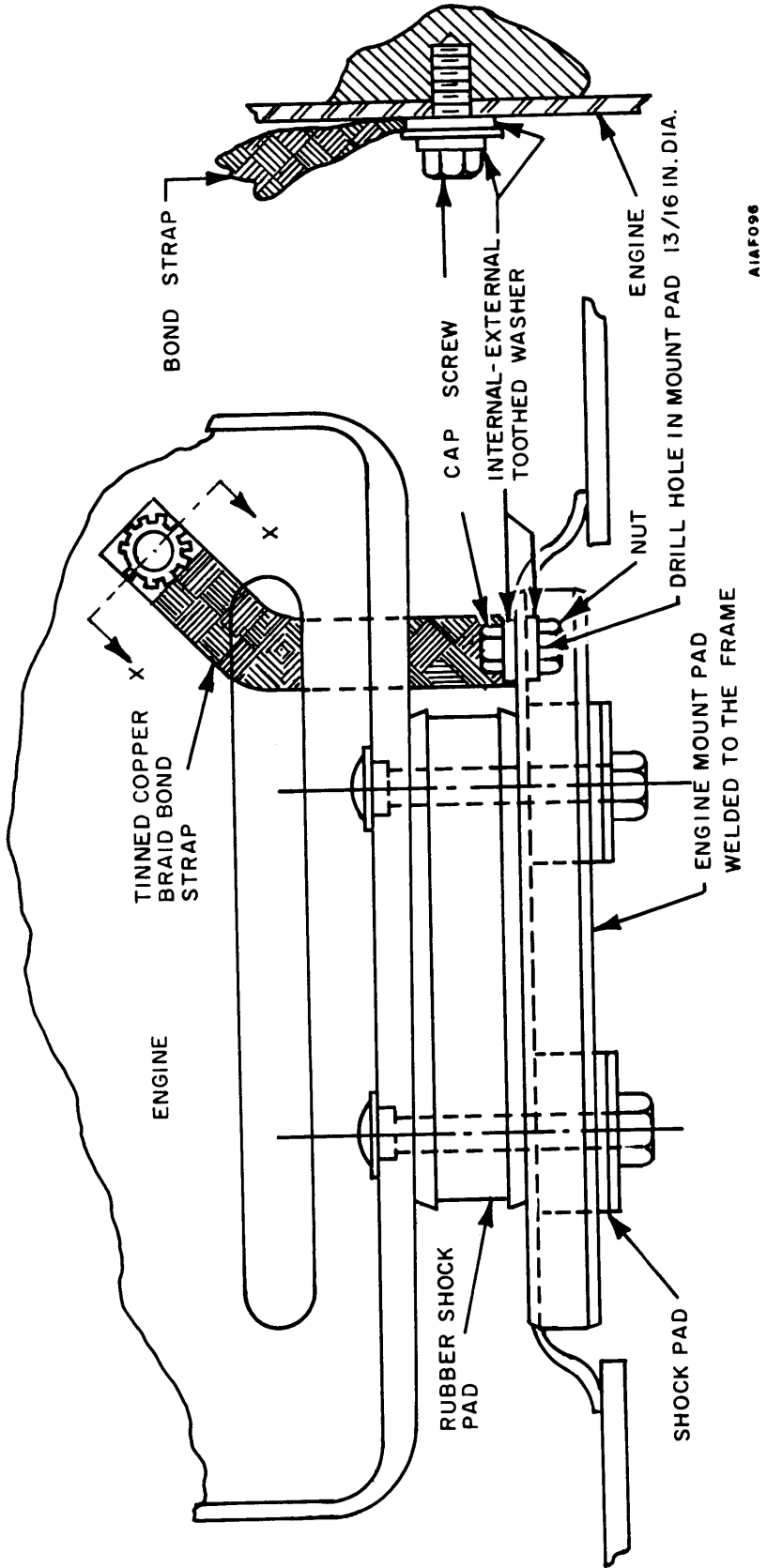


Figure 7 - 18. Bonded Engine Shock Mount-Front

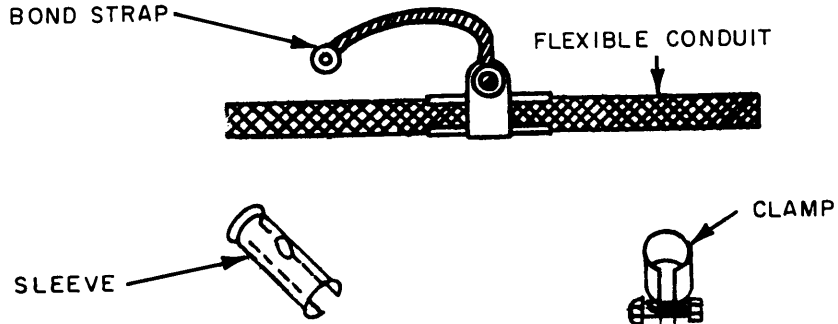
c. Tubing Conduit. The outer surfaces of long spans of conduit or shielded cable may be high-impedance paths for interference currents from external sources. To minimize this possibility, such spans should be properly bonded to structures at both ends and at several intermediate points. Ordinary clamps cannot be used to bond flexible conduit since the required pressure on a comparatively small surface area of the conduit may be sufficiently high to compress or collapse it. To overcome this, a flared split-sleeve is fitted around the flexible conduit. This sleeve distributes the high pressure of the bonding clamp over a large area, thereby exerting low pressure on the conduit (figure 7-19). Figure 7-19 illustrates a method for bonding rigid conduit to a structure through supporting attachments. The conduit or tubing, to which bonding clamps are attached, should be cleansed of paint and foreign material over the entire area covered by the clamps. All insulating finishes should be removed from the contact area before assembly, and anodized screws, nuts, and washers should not be used to attach contacting parts. If, in bolting the clamp to the bonding surface, a tooth-type washer is used, protective coatings, unless very thick or tough, need not be removed from the surface because the points of the washer will penetrate to the bare metal.

d. Hinges. Hinges do not provide a path for electrical conductivity; or an RF shield. Where hinges must be used, it is necessary to accomplish bonding by other means. Figure 7-20 shows a typical configuration for bonding hinges. Flexible bonding straps, made of thin metal, are separated along the hinges by not more than 2 inches.

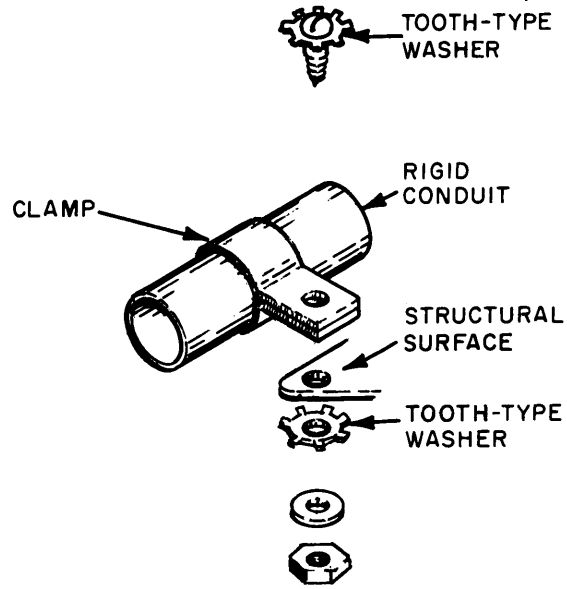
e. Cable Trays. Cable trays should be utilized as part of the overall system bonding scheme. Each section of each tray should be bonded to the following section to provide a continuous path (figure 7-21). The trays should also be connected to equipment housings by wide, flexible, solid bond straps. Such connections reduce the level of interference propagated into the equipment, thus precluding any difference of potential between equipment housings. A typical example of cable tray bonding is shown on figure 7-22.

f. Rack Bonding. The equipment rack provides a convenient means of maintaining electrical continuity between such items as rack-mounted chassis, panels and the ground plane. It also serves as an electrical inertie for the cable trays. A typical equipment cabinet, with the necessary modifications to provide such bonding, is shown on figure 7-23. Bonding between the equipment chassis and the rack is achieved through the equipment front panel and the rack right-angle bracket. This bracket is grounded to the unistrut horizontal slide that is welded to the rack frame. The lower surfaces of the rack are treated with a conductive protective finish to facilitate bonding to the ground plane mat. The ground stud at the top of the rack is used to bond the cable tray to the rack structure, which is of welded construction. Figure 7-24 illustrates a typical bonding installation. The cable tray is bonded to the cable chute; the cable chute is bonded to the top of the cabinet; the cabinet is bonded to the flush-mounted grounding insert (which is welded to the ground grid); and the front panel of the equipment is bonded to the rack or cabinet front panel mounting surface. Nonconductive finishes are removed from the equipment front panel before bonding. The joint between equipment and cabinet may have to serve a dual purpose: that of achieving a bond and that of preventing interference leakage from the cabinet if the joint is designed to provide shielding. If such shielding is a requirement, conductive gaskets should be used around the joint to ensure that the required metal-to-metal contact is obtained. If the equipment is in a shock-mounted tray, the tray should be bonded across its shock mounts to the rack structure. Connector mounting plates should use conductive gasketing to improve the chassis bonding. If chassis removal from the rack structure is required, a one-inch-wide braid with a vinyl sleeving should be used to bond the back of the chassis to the rack. The braid should be long enough to permit withdrawal of the chassis from the rack.

g. Other applications are illustrated in figures 7-25 through 7-33.



A. BONDING OF FLEXIBLE CABLE



B. BONDING OF RIGID CONDUIT TO PAINTED SURFACE

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Figure 7 - 19. Cable and Conduit Bonding

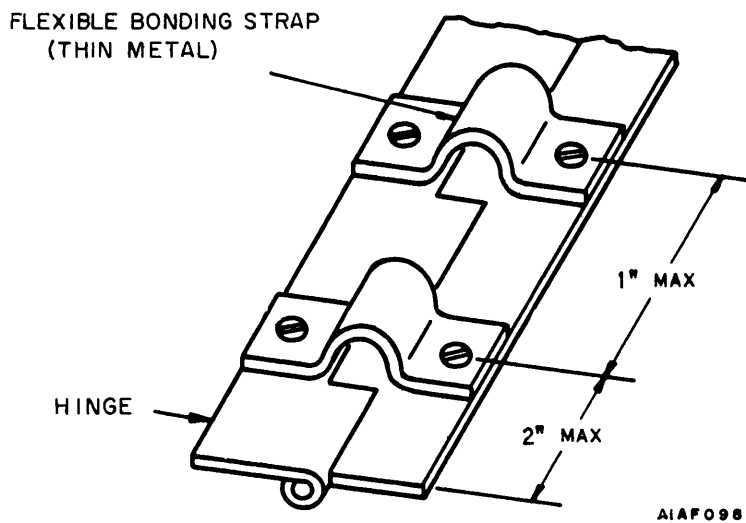


Figure 7 - 20. Bonding of Hinges

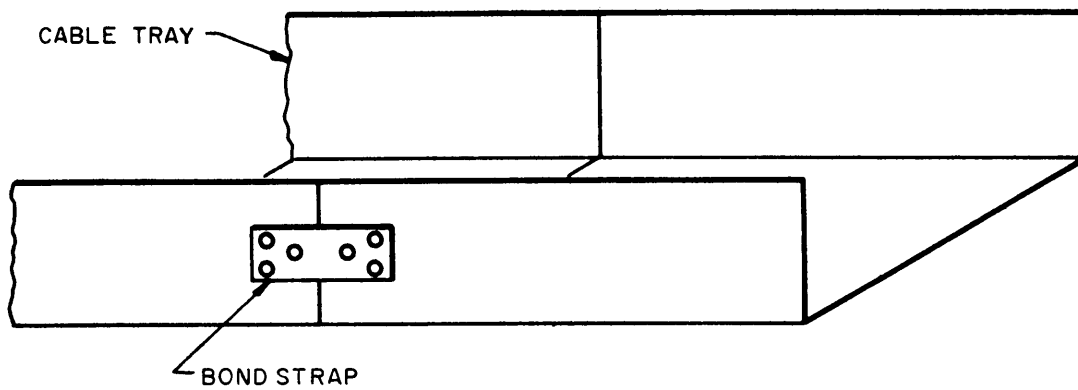


Figure 7 - 21. Cable Tray Section Bonding

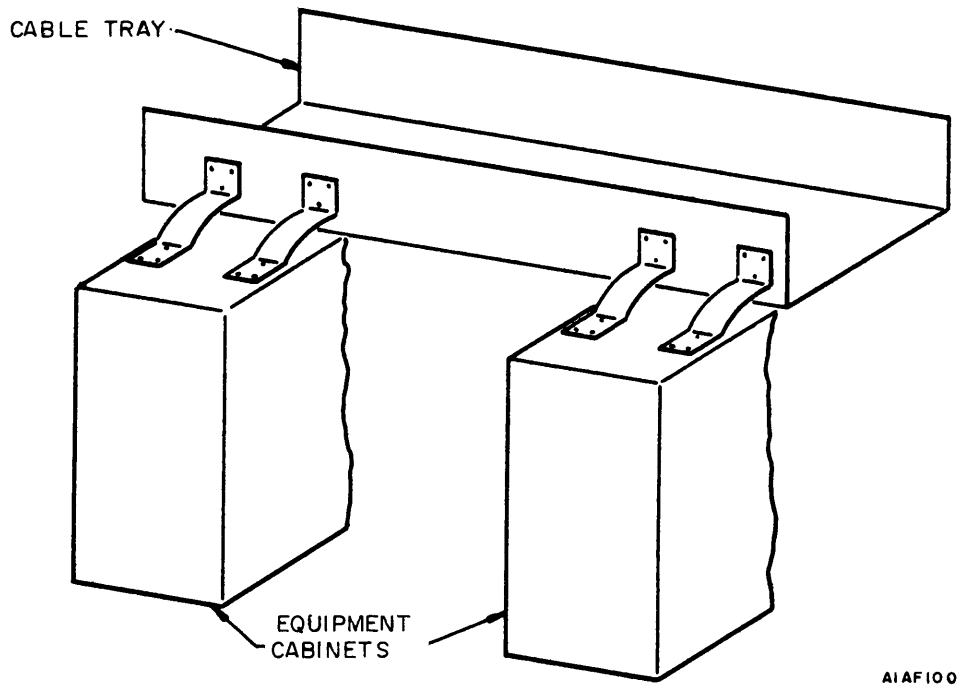
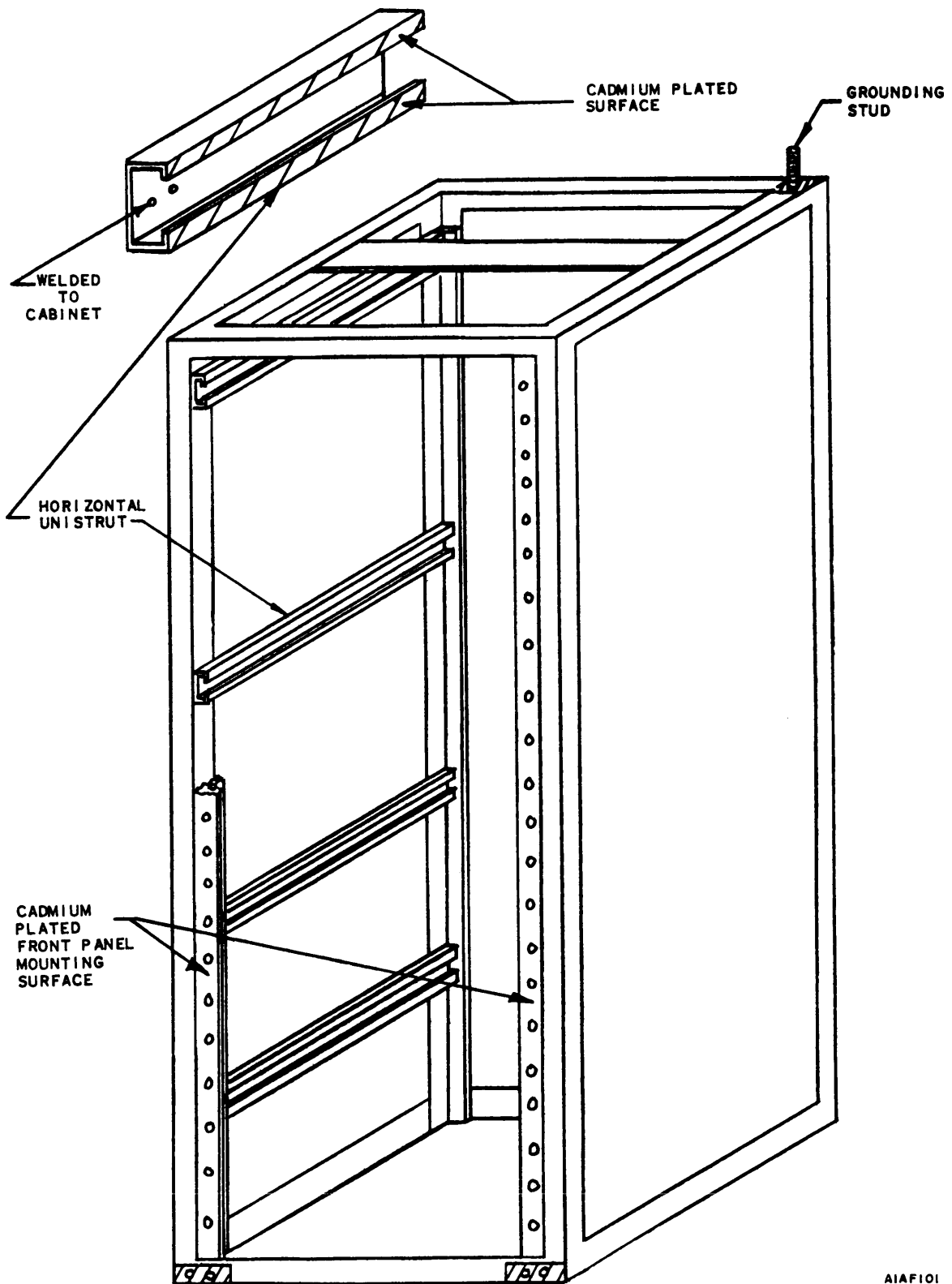
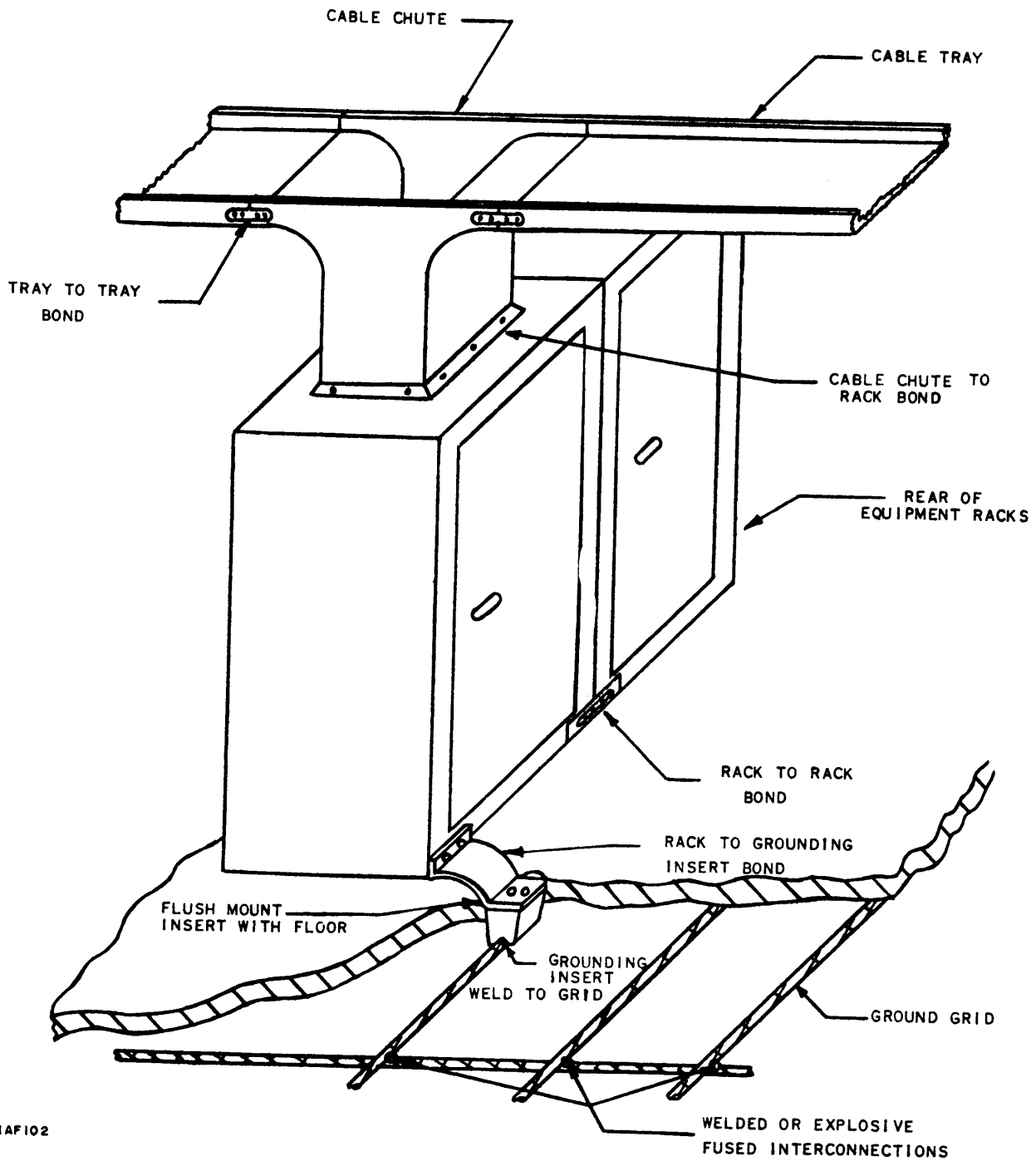


Figure 7 - 22. Equipment Cabinets Bonded to Cable Tray



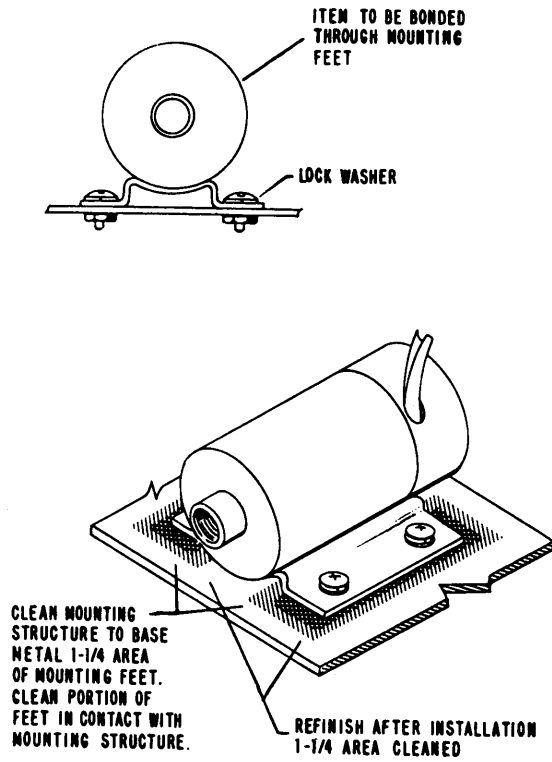
AIAF101

Figure 7 - 23. Cabinet Bonding Modifications



AIAF102

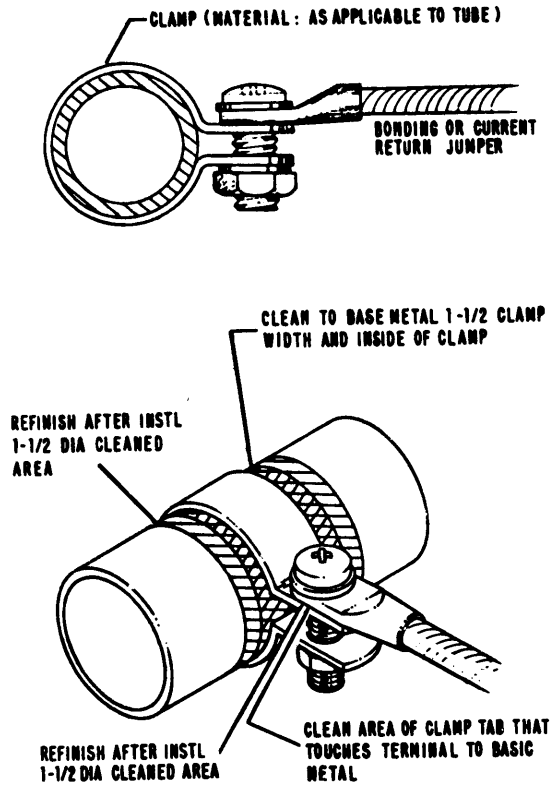
Figure 7 - 24. Typical Cabinet Bonding Arrangements



NOTE: ON ITEMS THAT HAVE THE BOLTS SPACED MORE THAN 6 INCHES APART, IT IS ONLY NECESSARY TO CLEAN THE AREA 2 INCHES ON EACH SIDE OF THE ATTACH BOLTS OR SCREWS.

AIAF103

Figure 7 - 25. Typical Bonding of Equipment Installed on Structure with Mounting Feet



A1AF104

Figure 7 - 26. Clamp Connection - Jumper to Tube

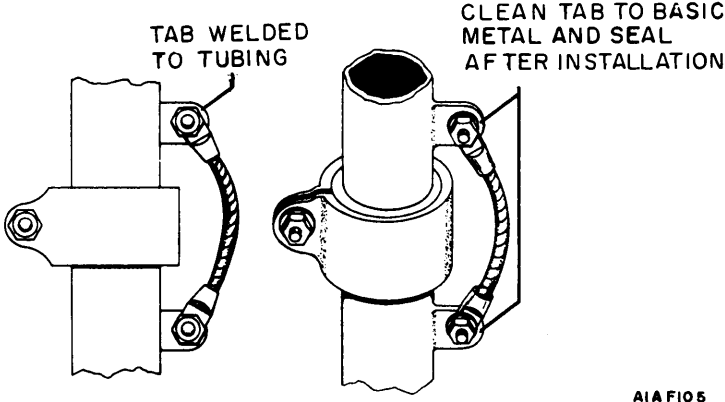


Figure 7 - 27. Typical Method of Bonding Tubing Across Clamps

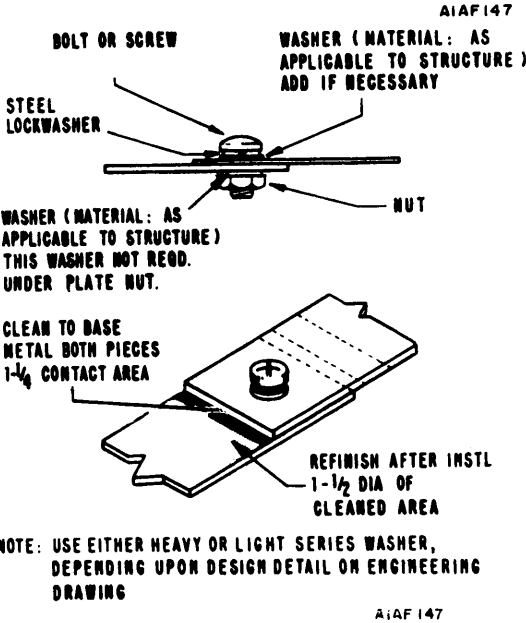
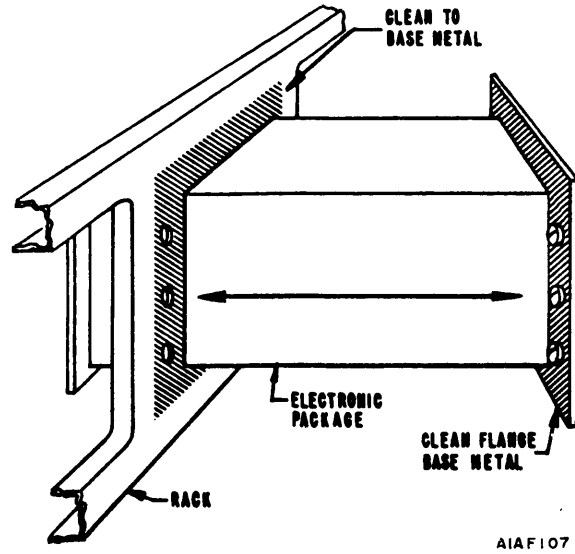
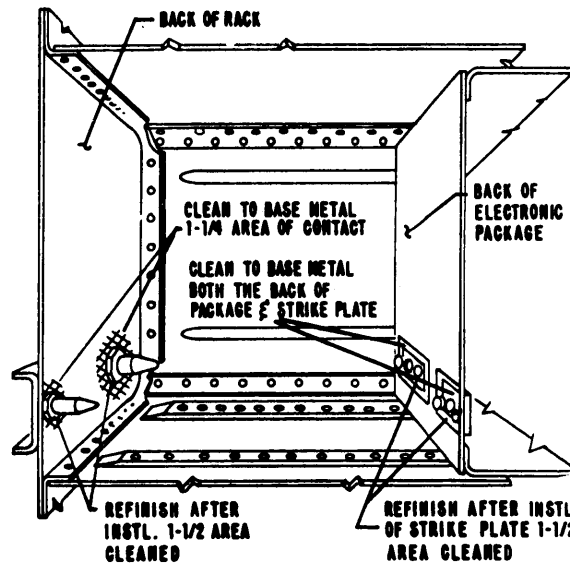


Figure 7 - 28. Preparation of Bonding Connection in Bolted Structural Joints



AIAF107

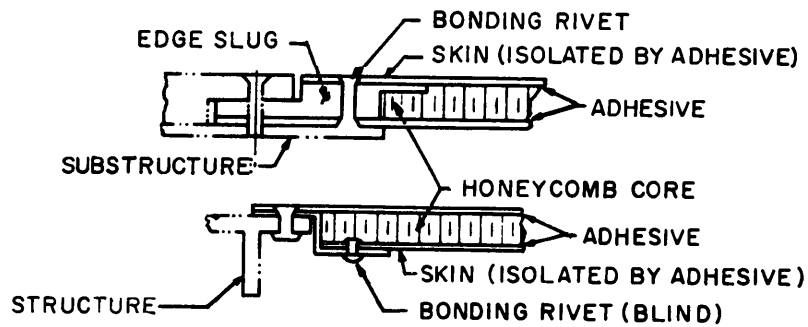
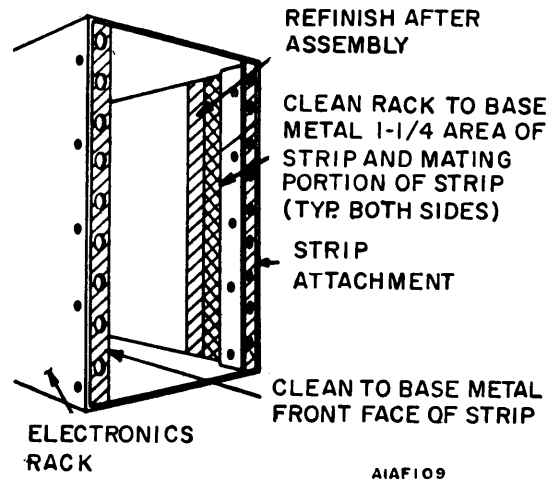
Figure 7 - 29. Typical Method of Bonding Between Attaching Flange of Electronic Package and Rack



NOTE: CLEAN ALL DAGGER PINS AND STRIKE PLATE HOLES AFTER INSTALLATION.

AIAF108

Figure 7 - 30. Typical Method of Bonding with Dagger Pins



NOTES:

1. USE A MINIMUM OF TWO RIVETS (TOTAL AREA ELECTRICALLY EQUIVALENT TO TWO 1/8 IN. DIAMETER RIVETS) FOR ANY ONE CONNECTION. INDICATE THE TOTAL NUMBER OF RIVETS AND RIVET SPACING ON THE INSTALLATION DRAWING
2. DRILL HOLES FOR ALL RIVETS AND INSTALL RIVETS AFTER ADHESIVES ARE CURED.

AIAF110

Figure 7 - 32. Typical Bonding of Details Which are Isolated by Adhesives

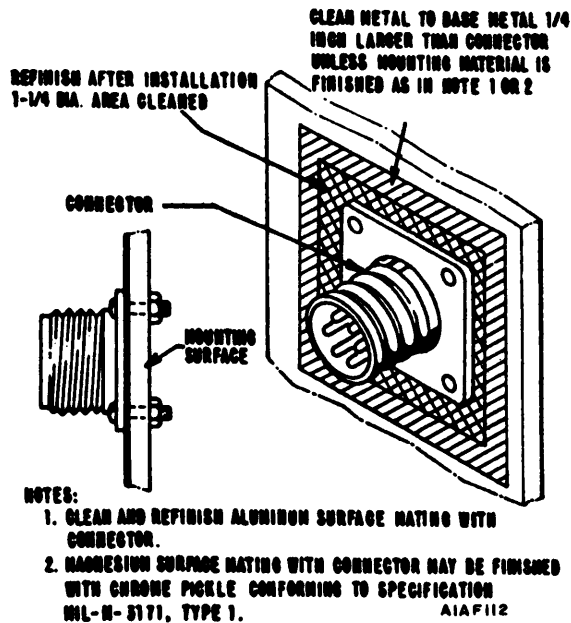


Figure 7 - 33. Typical Method of Bonding Through Bolted Connection

7.4.4 Bonding Practices Summarized

- a. Permanent-type bonds are more reliable than the semipermanent type, and are therefore preferred.
- b. Direct-type bonds, such as formed by individual welded, sweated, or brazed joints are, in general, bonds of lower impedance than indirect types, and are therefore preferred.
- c. Where bond joints exist between dissimilar metals, finished bond joints should have a protective coating such as a suitable grease or polysulphate to exclude moisture and retard corrosion.
- d. Bonds should afford good metal-to-metal contact over the entire mating surfaces of the bond joint. The mating surfaces should be clean and free from any nonconductive finishes. Bare, clean, metal-to-metal contact will ensure a low-impedance connection between mating surfaces.
- e. Indirect bonding conductors should preferably be in strap form, broad in width, thin, and as short in length as possible to afford desirable low-impedance electrical connections at radio frequencies. The length-to-width ratio of the bond straps should be less than 5:1.

f. The strap type of bond connection provides flexibility, sometimes necessary because of vibration, expansion, contraction, hinges, and equipment misalignment arising from normal fabrication and installation tolerances.

g. Where bonds must afford shielding integrity, permanent-type metal-to-metal joints, afforded by welding, brazing, or sweating, are preferred to semipermanent joints that depend on clamping pressures and/or conducting gaskets.

h. A soldered bond-joint should not depend on the solder for mechanical strength. The parent mating materials of the bond should be mechanically joined by other means such as bolting or riveting.

i. Bonding connections should be located in protected and accessible areas, where practical, to permit ready inspection and replacement if necessary.

7.4.5 Bonding Calculations

Because of the working nature of a bond, it must be capable of carrying potentially large fault or transient currents, be of low resistance and inductance at all frequencies of interest. The DC resistance and the inductance of simple wire forms are given below:

a. For a straight conductor the DC resistance is

$$R = \frac{\rho \ell}{A} \text{ ohms} \quad (7-1)$$

where:

- ρ copper = 1.724×10^{-6} ohm-cm
- ρ steel = 15×10^{-6} ohm-cm
- ℓ = length in cm
- A = cross sectional area in cm^2 .

The AC resistance R_{AC} increase is given by the relation

$$\frac{R_{AC}}{R_{DC}} \approx D \sqrt{f} \quad (7-2)$$

where:

- D = diameter of conductor in inches
- f = frequency in Hz

b. The self-inductance of a round conductor is

$$L = 0.002 \ell \left[2.3 \log \frac{2\ell}{r} - 1 + \frac{\mu}{4} \right] \text{ microhenries } (\mu \text{ h}) \quad (7-3)$$

where:

- ℓ = length in cm
- r = radius in cm
- μ = permeability of material = 1 for copper.

For wire of rectangular cross section of copper

$$L = 0.002\ell \left[2.3 \log \frac{2\ell}{B+C} + \frac{1}{2} + 0.22 \left(\frac{B+C}{\ell} \right) \right] \mu h \quad (7-4)$$

where:

- B = width in cm
- C = thickness in cm
- ℓ = length in cm

The last term may be neglected for $\ell > 50(B+C)$.

The maximum fractional decrease of the inductance as the frequency is indefinitely increased for copper wire is

$$\left(\Delta L/L \right)_{\infty} = -1/4 \log \frac{2\ell}{r} - 3 \quad (7-5)$$

where:

- r = radius of wire in any units
- ℓ = length of wire in any units
- L = DC inductance of the wire

and the limiting inductance as frequency increases (for copper) is

$$L' = 0.002 \ell \left[2.3 \log \frac{2\ell}{r} - 1 \right] \mu h \quad (7-6)$$

c. A solution for R_{AC} of a flat thin copper strap can be approached by shaping it into a hollow tube. Then

$$R_{AC} = \frac{4.15}{r} \times 10^{-8} \left(1 + \frac{t}{2ar} \right) \sqrt{f} \text{ ohms/cm} \quad (7-7)$$

where:

- r = outer radius of the tube - cm
- t = thickness of strap - cm
- a = $\frac{2142}{2} \sqrt{f}$ ohms/cm and f is in hertz

and where a is large

$$R_{AC} = \frac{4.15}{r} \times 10^{-8} \sqrt{f} \text{ ohms/cm} \quad (7-8)$$

The formulas are for isolated conductors and do not consider the contact resistances or impedances of mating surfaces. Since a DC resistance check with a voltohmmeter of mating surfaces or bonds is doubtful, a good rule of thumb is to use a Shallcross bridge and check that the contact resistance of the bond or other device is less than 0.0025 ohm. The bond itself should be as short as possible, and broad, or as great cross sectional area as possible.

As a sample calculation, the DC resistance of a ten-foot section of 1/4 in. x 2-1/2 in. copper bus is

$$R = \frac{\rho l}{A} = \frac{\rho l}{B \times C} \quad (7-9)$$

$$R = 1.724 \times 10^{-6} \times \frac{10 \times 2.54 \times 12}{2.5 \times 0.25 \times 2.54^2}$$

$$R = 130 \mu \text{ ohms}$$

An equivalent length of 4/0 wire yields

$$R = 500 \mu \text{ ohms}$$

The inductance of the bus is

$$L = 0.002 \times 10 \times 12 \times 2.45 \left[2.3 \log \frac{2 \times 10 \times 12}{2.75} + \frac{1}{2} \right]$$

$$L = 0.610 (4.45 + 0.5)$$

$$L = 3 \mu \text{h}$$

For the 4/0 cable

$$L = 0.002 \times 3.05 \left[2.3 \log \frac{2 \times 10 \times 12}{0.264} - 0.75 \right]$$

$$L = 0.610 (6.8 - 0.75) = 3.7 \mu \text{h}$$

A knowledge of the electrical parameters of any planned grounding system is of immeasurable help in precluding problems areas. Such simple calculations permit setting up equations for the entire system to be connected to the ground grid. Results of calculations of inductance for bonds of various width to length ratios are shown in figure 7-34. The impedance of a typical bond of length to width ratio of 5.5 to 1 is shown in figure 7-35 for both measured and calculated data.

The calculated data is derived from the formula for the minimum inductance at the highest possible frequency and, hence, is slightly lower than the measured value.

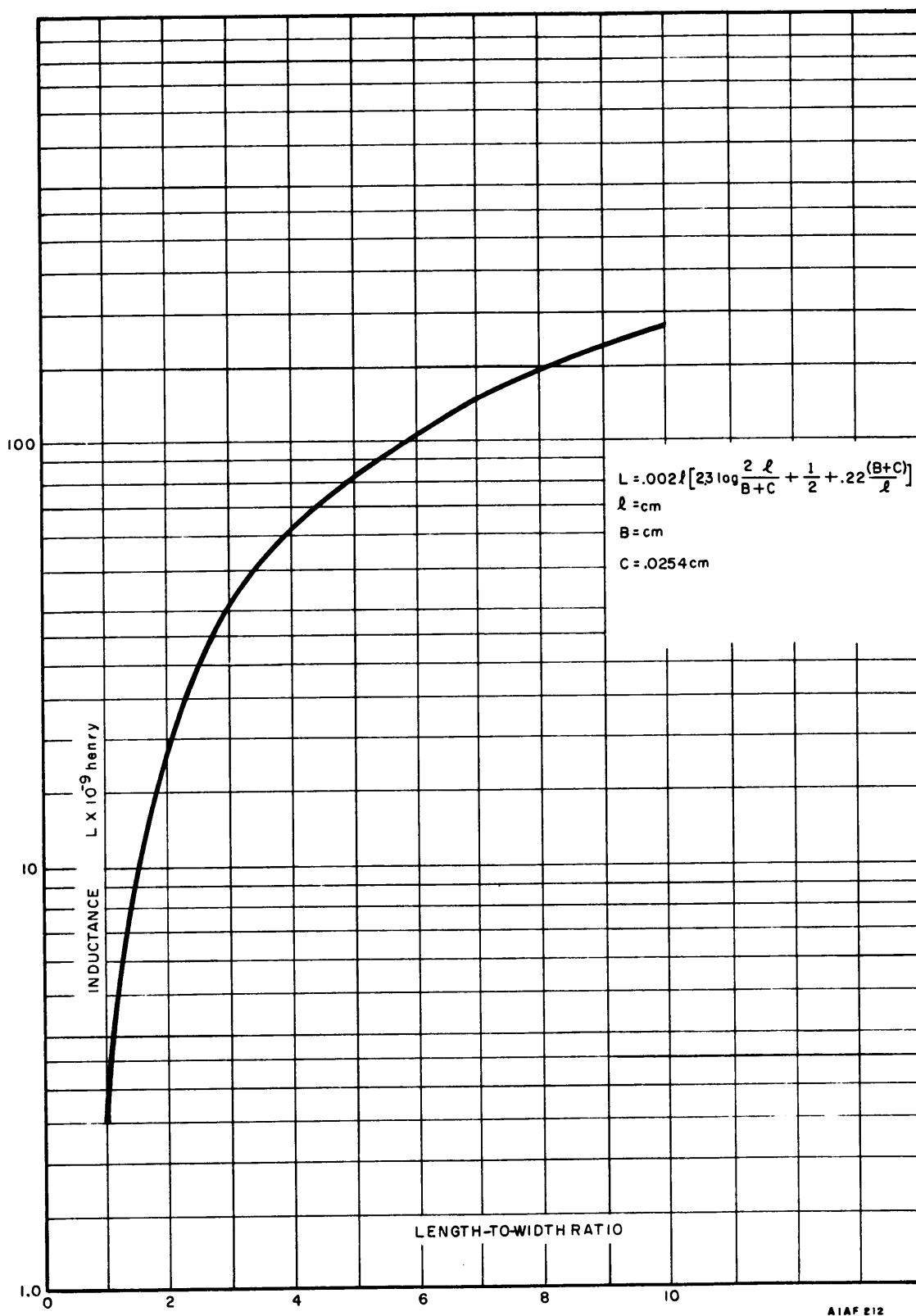


Figure 7 - 34. Theoretical Inductance Values with Varying Bond Length - to - Width Ratios

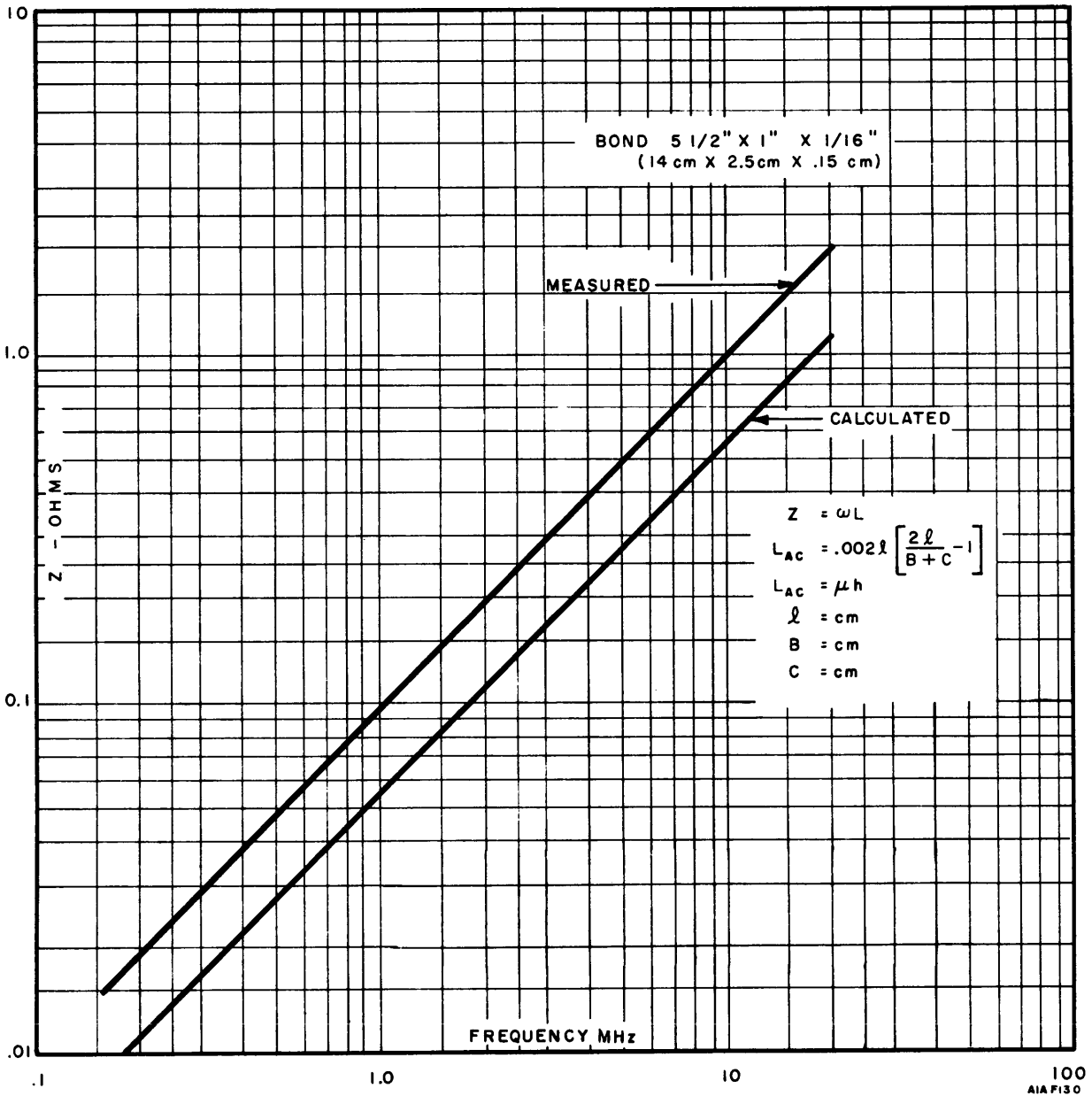


Figure 7 - 35. Measured and Calculated Values for a Bond Strap

7.5 SHIELDING

7.5.1 Basic Considerations

To preclude the possibility of EMI and RADHAZ problems, the installation designer should take advantage of all inherent shielding which the installation or system and its individual equipments as well as terrain, has to offer. Items such as building walls, partitions, towers and other similar structures may be used to advantage. The shielding effectiveness afforded by these items may be used to isolate EMR generating equipment from potentially susceptible devices, personnel, flammable mixtures, and other items. In addition, equipments used in a console or rack may be placed to take advantage of the inherent shielding of that rack.

Shielding can be very complicated or quite simple depending upon the particular installation under consideration. Fixed ground equipments, except those of extremely high sensitivity, are relatively easy to shield. Generally, mobile systems pose special problems because the individual equipments must be mounted close together resulting in all of the energy being concentrated near susceptible devices. In addition, the energy may be directed in the vicinity of personnel, fueling or ordnance handling areas. Extremely sensitive, as well as high powered equipments, also present special shielding problems. In addition, the more electronic equipments used on an installation the more difficult the shielding problem becomes, regardless of how well the shielding is designed.

A good shield must have the following general characteristics:

- a. It must contain undesired EMR generated by source equipment.
- b. It must permit only such undesired energy to pass that will not interfere with performance of adjacent equipment or create hazardous situations as described in this handbook.
- c. It must prevent externally generated EM energy from degrading or damaging electronic or electrical equipments.

If it were not for the many mechanical and electrical interfaces required in an installation and its equipments, the shielding problem would be reduced to choosing a proper shield material and applying it. Since each interface degrades the shield to some degree, the selection and implementation of techniques to provide continuity at these interfaces is important. Figure 7-36 illustrates some of these interfaces. Despite the complexity of the problem, a series of principles may be used for the design and use of shields that will be effective in the control of EMR as well as the protection from the effects of the emissions.

7.5.2 Shielding Effectiveness

The shielding effectiveness (SE), or insertion loss, expressed in dB, attenuation, can be generalized as follows:

$$SE = A + R + K \quad (7-10)$$

A = Absorption loss for both sides (dB)

R = Reflection loss for both sides (dB)

K = Correction factor for waves reflecting inside wall. This factor is insignificant for metal walls of enough thickness to support their own weight.

a. Absorption loss. This factor represents the reduction in signal due to dissipation as it proceeds through the body of the shield and is calculated by the following formula:

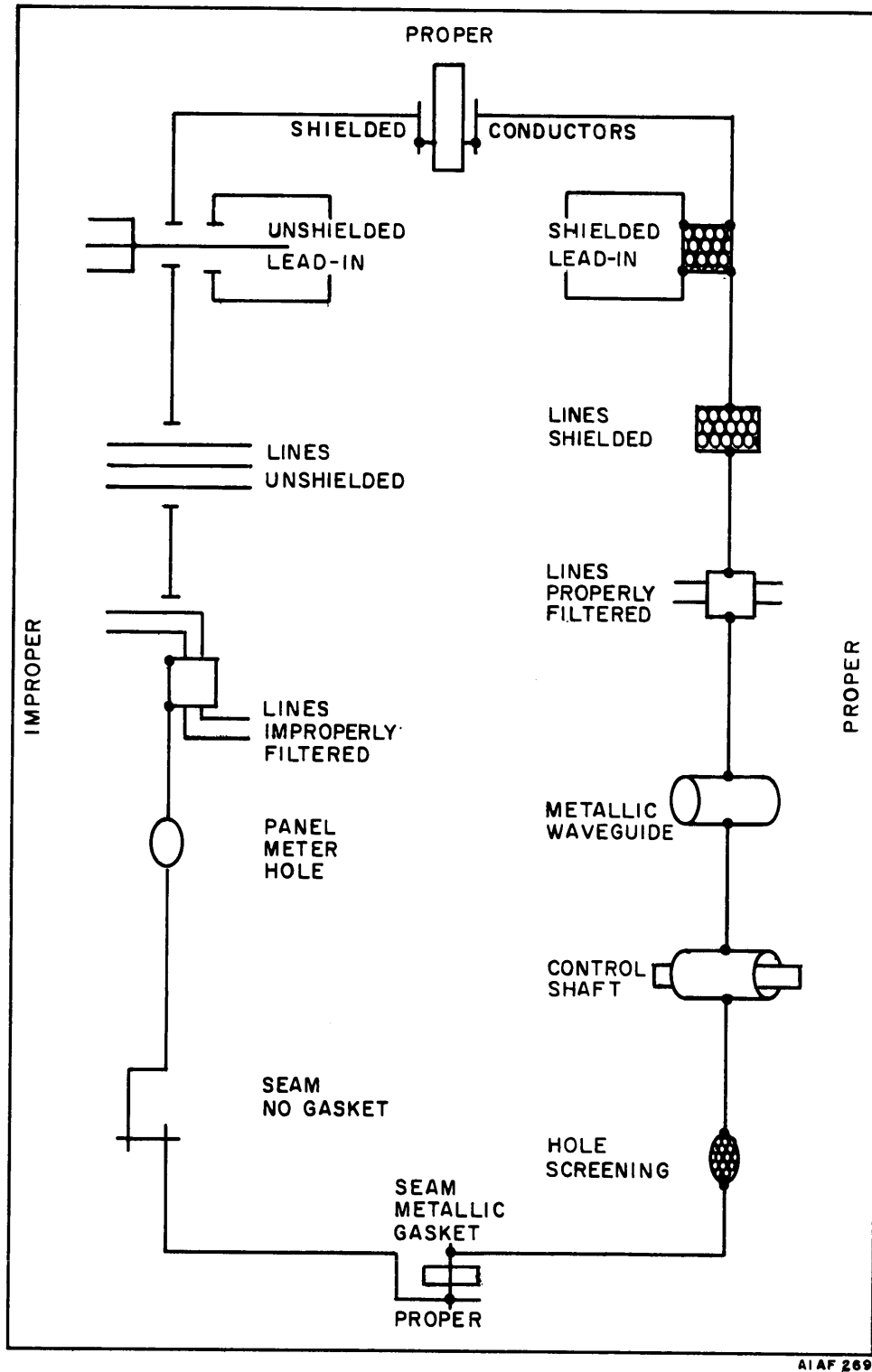


Figure 7 - 36. Typical Shielded Compartment Interfaces with Proper and Improper Controls

$$A = 3.338 \times 10^{-3} T \sqrt{F \sigma \mu} \quad (7-11)$$

A = Wall absorption loss (dB)

T = Wall thickness in mils

F = Frequency in hertz

σ = Material conductivity relative to copper

μ = Material magnetic permeability (vacuum = 1)

Figure 7-37 is presented to assist the designer in determining, for various magnetic and nonmagnetic materials, the penetration or absorption loss at a chosen frequency. For a desired amount of absorption loss at a known frequency, the required thickness for a known metal may be determined as follows:

(1) Locate the frequency on the F scale and the desired absorption loss on the A scale. Place a straightedge across these points and locate a point on the unmarked scale (Example: A=10 dB, F=100 kHz).

(2) Pivot the straightedge about the point on the unmarked scale to various metals noted on the $\mu \times \sigma$ scale. A line connecting the $\mu \times \sigma$ scale and the point on the unmarked scale will give the required thickness on the T scale. Example: for copper T = 9.2 mils, for commercial iron T=5.2 mils.)

The figure may also be used in reverse of the above order to determine absorption loss of a known thickness and metal.

Although the shielding effectiveness due to the absorption loss at low frequencies drops off considerably, this is of little consequence since the configuration is not likely to be an efficient receiving aperture at these frequencies.

b. Reflection Loss. As an electromagnetic wave propagates from free space into another medium, such as a metallic barrier, the wave impedance will change suddenly and reflection will occur at the boundary of the two media.

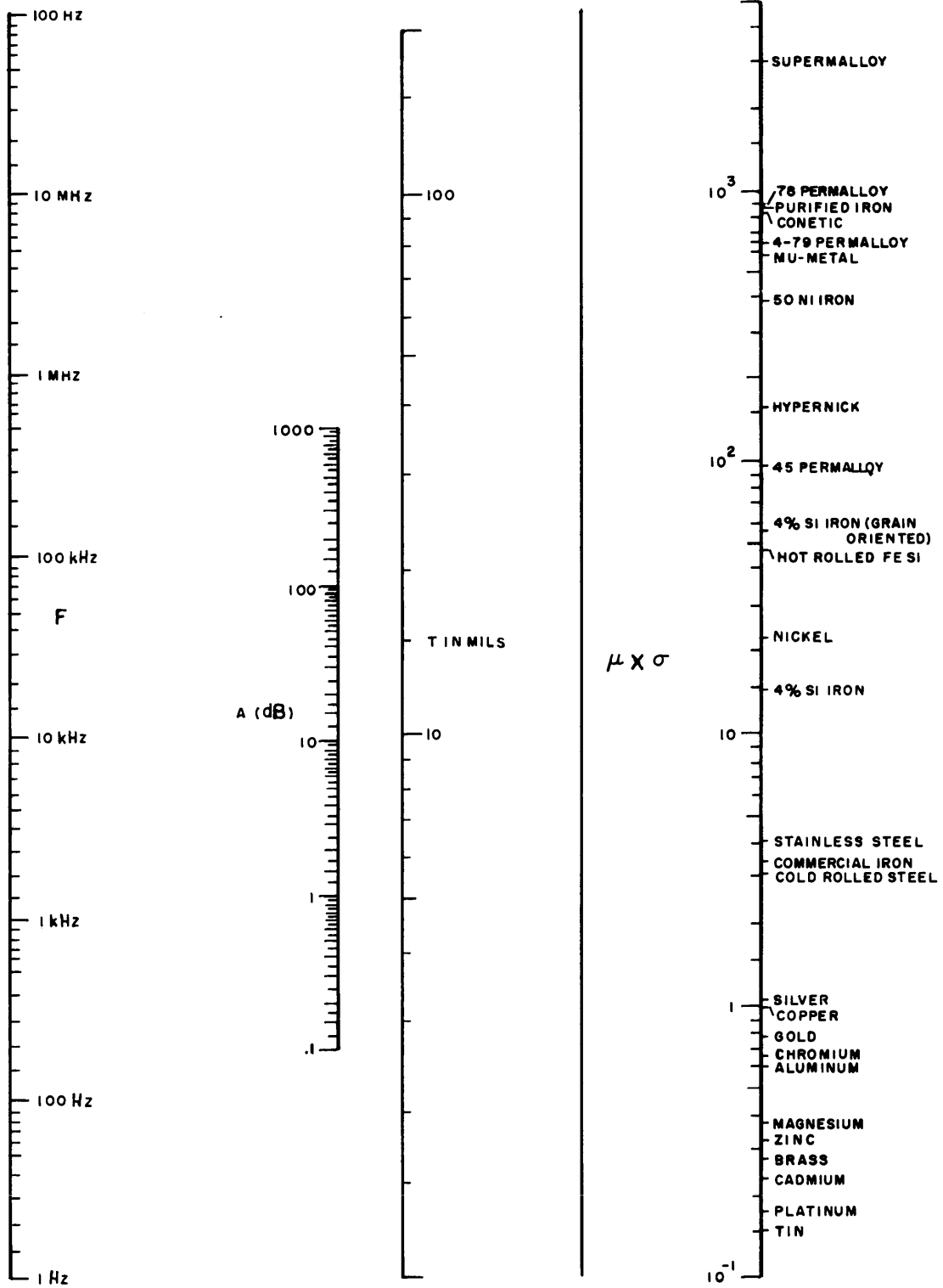
For plane waves, shielding magnetic material provides the best absorption loss (since $\mu \gg \sigma$ at a given thickness T) while good conductors provide better reflection loss ($\sigma \gg \mu$). To calculate reflection loss for plane waves the following equation or figure 7-38 can be used.

$$R_p = 168 + 10 \log \frac{\sigma}{\mu F} \quad \text{in dB} \quad (7-12)$$

In determining plane wave reflection loss R_p :

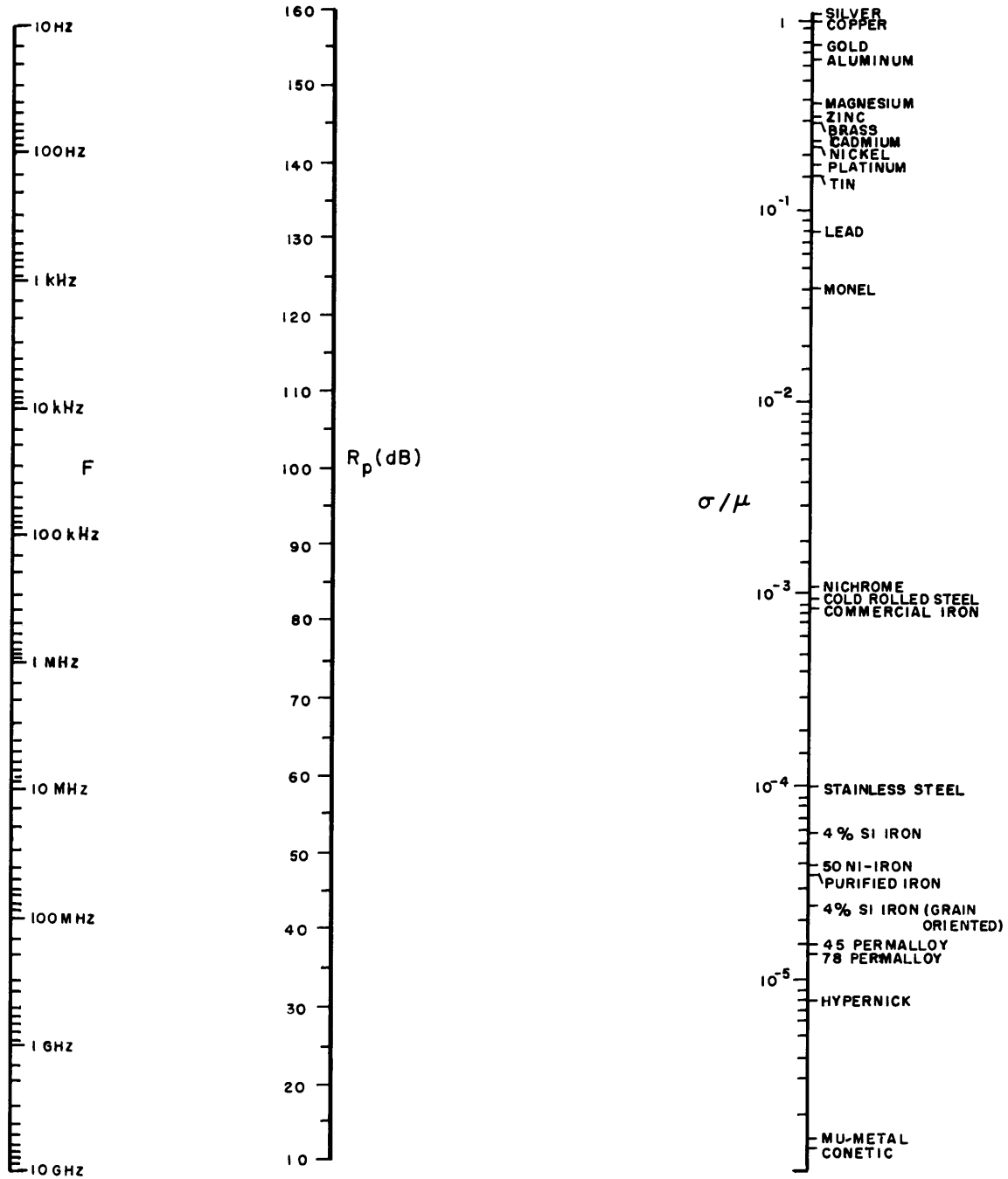
o Locate a point on the σ/μ scale for one of the metals listed. If the metal is not listed, compute σ/μ and locate a point on the numerical scale.

o Place a straightedge between the σ/μ scale and the desired frequency on the "F" scale.



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Figure 7 - 37. Absorption Losses (A)



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Figure 7 - 38. Plane Wave Reflection Losses R_p

- o Read the plane wave reflection losses from the R_p scale.

The electric field that exists close to the radiating antenna is high in impedance and is more in keeping with the nature of the radiating elements within an equipment group. The reflection loss for the high impedance or E - field wave can be calculated with the following equation or from the nomograph in figure 7-39.

$$R_e = 353.6 + 10 \log \frac{\sigma}{F^3 \mu D^2} \quad (\text{dB}) \quad (7-13)$$

D = Distance from radiating element to shield (inches)

Both R_e and R_h (see below) can be computed using the following steps:

- o Locate a point on the σ/μ for one of the metals listed. If the metal is not listed, compute σ/μ and locate a point on the numerical scale.
- o Locate the distance between the energy source and the shield on the "D" scale.
- o Place a straightedge between D and σ/μ and locate a point on the blank scale.
- o Place a straightedge between the point on the blank scale and the desired frequency on the F scale.
- o Read the reflection loss from the R_e or R_h (figure 7-40) scale.
- o By sweeping the F scale while holding the point on the blank scale, R_e or R_h versus frequency can be obtained.

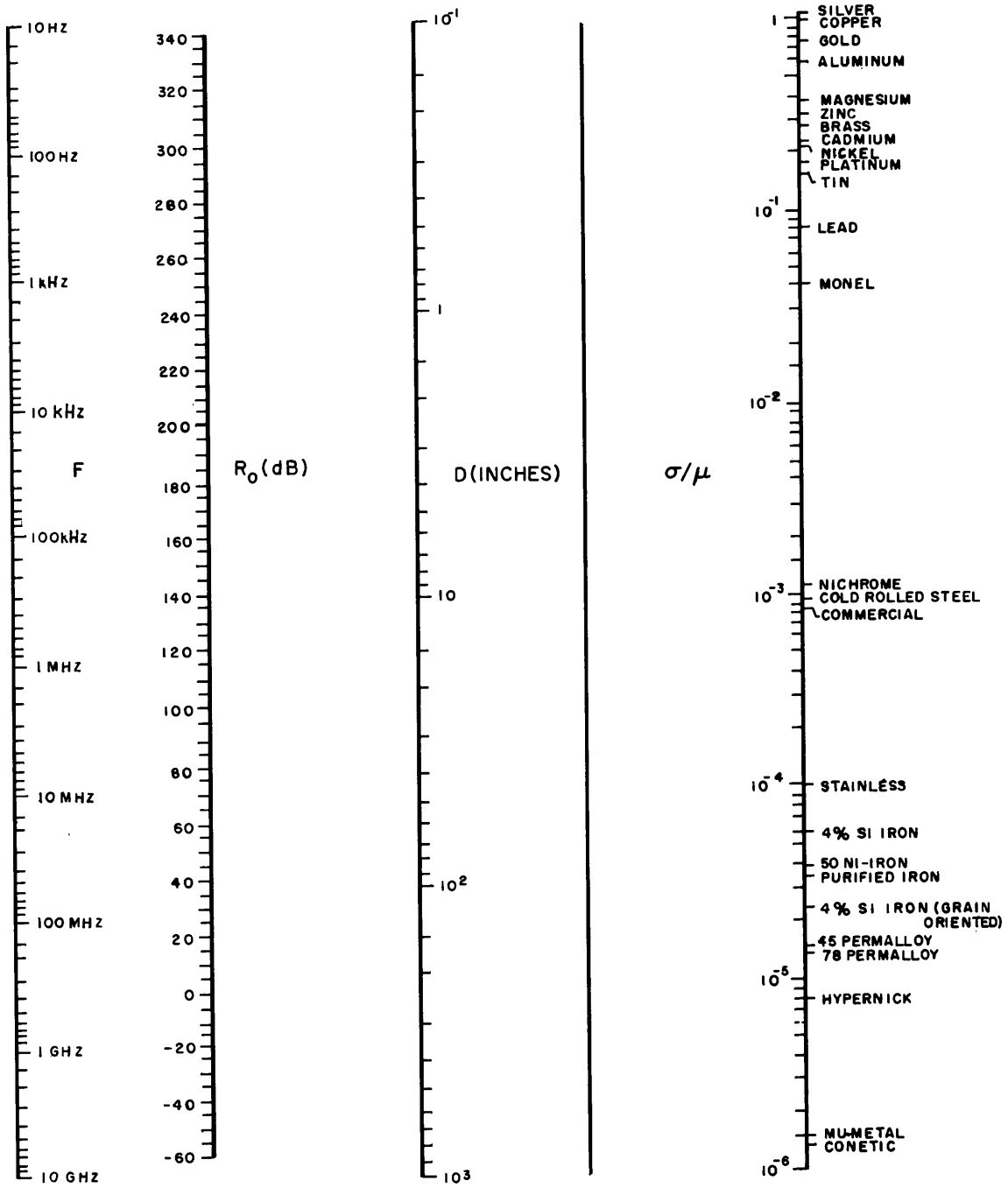
The magnetic field is known as a low impedance field. Magnetic field shielding may best be achieved through the use of magnetic material such as mu-metal, permalloy, steel, etc. The reflection loss for magnetic fields can be calculated with the following equation or from the nomograph on figure 7-40.

$$R_h = 20 \log \left[\frac{0.462}{D} \sqrt{\frac{\mu}{F\sigma}} + 0.136D \sqrt{\frac{F\sigma}{\mu}} + 0.354 \right] \quad (\text{dB}) \quad (7-14)$$

c. Correction Factor, K. This factor, described earlier, is usually applied when the absorption losses are less than 10 dB. Figure 7-41 gives approximate values of K up to 300 mils of metal thickness. This figure is obtained by plotting data given in table 7-6 for copper magnetic field shielding. From this type of graph any correction factor can be calculated between 60 Hz and 1 MHz.

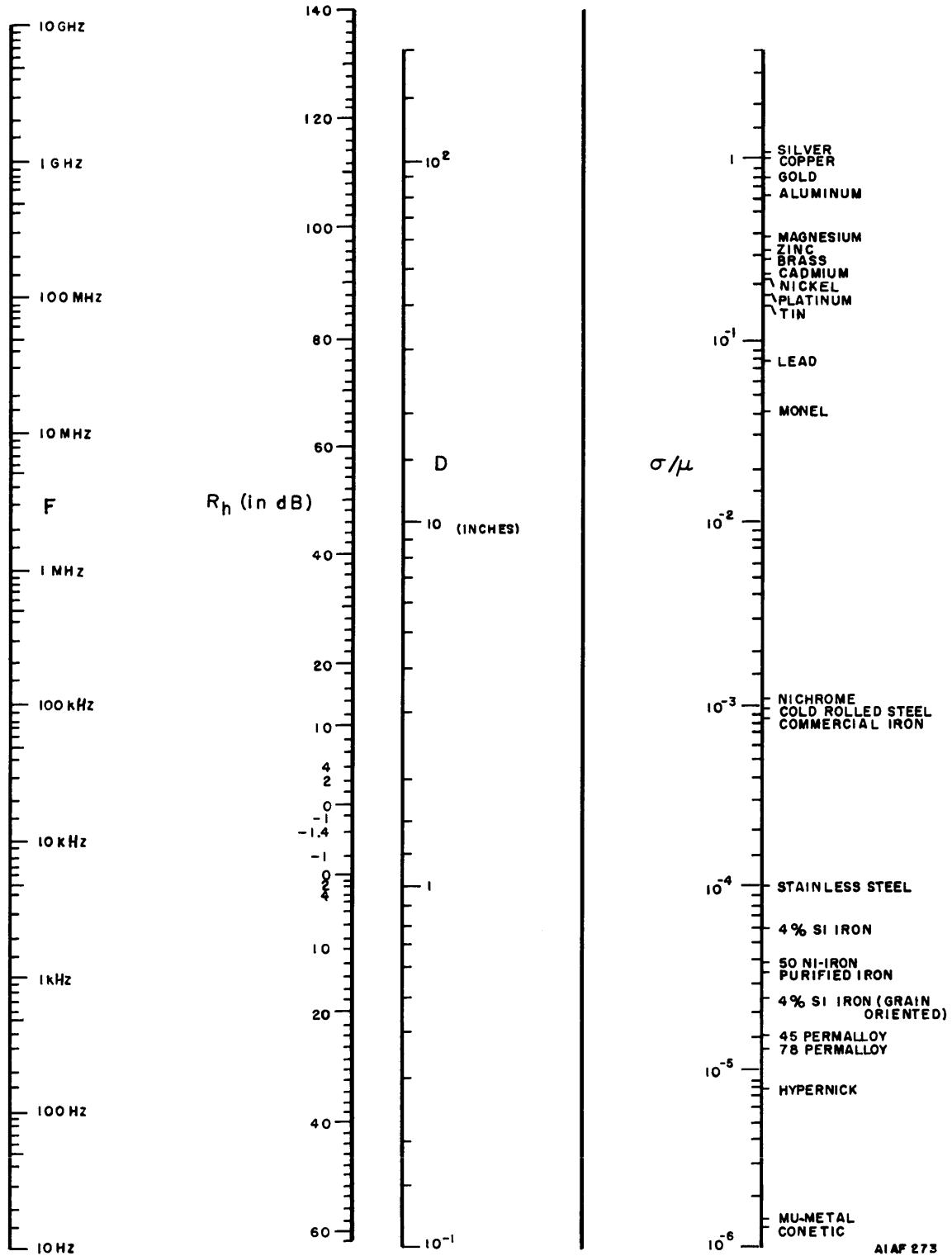
7.5.3 Shielding Materials

It is noted that magnetic fields are difficult to shield at low frequencies since the reflection losses may approach zero at certain combinations of material and frequency; also, with decreasing frequency, reflection and absorption losses decrease for nonmagnetic metals. At high frequencies, the shielding efficiency is good because of the reflection at the discontinuity in media and the rapid dissipation of the field by absorption. The high theoretical values of shielding effectiveness for magnetic materials are seldom achieved in practice. Some success has been achieved with the use of multiple permalloy shields separated by copper shields, since the shielding effect at these frequencies is largely due to reflection. Copper clad steel is sometimes used for this same reason. Multiple shields may provide reflection losses as high as 100 dB, if the shields are isolated from one another or connected at most at one common point.



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Figure 7 - 39. Electric Field Reflection Losses R_e



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Figure 7 - 40. Magnetic Field Reflection Losses R_h

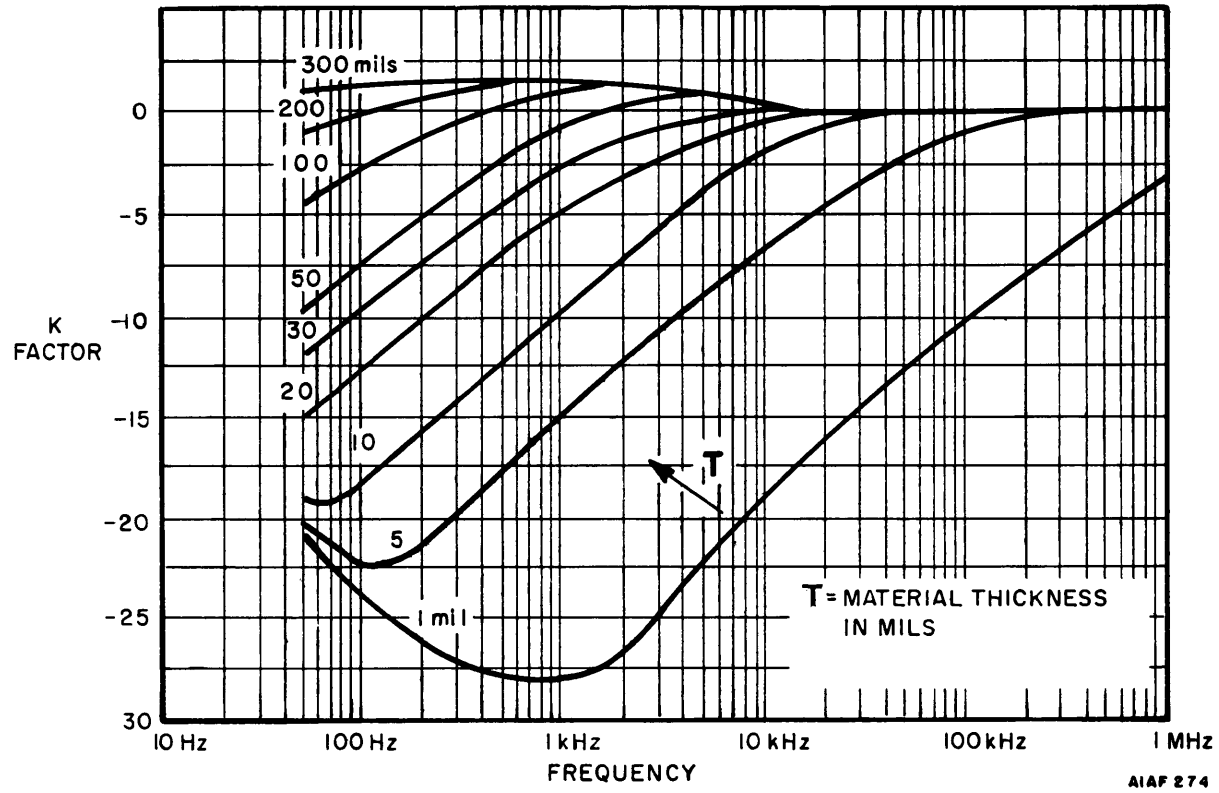


Figure 7 - 41. Graph of K Correction Factor for Copper Magnetic Field

Table 7-6. K Correction Factors in dB for Solid Metal Shield

	SHIELD THICKNESS (MILS)	FREQUENCY					
		60 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
MAGNETIC FIELDS COPPER ($\mu=1, \sigma=1$)	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	-
	20	-15.85	-13.77	-5.41	+0.13	-0.10	-
	30	-12.55	-10.76	-2.94	+0.58	-	-
	50	-8.88	-7.07	-0.58	-	-	-
	100	-4.24	-2.74	+0.50	-	-	-
	200	-0.76	+0.05	-	-	-	-
	300	+0.32	+0.53	-	-	-	-
ELECTRIC FIELDS AND PLANE WAVES COPPER ($\sigma=1, \mu=1$)	1	-41.52	-39.31	-29.38	-19.61	-10.33	-2.61
	5	-27.64	-26.46	-15.82	-6.96	-0.55	+0.14
	10	-21.75	-19.61	-10.33	-2.61	+0.57	-
	20	-15.99	-13.92	-5.37	+0.14	-0.10	-
	30	-12.73	-10.73	-2.90	+0.58	-	-
	50	-8.81	-6.96	-0.55	+0.14	-	-
	100	-4.08	-2.61	+0.51	-	-	-
	200	-0.62	+0.14	-	-	-	-
	300	+0.41	+0.58	-	-	-	-
MAGNETIC FIELDS IRON ($\mu=1000, \sigma=0.17$)	1	+0.95	+1.23	-1.60	-1.83	-	-
	5	+0.93	+0.89	-0.59	-	-	-
	10	+0.78	+0.48	+0.06	-	-	-
	20	+0.35	+0.08	-	-	-	-
	30	+0.06	-0.06	-	-	-	-
	50	-	-	-	-	-	-
ELECTRIC FIELDS AND PLANE WAVES IRON ($\mu=1000, \sigma=0.17$)	1	-19.53	-17.41	-8.35	-1.31	-	-
	5	-6.90	-5.17	+0.20	-	-	-
	10	-2.56	-1.31	+0.36	-	-	-
	20	+0.16	+0.54	-	-	-	-
	30	+0.58	+0.42	-	-	-	-
	50	+0.13	-	-	-	-	-

a. Material Thickness. It is commonly assumed that most materials which have adequate structural rigidity will also possess sufficient thickness to provide satisfactory shielding effectiveness. While this is an adequate approximation in the radio-frequency range, this does not necessarily hold true for equipments operated in the audio frequency range if high intensity fields are involved. At these frequencies a high permeability material, such as mu-metal, or permalloy is normally required, to provide good shielding efficiency to magnetic fields. When such magnetic shields are used, reflection losses may be obtained even at very low frequencies. Since the shielding effect at these frequencies is a result of surface reflections and not of absorption, the thickness of the shield at that frequency will not be of significance.

b. Non-Solid Shields. There are many applications in which the shield cannot be made of a solid material due to system design requirements. Screens and perforated materials must be employed if an enclosure must be transparent (e.g., a meter face) or ventilated. Since there is no practical means of calculating the shielding effectiveness of woven materials, the installation engineer is referred to the literature for the attenuation characteristics of the various materials and configurations. Often, the exact situation may not be treated sufficiently; therefore, measurements will be required to validate the material and configuration intended for use in the system or installation. In general, the shielding effectiveness of woven materials for radiated fields decreases with increasing frequency, and the shielding effectiveness increases with the density of the weave.

In the induction field where the magnetic component is large, the shielding effectiveness increases with frequency, with the density of the woven material, and with the permeability of the material. Table 7-7 shows the magnetic field attenuation versus frequency for two common types of wire mesh cloth, one made of copper and the other of galvanized steel. The radiated field attenuation of these wire mesh cloth materials is shown in table 7-8.

Table 7-7. Wire Mesh Cloth: Magnetic Field Attenuation vs Frequency

FREQUENCY (MHz)	COPPER		GALVANIZED STEEL	
	18 x 18	22 x 22	22 x 22	26 x 26
	(Attenuation in dB)		(Attenuation in dB)	
0.01	59.3	65.4	94.1	100.3
0.03	70.0	76.1	101.3	107.4
0.06	76.7	82.8	104.0	110.1
0.1	81.1	87.2	105.4	111.5
0.3	90.3	96.4	106.7	112.8
0.6	94.7	100.8	107.0	113.1
1.0	97.0	103.1	107.1	113.2
3.0	99.8	105.9	107.3	113.4
6.0	100.6	106.7	107.3	113.4
10.0	100.8	106.9	107.3	113.4
30.0	101.2	107.2	107.3	113.4
60.0-10GHz	101.2	107.2	107.3	113.4

Table 7-8. Wire Mesh Cloth: Radiated Field Attenuation vs Frequency

FREQUENCY (MHz)	COPPER		GALVANIZED STEEL	
	18 x 18	22 x 22	22 x 22	26 x 26
	(Attenuation in dB)		(Attenuation in dB)	
0.01	103.6	109.1	137.7	143.9
0.03	104.7	110.2	135.4	141.6
0.06	105.4	110.2	132.1	138.3
0.1	105.4	113.6	129.1	135.3
0.3	105.0	110.5	120.8	127.0
0.6	103.4	108.9	115.1	121.3
1.0	101.3	106.8	110.8	117.0
3.0	94.5	100.0	101.4	107.6
6.0	89.3	94.8	95.4	101.6
10.0	85.1	90.6	91.0	97.2
30.0	75.8	81.3	81.4	87.6
60.0	69.9	75.4	75.4	81.6
100.0	65.6	71.0	71.0	77.2
300.0	55.9	61.4	61.4	67.6
600.0	49.9	55.4	55.4	61.6
1 GHz	45.5	51.0	51.0	57.2
3 GHz	35.9	41.4	41.4	47.6
6 GHz	29.9	35.4	35.4	41.6
10 GHz	25.5	31.0	31.0	37.2

c. Honeycomb Material. Where shielding, ventilation, and strength are required and weight is not a critical condition, honeycomb panels may be used. The shielding effectiveness of honeycomb panels is based on, and predicted by, the attenuation properties of waveguides operated below cut-off. It is a function of the size and length of the waveguide and the number of waveguides in the panel. Table 7-9 indicates the shielding effectiveness of a honeycomb panel constructed of steel with 1/8-inch hexagonal openings 1/2-inch long.

Table 7-9. Shielding Effectiveness of Hexagonal Honeycomb Made of Steel With 1/8 - Inch Openings 1/2 - Inch Long

FREQUENCY (MHz)	SHIELDING EFFECTIVENESS (dB)
0.1	45
50	51
100	57
400	56
2,200	47

d. Screened Apertures Calculations. The following equations are to be used when an aperture is covered by some type of screening material, but they can be used for cabinet panels if the aperture is considered to be the panel size and the perforations are the holes in this panel, assuming that perforations are equally spaced. If this is not the case, make the substitution of $C^2 = A/N$, in the following equations. To use the equations all parameters must be calculated in the same units (inches, cm, etc.)

C = Center to center

A = Area

N = Number of holes

T = Thickness of cabinet wall

l_a = Length of aperture

l_p = Length of perforation

(1) Square Perforations over Square Aperture

$$SE = 20 \log \frac{C^2 l_a}{l_p^3} + 27.3 \frac{T}{l_p} \text{ dB} \quad (7-15)$$

Use when there are square perforations in a square section of cabinet panel or a square aperture in the cabinet panel covered with material having square holes or perforations, d_a =Diameter of circular aperture; d_p =Diameter of circular perforation.

(2) Round Perforations over Round Apertures

$$SE = 20 \log \frac{C^2 d_a}{d_p^3} + 32 \frac{T}{d_p} + 2.08 \text{ dB} \quad (7-16)$$

Use when there are round perforations in a circular area of cabinet panel or round aperture covered with a material having round perforations.

(3) Round Perforations over a Square Aperture

$$SE = 20 \log \frac{C^2 l_a}{l_p^3} + 32 \frac{T}{d_p} + 3.83 \text{ dB} \quad (7-17)$$

Use when there are round perforations in a square area of a cabinet panel or when a square aperture is covered with a material having round perforations.

(4) Square Perforations over a Round Aperture

$$SE = 20 \log \frac{C^2 d_a}{d_p^3} + 27.3 \frac{T}{l_p} - 1.76 \text{ dB} \quad (7-18)$$

Use when there are square perforations in a circular area of a cabinet panel or when a round aperture is covered with a material having square perforations.

7.5.4 Preservation of Shielding Integrity

As noted earlier the choice of material depends primarily on the type and degree of shielding performance desired. Paragraph 7.5.2 gave details for use in calculating shielding effectiveness. However, many factors must be considered in the total evaluation for shielding effectiveness. Careful attention must be paid to mechanical design and openings for control and power leads, ventilation, doors and covers, meters, control shafts, seams, and other mechanical features which may introduce electrical discontinuities in the shield. Such openings may permit radiation of electromagnetic energy from transmitters, or permit the introduction of spurious signals into a receiver or sensitive instrumentation. Such should be precluded by a combination of design features which form an effective shielded enclosure. Factors to be considered are outlined. Additional information as required may be obtained from many available reference documents.

a. Seams. It is important to obtain a clean metal-to-metal contact at seams to prevent leakage and radiation of energy. Where possible, such seams should be welded, brazed, or soldered such that the joint is continuous; however, satisfactory results can be obtained with construction utilizing closely spaced rivets, provided that no protective finish or corrosion exists to prevent contact between the mating metal surfaces. Also the finish should be removed between the mating surfaces of removable panels or doors. Several configurations for seams between two metallic members are shown in figures 7-42 to 7-44. Regardless of the type of seam used, the RF impedance of the seam must not differ appreciably from that of the material. If the RF impedance of the seam is relatively high, RF voltages can develop across the seam from skin currents, permitting RF energy to enter the shielded enclosure. It is usually necessary to use continuous welding of seams to ensure shielding effectiveness.

b. Gaskets. Openings which occur at joints or removable partitions may be shielded effectively by utilizing conductive gaskets. The important properties of resilience and high conductivity can be obtained from commercially available gasket materials. The problems involved in designing gaskets include providing the minimum gasket thickness which will allow for the expected surface discontinuities of the joint, providing correct height and pressure and allowing for the frequency of use of the joint. The gasket materials which are selected must be corrosion resistant, conductive, and possess an adequate degree of strength, resiliency, and hardness. They are available in various configurations, including the round type, rectangular type, and a combination gasket used for sealing against fluid flow as well as radio frequency leakage. Good gasket design includes the following criteria:

(1) Gasket materials used for RF shielding and sealing should have unconnected paths to conduct the current across a joint.

(2) Paths should be evenly spaced over the surface of the gasket material as to make contact with the gasket surfaces when pressure is applied.

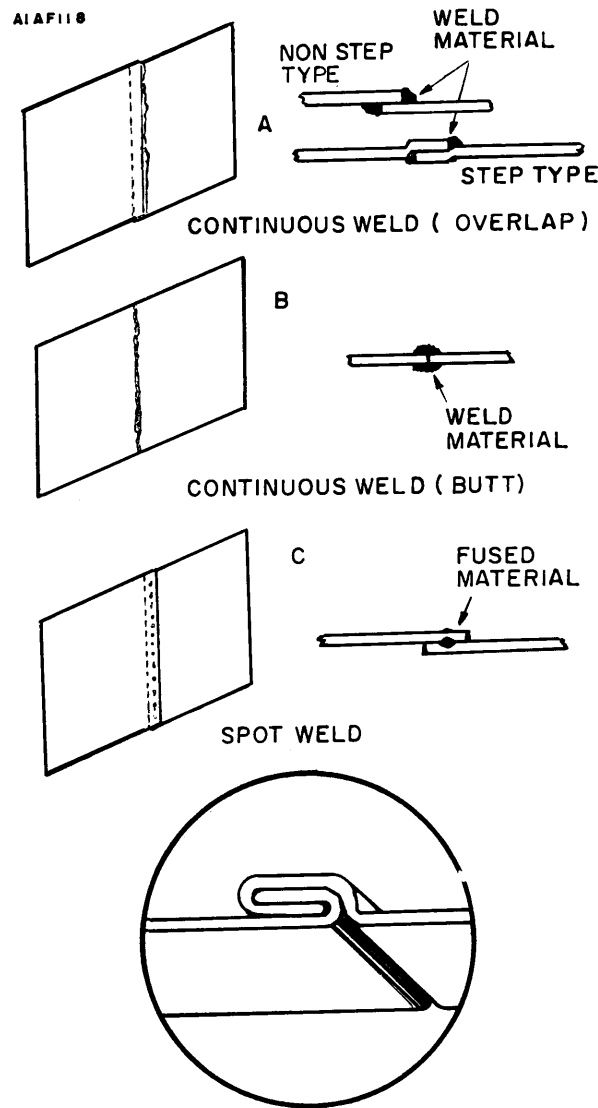
(3) Conductors used in gaskets should be relatively stable chemically and have good electrical conductance.

(4) Conductors perform best if they are made in a hard temper to break through the surface of the flanges.

(5) The number of conducting paths per square inch is important in controlling contact pressure.

(6) There is an optimum number of conductors per square inch for every combination of gasket design and conducting material.

(7) The mechanical properties of the metal elements and the sealing agent must be such that after sufficient clamping pressure has been applied to establish electrical conducting paths, the remainder shall be sufficient to provide sealing pressure.



FORMATION OF PERMANENT OVERLAP SEAM

D
NOTE: SOLDERING OR WELDING IS DESIRABLE FOR MAXIMUM PROTECTION.

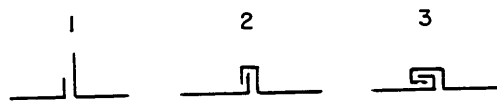


Figure 7 - 42. Panel Seam Configuration

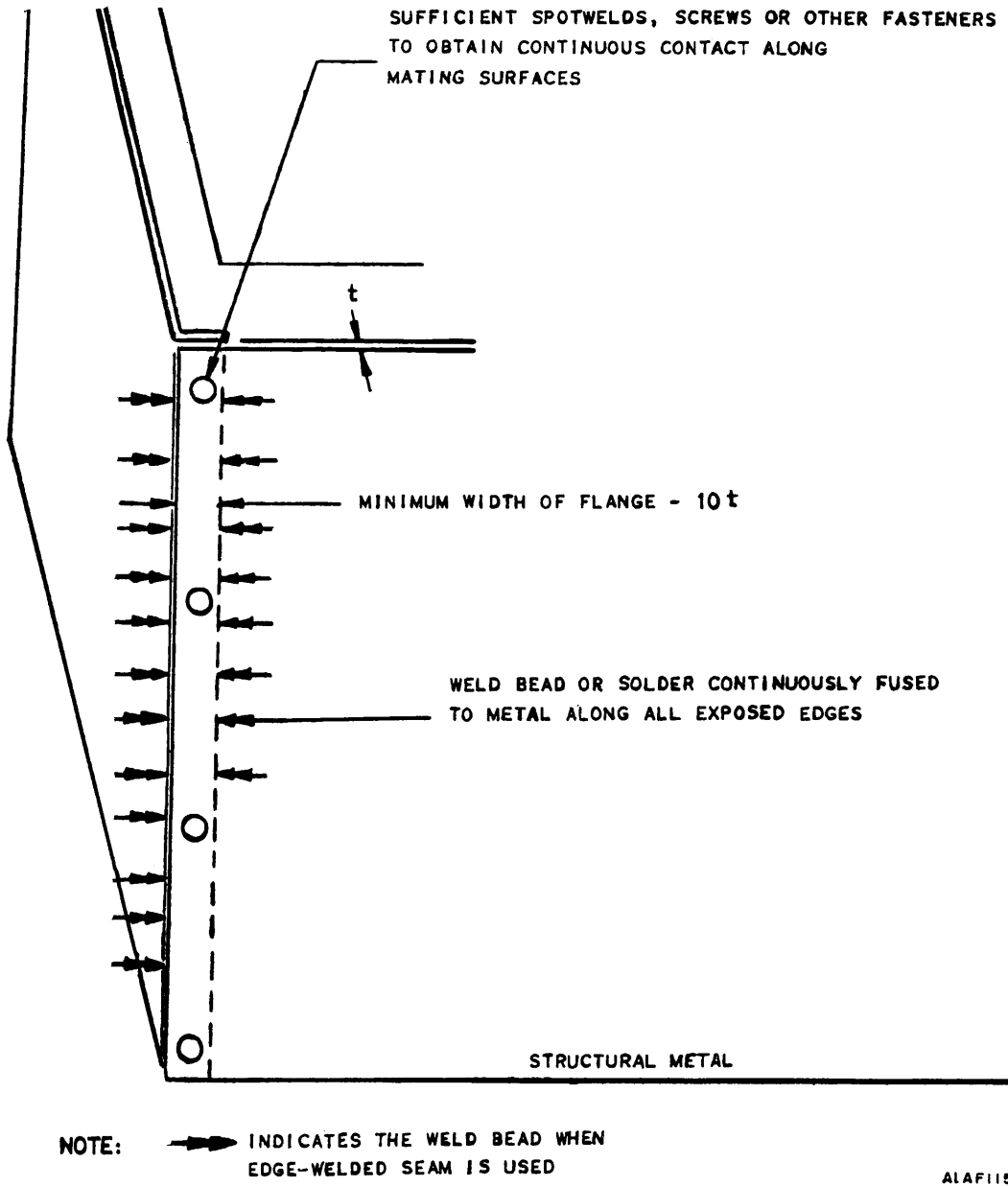
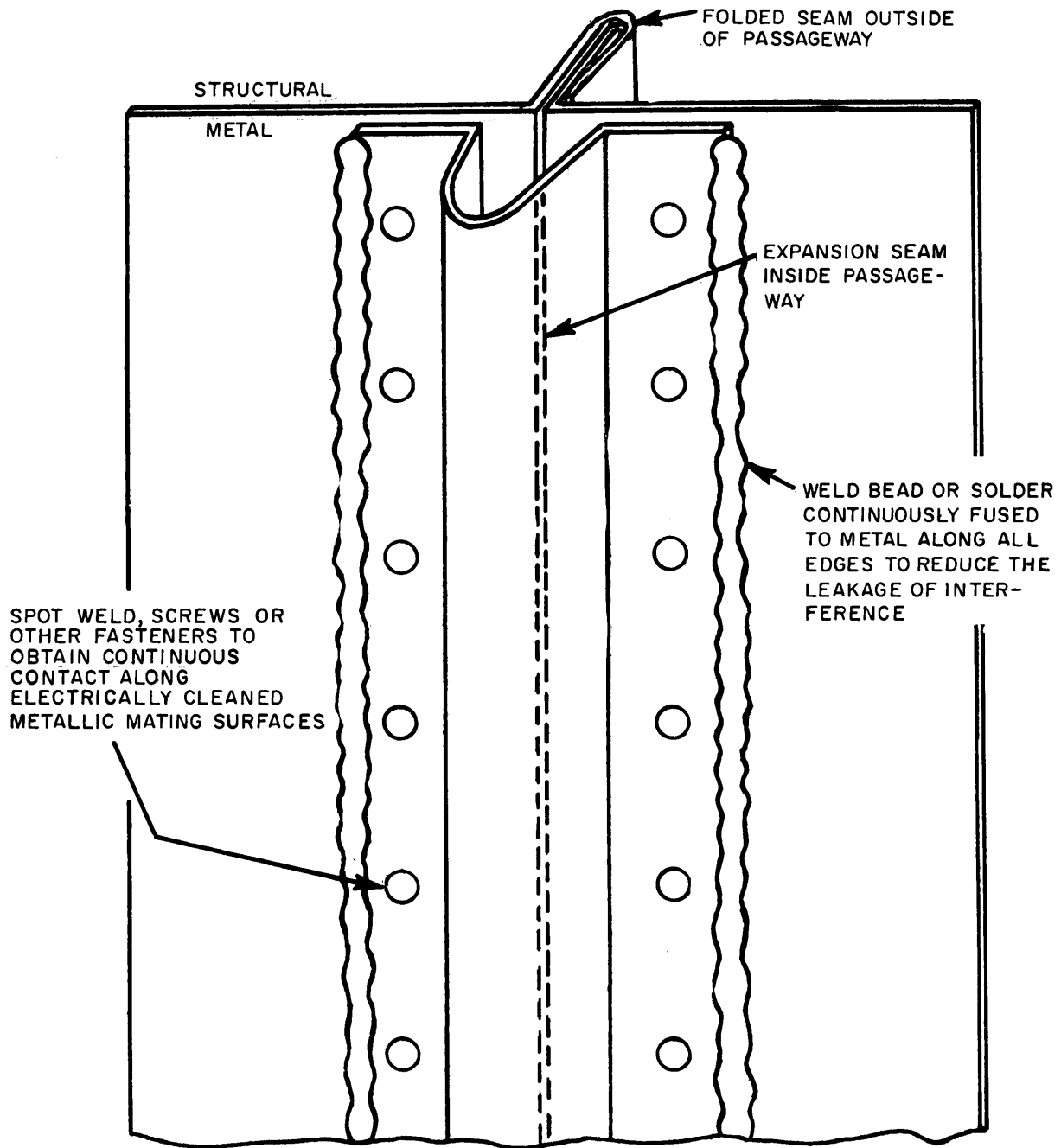


Figure 7 - 43. Seam Design for Minimum Interference



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Figure 7 - 44. Vertical Expansion Joint, An Example of a Seam

Figure 7-45 illustrates an acceptable method of making a construction seam using RF gasket material. The features to be observed in the figure are:

“A” - Gasket bonded to one metallic surface of the seam with conductive adhesive; surfaces cleansed of nonconductive material before application.

“B” - Metallic surface machined to smooth finish and all nonconductive materials removed.

“C” - Appropriate mechanical techniques (i.e., clamps, bolts, etc.) used to provide a high pressure on the RF gasket. The pressure must be nearly uniform along the entire length of the seam.

Figure 7-46 illustrates an acceptable method of making construction seams where sections must be removed and replaced for maintenance or loading and handling operations. Table 7-10 is a guide to RF gasket design and usage.

c. Shielded Cables and Fittings. Unshielded and unfiltered conductors entering or leaving an enclosure may completely negate previous shielding efforts. Therefore, it is necessary to provide adequate shielding on all conductors which are likely to carry interference producing currents. The purpose of shielding individual conductors or cables is to prevent radiation or coupling between circuit conductors. The shield may be of solid or flexible conduit or may consist of single or multiple layers of closely-woven metallic braid. The shielding effectiveness of the flexible and mesh material varies with frequency, since at higher frequencies more energy may escape through the shield openings.

It is good practice, and in many systems mandatory, to physically separate pulse cables, and low level signal and control cables. Each signal carrying lead of the cables should be routed through a separate insulated shield. Each shield should be terminated in a separate, low impedance connector, well bonded to the shield. The construction of the connector is very important, for inadequate connectors may radiate at the junction and permit the flow of interference currents on the surface of the shielded cable.

In general, the most important shielded cables of any system or installation are those carrying low level signals and those carrying low level signal circuits to sensitive equipments. The proper installation of these signal cables is essential if interference difficulties are to be avoided.

d. Aperture Design. It is necessary to keep holes for ventilation or drainage of moisture small in effective electrical area to avoid decreasing the shielding efficiency. A “small” hole is one which is small in dimension compared to the operating wavelength. Larger holes should be covered by a fine mesh copper screen, or alternately, a series of small holes may be used.

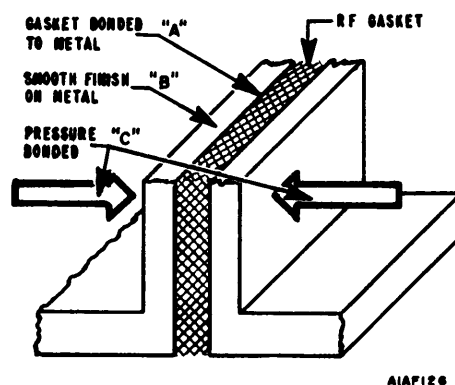


Figure 7 - 45. Acceptable Method of Making Permanent Seam Using RF Gasket

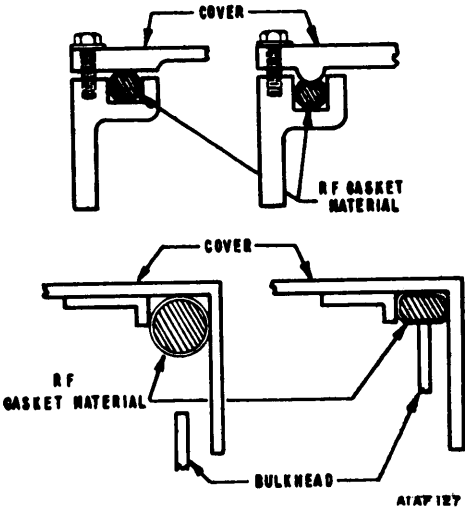


Figure 7 - 46. Covers with Gaskets

Table 7-10. RF Gasket Design and Usage

GASKET CONSIDERATION	DETERMINED BY
Material	Corrosion, mechanical wear, spring qualities, and RF properties
Form	Attachment methods, force available other gasketing functions, joint unevenness, and space available
Thickness	Class of joint, joint unevenness, force available, and RF level

Where screen mesh is used, the mesh should have about a 50 percent open area and 60 or more strands per wavelength. It is important that continuity of the individual wires be preserved at their point of intersection by joining in some manner, so subsequent oxidation will not reduce the shielding efficiency.

Where large openings are required such as for ventilation, these should be equipped with suitable panels to prevent passage of electromagnetic energy. The most efficient type of panel for this purpose consists of honeycomb sections similar to automobile radiator designs, except that the intercellular connections are soldered throughout their length. Shielding may also be provided by layers of copper screening, but lower shielding effectiveness and higher air resistance will result.

An interference reduction technique which may be of value is to design the aperture, through which leakage occurs, as a waveguide-type attenuator, which acts as a high pass filter. For a particular waveguide there exists a cutoff frequency, which is the lowest frequency at which propagation will occur without attenuation. Below cutoff, attenuation is a function of guide length and the frequency. By designing an aperture in a shielded enclosure as a waveguide operating below cutoff for the dominant mode (lowest propagation frequency), from 80 to 100 dB of attenuation can be provided. The most common waveguide apertures are either rectangular or circular openings. As a design guide or approximation for frequencies well below cutoff, making the length 3 times the diameter affords 100 dB of attenuation with circular guides; and 80 dB of attenuation with rectangular guides.

Some commercial signal generators and orifices for screen rooms make use of waveguide attenuators. The waveguide attenuator is also of considerable value when control shafts must extend through an enclosure. By making use of an insulated control shaft passing through the waveguide attenuator, the control function can be accomplished with little possibility of radiation. However, where a metallic control shaft is required, it must be grounded to the case by a close-fitting gasket or metallic fingers. The waveguide attenuator approach may also be considered where holes must be drilled in the enclosure. If the metal thickness is sufficient to provide a "tunnel" with adequate length, a waveguide attenuator is effectively produced. For example, a metal wall 3/16-inch thick would permit a 1/6-inch hole to be used, without excessive leakage. This technique definitely should be considered where it is necessary to confine extremely intense interference sources.

Other openings, such as for fuse receptacles, phone jacks, and meter jacks should be shielded with a removable or spring loaded cap. A panel meter usually requires a fairly large mounting hole and should be provided with a shield which can be made contiguous with the case. Metallized glass for use on meters and other instruments, as well as viewing panels, has been developed which reduces RF leakage through the glass and still results in a light transmission of 70 to 80 percent. Figures 7-47 through 7-49 illustrate acceptable methods for shielding various apertures.

If hinges are used on panels, it is recommended that a mesh such as conductive weather stripping be used on the hinged side of the panel. An alternative method for shielding at the hinge side of the panel is to use metal fingers. The shielding material must be electrically and mechanically bonded to the frame at close intervals to ensure proper shielding.

The best arrangement of spring contact fingers around removable panels or doors calls for the installation of two sets of fingers at right angles to each other. One set is a wiping set; the other is in compression; and the combination makes good electrical contact when the door is closed. The pressure exerted by these springs is highly important and it should be carefully maintained. Cleanliness is also important.

7.5.5 Enclosures

Where possible internal walls and compartments may be used to limit propagation of interference within an enclosure or equipment case. Lead entry and exit should be designed as follows:

- a. Isolate leads likely to be noisy (such as power leads) from other leads, or if connectors are used, employ separate connectors.
- b. Power input circuit configuration should complement the power and power grounding system into which

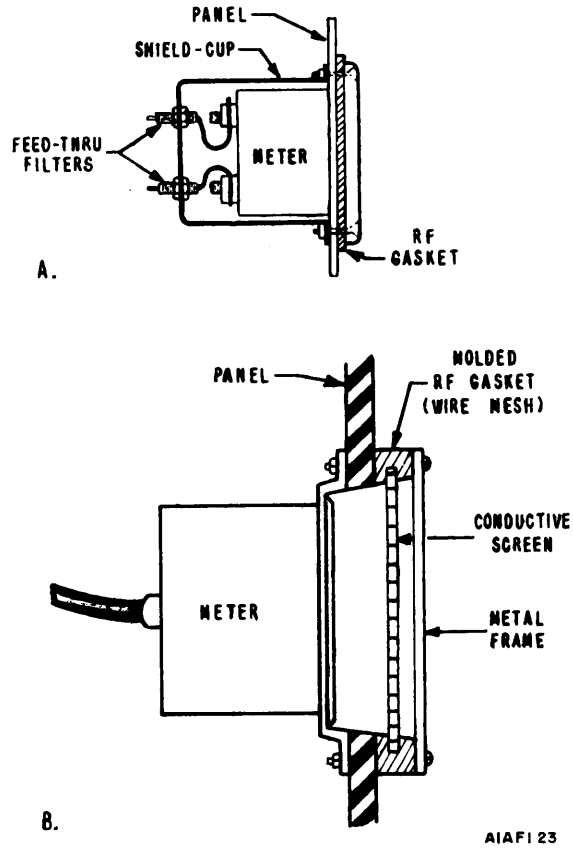


Figure 7 - 47. Acceptable Methods of Shielding Panel-Mounted Meters

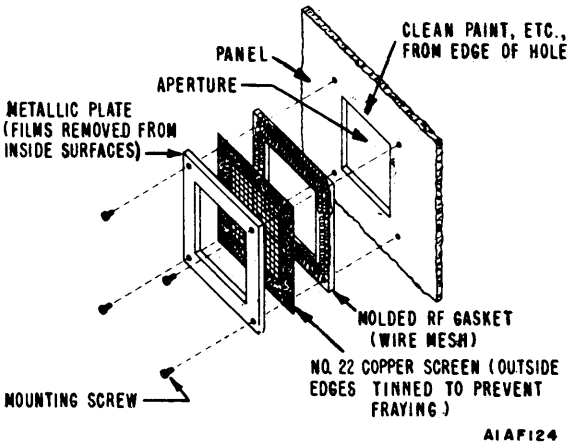


Figure 7 - 48. Method of Mounting Wire Screen Over a Large Aperture

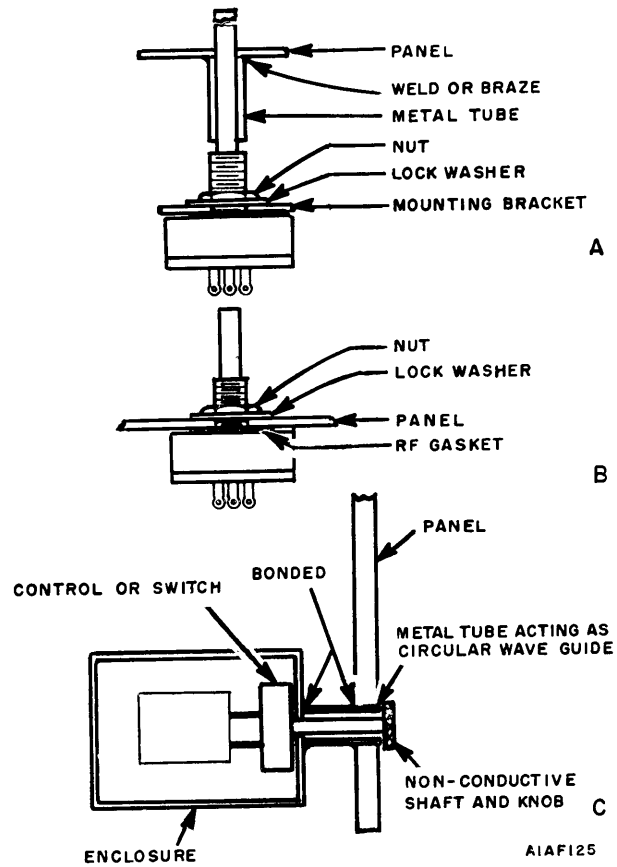


Figure 7 - 49. Acceptable Use of Circular Waveguide in a Permanent Aperture for Control Shaft

the equipment will be integrated. Do not ground a power return lead internally if the total system follows the wired power return concept. Do not use a sensing device or transducer that uses the shield for signal return in a system or subsystem having balanced symmetrical input circuits.

MIL-E-8881 covers shielded enclosures and screened rooms which will provide specified degrees of attenuation from external electromagnetic fields between the frequencies of 100 kHz and 20 GHz. The enclosure is used for testing and alignment of electronic equipment and other such related purposes. The shielding attenuation of shielded enclosures is to be measured in accordance with MIL-STD-285.

7.5.6 Shielding Checklist

The following checklist is furnished as a guide for shielding.

- o Design shielded wires and enclosures to provide maximum shielding efficiency.
- o Use a minimum number of joints, seams, gasket seals, and openings.
- o Use conductive material for gasket seals.
- o Compress all RF gaskets.
- o Use a minimum number of inspection plates, adjustment holes, and screened ventilation parts.
- o Check equipment enclosure for RF leaks through:
 - Meters
 - Toggle switches
 - Indicator lamps
 - Fuse holders
 - Handles
 - Access doors
 - Any other such openings
- o Electrically bond screens and honeycomb material to their frame.
- o Whenever possible, electrically bond all discontinuities.
- o Ensure that shielding interfaces with the other EMC disciplines.

7.6 FILTERING

7.6.1 Introduction

The most economical method of controlling emissions is to reduce the level of spurious radiations at the source. The reason for this should be apparent. A single high level spurious radiation from a transmitter may produce interference in a number of receivers. If this spurious output is not reduced to a tolerable level at the transmitter, it will be necessary to provide interference reduction and control techniques at each of the susceptible receivers in order to eliminate the interference.

In general, there are three methods which may be used to reduce the spurious outputs of a transmitter. First, the level of spurious outputs may be reduced considerably by operating the various components in the transmitter in a more linear operating region. However, linear operation impairs the performance of frequency generators and modulators, and reduces the efficiency of amplifiers. Second, shielding as described in 7.5, may be incorporated between circuits to eliminate undesired coupling of signals. Third, the potential interference emissions can be reduced by introducing filters between the various stages of the transmitter to reduce spurious outputs as they are generated, and to restrict the magnitude of this spurious output at the final power amplifier. Filters also play a very important role in receiver design to insure that a receiver has adequate interference rejection.

Many networks may be employed as filters. Some will be described herein, along with other factors which must be considered when using the filters.

7.6.2 Capacitors

Capacitors offer impedance to the flow of alternating current in the form of capacitive reactance (X_c). The formula for capacitive reactance

$$X_c = \frac{1}{2\pi f C} \quad (7-19)$$

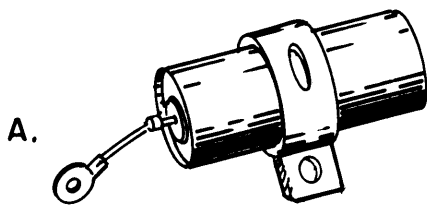
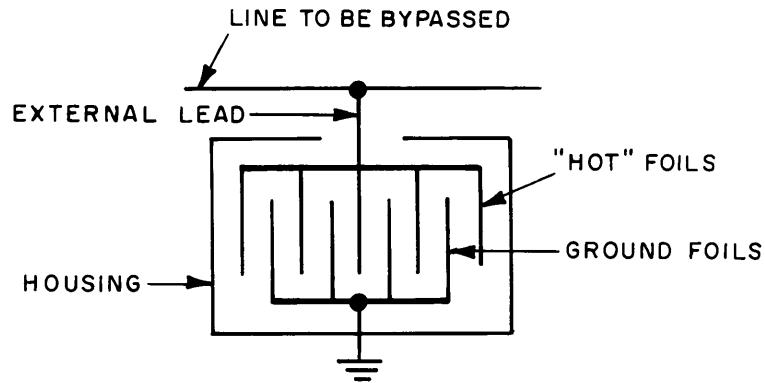
shows that the impedance is a function of the rated capacitance and the frequency of the input signal.

- o Capacitive reactance decreases with an increase in the rated capacitance of a capacitor.
- o Capacitive reactance decreases with an increase in the frequency of the signal applied to the capacitor.

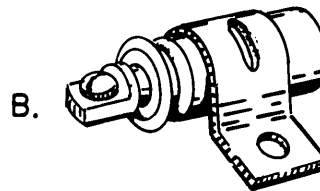
Low impedance to the flow of high-frequency alternating currents and the ability to store a charge are the properties of capacitors that make them useful in suppression applications.

The two major types of capacitors used for suppression purposes are the bypass type and the feedthrough type, as shown in figure 7-50. They are distinguished by their internal construction and electrical characteristics; because of resonance effects with lead inductances, the bypass capacitor is limited in frequency range. The feedthrough was developed to overcome this frequency limitation.

The overall superiority of the feedthrough capacitor is illustrated by the curve shown in figure 7-51, which compares the insertion loss of a feedthrough capacitor with a bypass capacitor of the same rated capacitance. At the 100-megahertz point the feedthrough capacitor is about 38 dB, or 100 times more effective than the bypass capacitor. The suppression effectiveness of the feedthrough capacitor nearly approaches the effectiveness of a capacitor with no inductive component. As frequency rises, the insertion loss rises indefinitely. This indicates that the feedthrough capacitor is a broad band suppression device. Feedthrough capacitors are intended for mounting in a grounded through-panel or bulkhead. The capacitor case must make complete circumferential contact with the bulkhead in order to obtain maximum suppression effectiveness. Under these conditions the bulkhead acts as a shield that prevents coupling between output and input signals. Flanged bracket, threaded body, and threaded neck mounting methods provide the degree of contact with the bulkhead that is necessary. A wrap-around bracket should not be used to mount a feedthrough capacitor, since the additional inductance introduced will lower the effectiveness of the feedthrough capacitor to the level of the bypass type. The live terminals on the feedthrough capacitor may be solder lugs or studs. Feedthrough capacitors are similar to small sections of low-impedance coaxial cable. They have an inner conductor that consists of a piece of heavy bus wire surrounded by a dielectric that, in turn, is surrounded by an outer conductor. The inner conductor must always carry the full load current. The feedthrough capacitor is difficult to install in equipment in the field compared with the bypass capacitor. Feedthrough capacitors are described in terms of their current-carrying ability, their working voltage rating, and their capacitance.

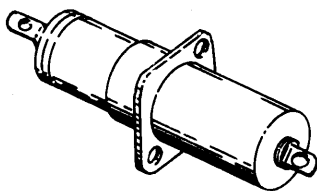
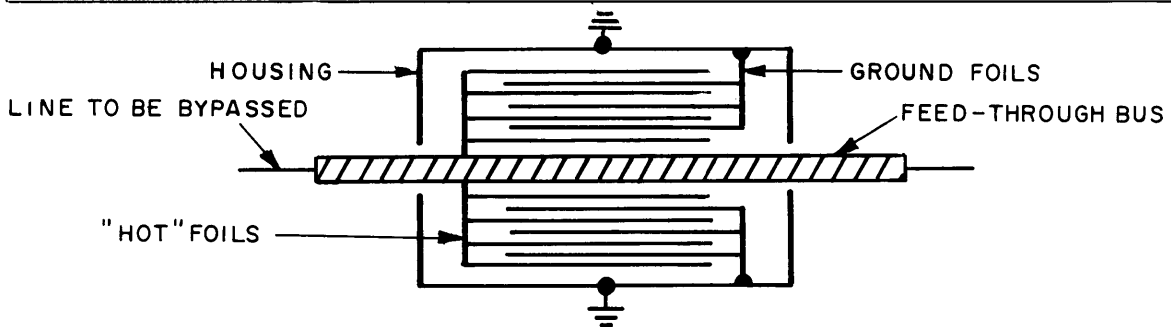


SINGLE LEAD TERMINAL;
WRAP-AROUND BRACKET

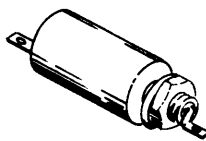


STUD TERMINAL;
WRAP-AROUND BRACKET

THE BYPASS CAPACITOR



STUD TERMINALS;
FLANGE



SOLDER LUG TERMINALS;
THREADED NECK



STUD TERMINALS;
THREADED BODY

THE FEED-THROUGH CAPACITOR

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Figure 7 - 50. Suppression Capacitors

a. Applications

(1) Bypass capacitors are used in many applications because they are easily obtained, easily mounted, adaptable to many functions, and rugged. A disadvantage is that they are unable to bypass broadband noise.

(2) Wire lead bypass capacitors may be used to suppress interference in many different types of equipment including ignition systems, generators, DC motors, power lines, voltage regulators, fluorescent lamps, etc.

(3) Feedthrough capacitors are the best types available for general purpose applications because they are able to eliminate the highest frequency of transients ordinarily left unbypassed by other capacitors. Their chief disadvantage in field applications lies in the installation difficulties they present. Feedthrough capacitors may be used to suppress interference in DC motors, rotary inverters, dynamotors, ignition systems, and similar equipments. See figure 7-52.

(4) A power line that carries the relatively low-frequency alternating currents (50 to 400 hertz) required in most installations, may be cleared of undesired high-frequency transients with a capacitor. Capacitors control interference from a line by short-circuiting high-frequency signals that are present, while permitting the line current to pass on to the load. See figure 7-53.

(5) Used across switches, capacitors provide a means of reducing the generation of radiated emissions.

(a) The tendency for current-carrying switches to arc when opened may be minimized through the proper application of a capacitor. Tied across the contacts, either alone or in combination with a resistor or diode, capacitors will prevent arcing by providing a short circuit for the surge current that is present when a switch is opened. See figure 7-54.

(b) Capacitors can be used in this application in both AC and DC circuits. Choose the correct value of capacitance for the AC application to prevent pitting of contacts.

b. Installation Techniques. Two procedures to follow when installing capacitors intended for suppression applications are:

(1) Keep all lead lengths short.

(2) Secure brackets and threads to chassis ground, using the best means available to insure good electrical ground connections. The use of a tooth-type lockwasher that bites into a chassis may be used for such applications. It is noted that feedthrough capacitors must have the output shielded to prevent undesirable coupling with the input.

7.6.3 Filter Networks

A filter is a network that permits the transmission of signals at some frequencies and impedes their transmission at others. This is achieved by introducing a high impedance into the path of the undesired currents and then shunting them to ground through a low impedance. Although usually more effective than capacitors alone, filters, because of their bulk, should not be used as a field expedient if a capacitor will perform adequately as the suppressor. Filters are designed to affect the normal operation of power, control, or signal circuits as little as possible. By proper selection of the values of the elements, a filter may be made to attenuate almost any undesired frequency while passing others essential to the proper operation of equipment.

a. Classifications

Filters are generally classified in three ways:

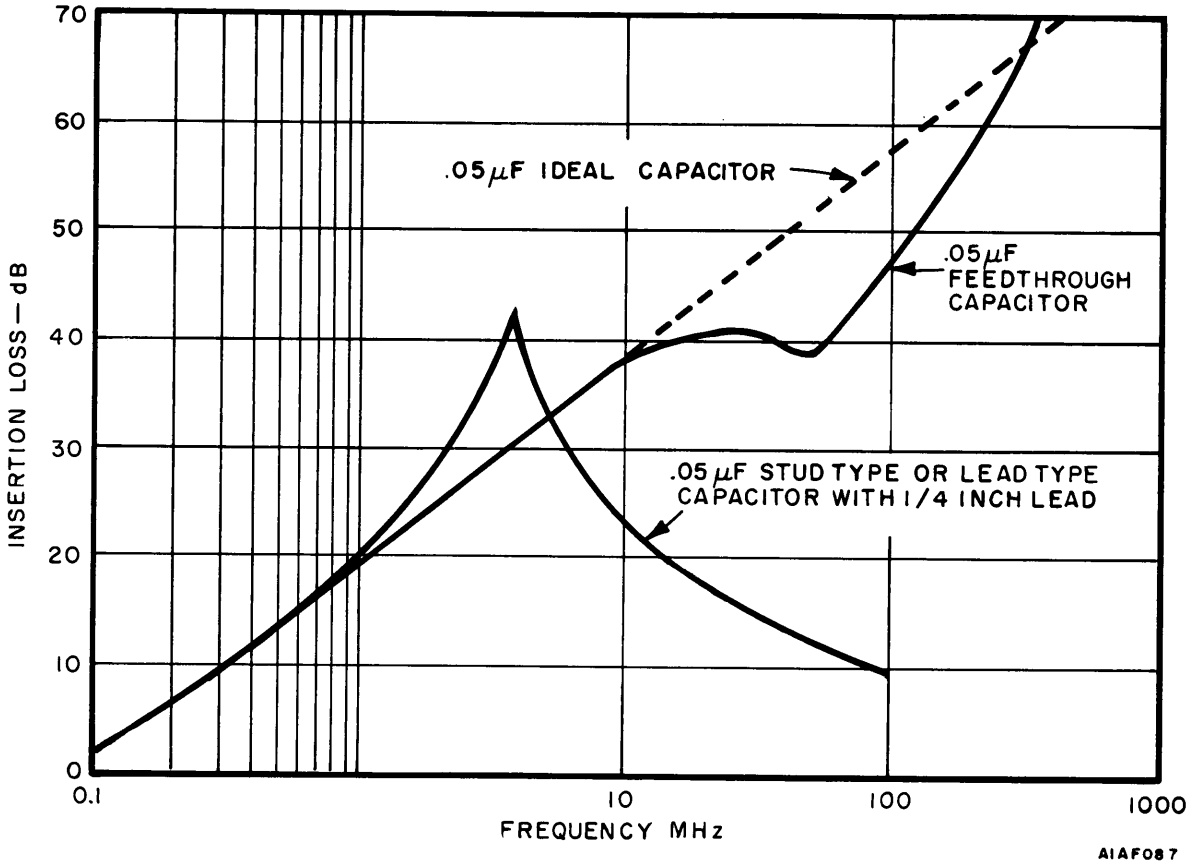


Figure 7 - 51. Comparison of Insertion Loss Characteristics for Typical Feedthrough With Lead-Type Capacitor of Same Value

(1) By the configurations they assume (figure 7-55)

L-type
 T-type
 Pi-type
 Combinations of L-T, and Pi-type.

(2) By the circuits in which they are used:

Power line
 Harmonic suppression
 Rectifier output.

(3) By the frequencies they pass:

- o Low-pass filters. Band-pass filters pass low-frequency currents while attenuating high-frequency currents.
- o High-pass filters. High-pass filters pass high-frequency currents while attenuating all low-frequency currents.
- o Band-pass filters. Band-pass filters transmit frequencies within a certain region while attenuating all frequencies above and below that region. Band-pass filters are frequently used in intercommunication systems, in the input circuits, and in intermediate frequency (IF) circuits. They are used also in the output circuits of transmitters to suppress spurious radiations. A variation of the band-pass type is the bandstop filter which passes everything except a specific band of frequencies, which it attenuates. Band-pass filters are usually incorporated into equipment during manufacture.

The attenuation characteristics of the various filter types are shown in figure 7-56.

Attenuation, insertion loss, and frequency range of attenuation are the primary characteristics that determine filter suitability for emission control. If a selected filter does not provide the minimum attenuation required for the stop-band, it is not satisfactory, regardless of its other characteristics. The attenuation of a filter is expressed as the ratio of the filter input voltage to the filter output voltage, measured under normal circuit conditions:

$$\text{Attenuation (dB)} = 20 \log \frac{E_1}{E_2}$$

where:

E_1 = voltage across filter input terminals
 E_2 = voltage across filter output terminals

The attenuation figure, however, does not take into consideration the source and load impedances and, therefore, does not represent a true indication of the suppression effectiveness of a filter. The insertion loss criterion is a far more realistic measure of a filter's effectiveness, as it is a function of both source and load impedances as well as a function of the filter network itself.

In their catalogs, most filter manufacturers quote values of insertion loss (the ratio of voltages at a given frequency appearing across the load terminals before and after the filter is inserted into a circuit):

$$\text{Insertion loss (dB)} = 20 \log \frac{E_3}{E_2}$$

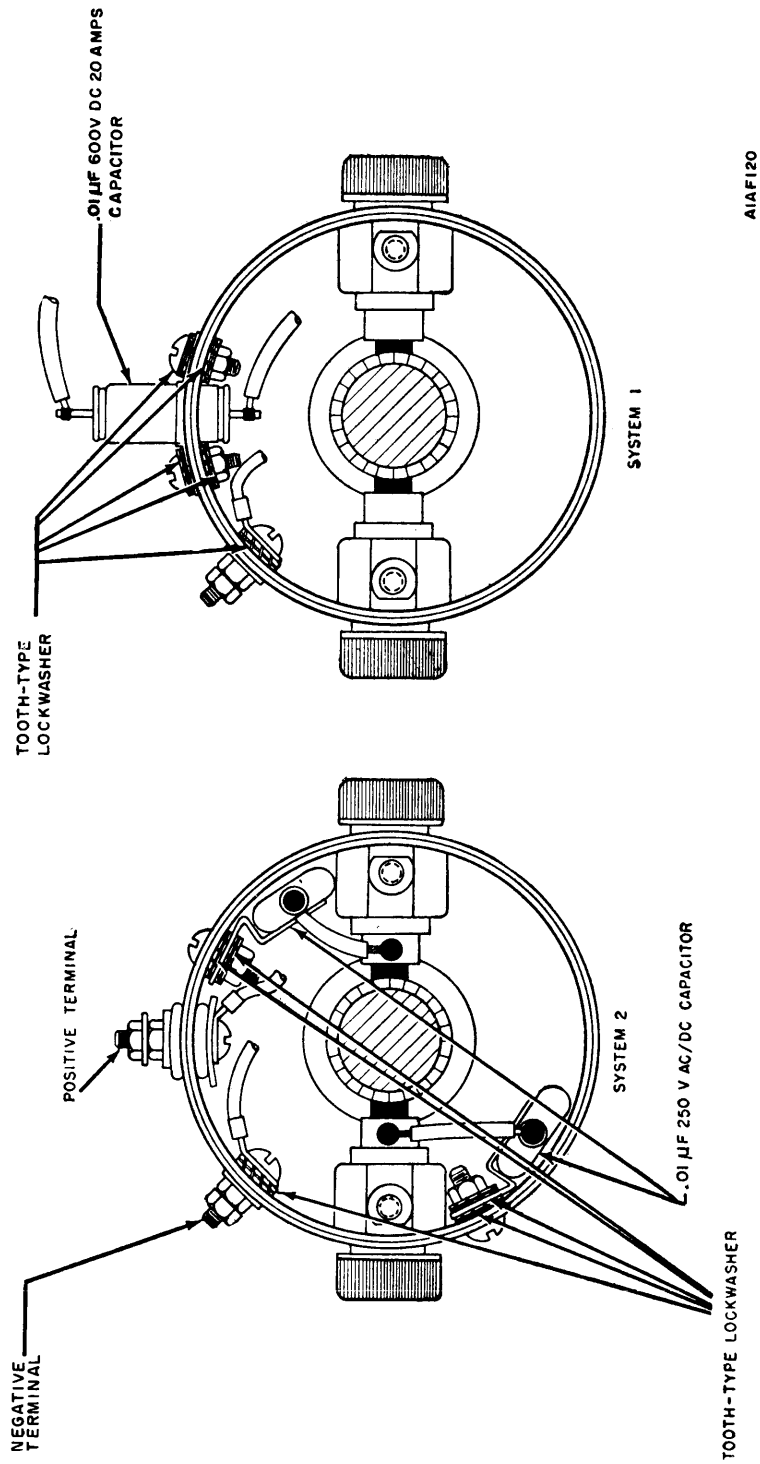
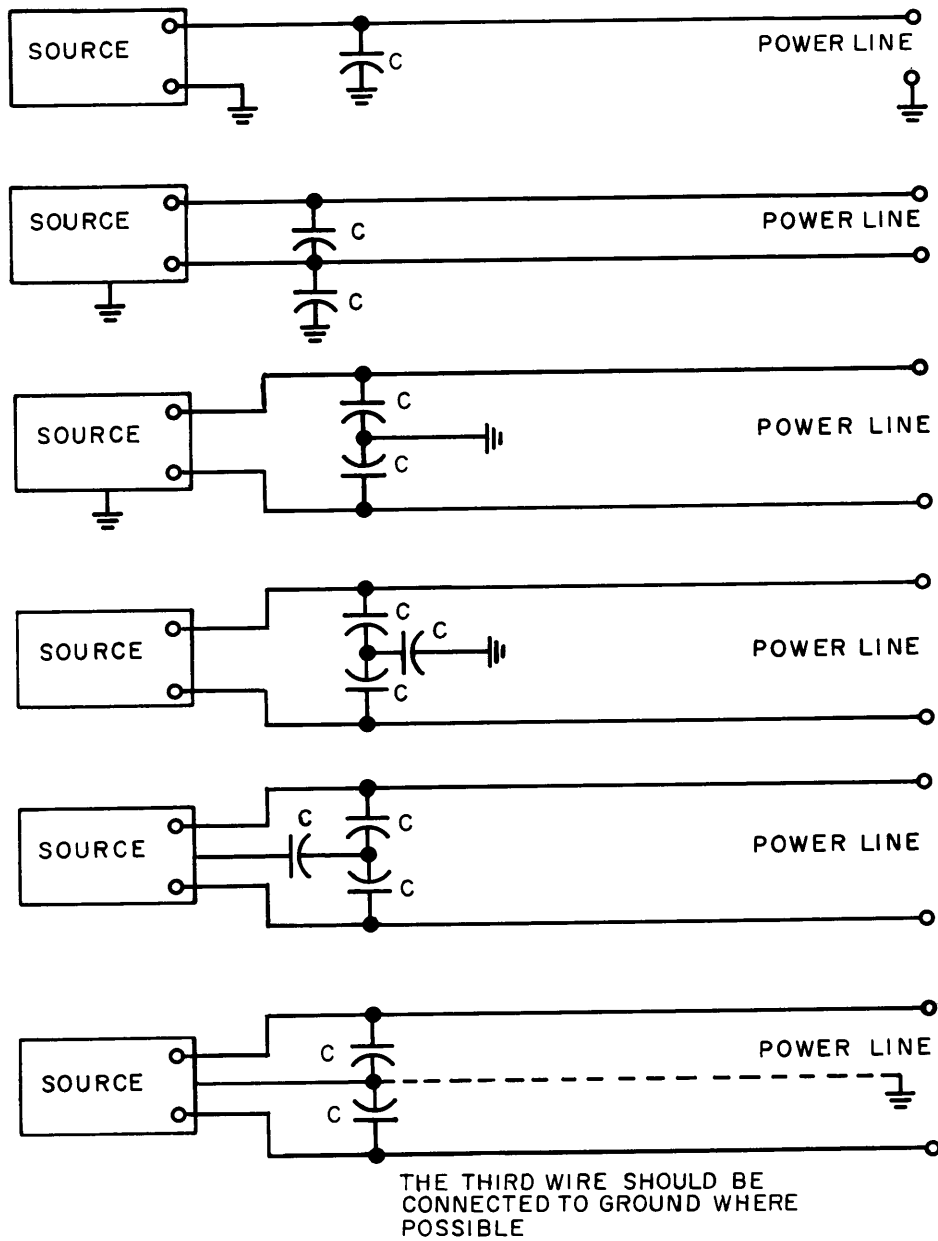


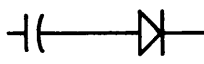
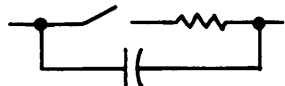
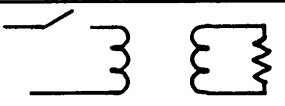
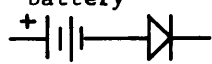
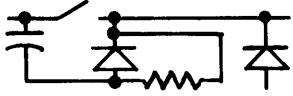
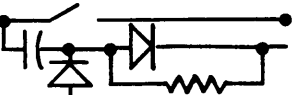
Figure 7 - 52. System 1: Installation of Feedthrough Capacitor Mounted at Positive Terminal in DC Motor
System 2: Alternate Installation of Bypass Capacitors Mounted at Brushes

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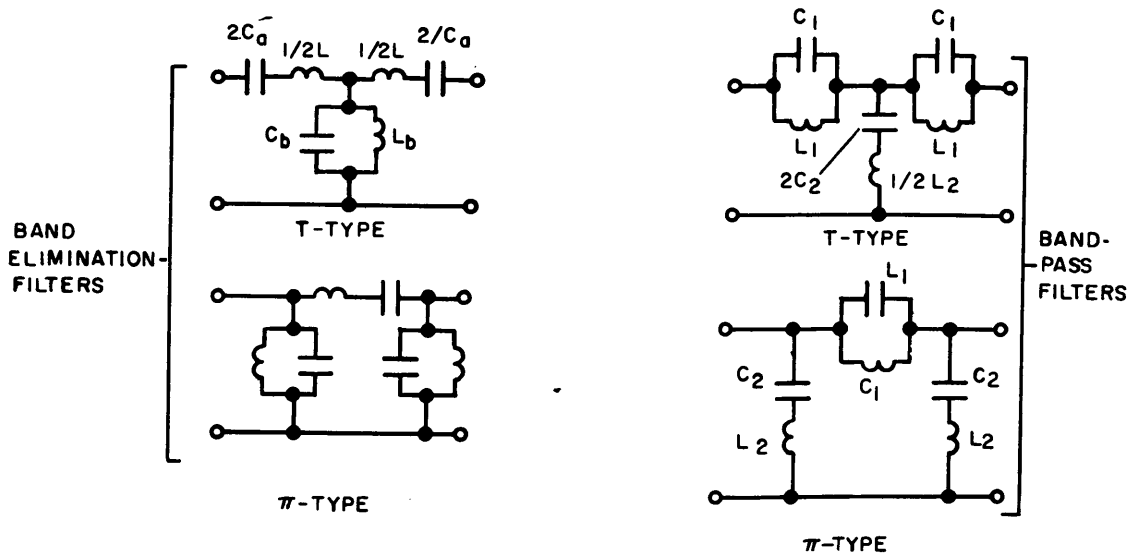
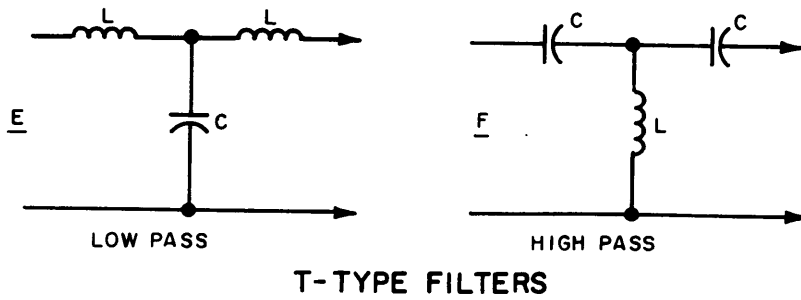
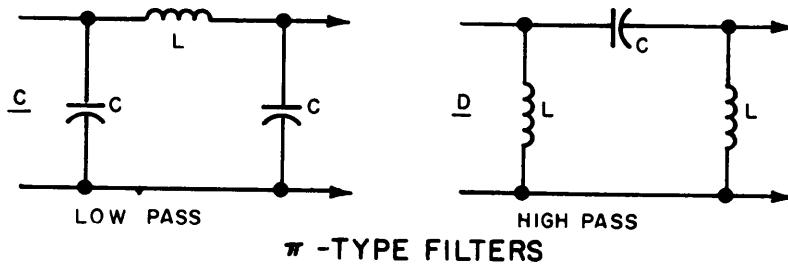
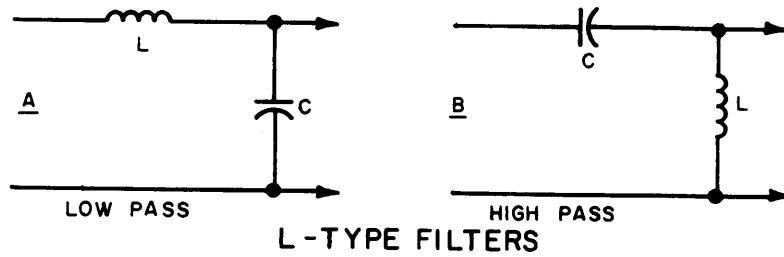
Figure 7 - 53. Bypass Capacitors Used to Filter Grounded and Ungrounded Power Lines that Supply Grounded and Ungrounded Equipment

Components	Placement	Requirements		
		1 Retard Build up of Gap voltage	2 Limit Peak of Gap Voltage	3 Minimize Sharp Wave Front Transients
Capacitor	Load	G	A ^c	P
	Switch	G	A ^c	P
Linear resistor	Load	P	A ^d	A
	Switch	P	A ^d	G
Semiconductor diode	Load	P	G	A ^b
	Switch ^a	P	G	
Back-to-back diodes	Load	P	G	A ^b
	Switch ^a	P	G	A ^b
Capacitor and diode 	Load	Capacitor is superfluous		
	Switch	G	A ^c	G
Series R shunt C 		A ^d	A ^c	G
Coupled secondary 		P	G ^d	A
Diode and battery 	Load	P	G	A ^b
	Switch	P	G	G
Composite circuit 		G	G	A
Composite circuit 		G	G	G

LEGEND
G = Good
A = Intermediate
P = Poor

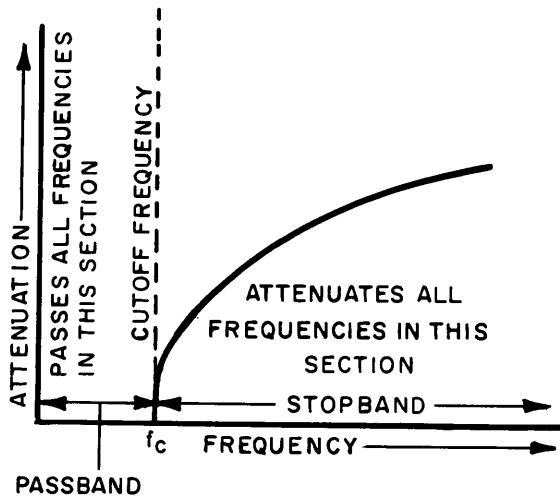
- NOTES**
- a = Diode must have knee at voltage greater than that of supply
 - b = Determined by inherent shunt capacitance of diode
 - c = Capacitance must be sufficiently large
 - d = Resistance must be sufficiently small

Figure 7 - 54. Switch Suppression Methods

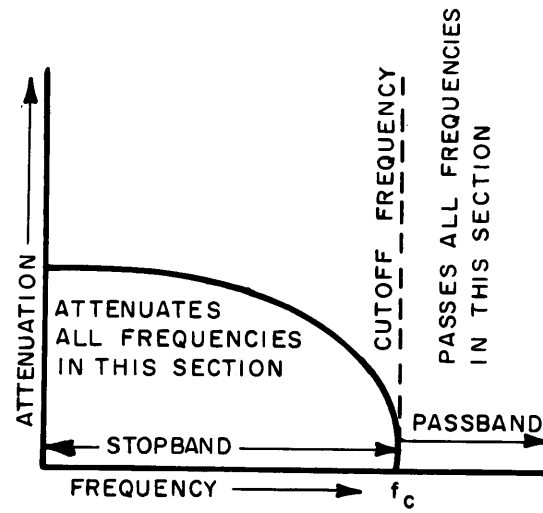


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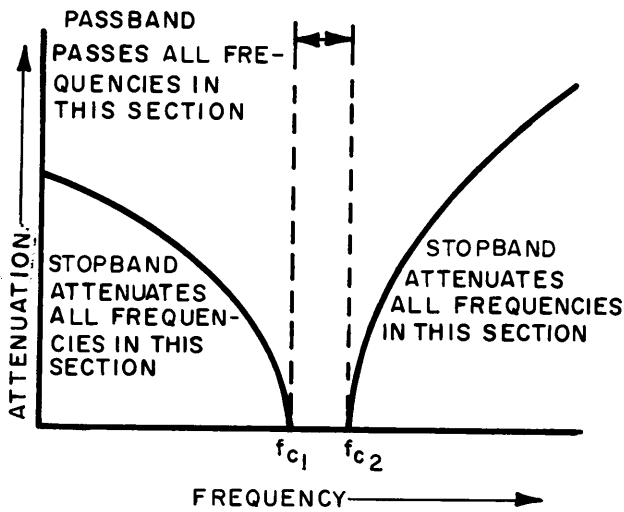
Figure 7-55. Filter Types



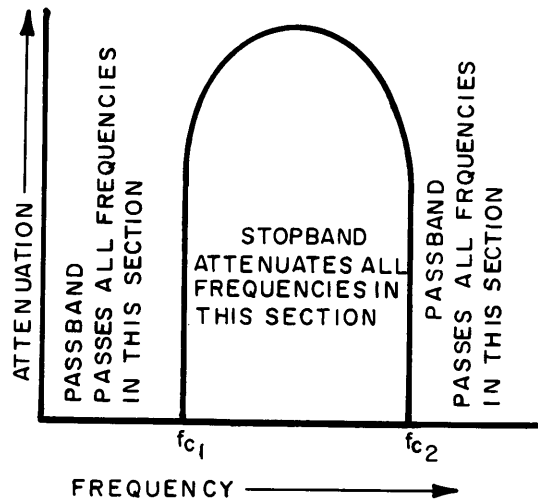
A. LOW-PASS FILTER



B. HIGH-PASS FILTER



C. BAND-PASS FILTER



D. BAND-REJECT FILTER

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Figure 7 - 56. Filter Attenuation Characteristics

where:

$$E = \text{load voltage with the filter in the circuit}$$

$$E_3^2 = \text{load voltage without the filter in the circuit}$$

However, the insertion loss is usually quoted by the manufacturers for a 50-ohm system. If the circuit to be filtered does not have both a 50-ohm input and output impedance, as will be the case in most installations, the insertion loss will differ from the catalog value. MIL-STD-220 specifies procedures for the measurement of insertion loss in a 50-ohm system. Other procedures are described in the referenced IEEE-GEMC Symposium documents for measuring insertion losses in other than 50-ohm systems, and under "worst-case" resonance conditions.

b. Applications

(1) Simple Filters. Simple filters, sometimes called brute force filters, are used as low-pass power-line filters where appreciable filter selectivity is not required. The selection of the configuration to use depends on the equipment to be suppressed and the amount of suppression required.

Applications of L, Pi, or T filters for use in power lines are shown in figure 7-57. Power-line filters as a class of filters are generally of the low-pass variety. Low-pass filters are usually applied at either the output of interference sources, or at the input of the associated load.

Low-pass filters intended primarily for filtering high-frequency noise currents from low-frequency AC power leads are also used for DC applications. These filters have a low insertion loss at power frequencies and DC, but a high insertion loss for higher frequencies. Low-pass filters are in use primarily to prevent conducted interference from entering a sensitive receiver through the AC or DC supplies feeding it.

(2) Complex Filters. In simple power-line filters, only one frequency is of importance in the pass band. To obtain optimum effectiveness over a selected range of frequencies, more complex filters are required. Such filters are called m-derived composite filters. For frequencies above 70 or 80 MHz, sections of coaxial transmission lines are used as filter elements to simulate the required values of lumped capacitance and inductance.

(3) Harmonic Suppression Filters. These filters are used at the output of transmitters to prevent any harmonic of the desired transmitter frequency from reaching the antenna. They are usually band-pass filters and are inserted in the output of the transmission line feeding the antenna, or between the transmitter and the antenna. In the pass band, the filter must perform electrically as though it were a section of the transmission line cable into which it is inserted. When great attenuation is desired, it is better to use two or more filters in series than to use one complete filter. For ultra-high frequency (UHF) use, short sections of transmission line are used as filter elements. Harmonic suppression filters are usually incorporated into equipments during the equipment design.

c. Installation Techniques. When using filters, proper installation is absolutely necessary to achieve good results. Effective separation of input and output wiring is mandatory, particularly for good high-frequency performance, because the radiation from wires carrying potential interference signals can couple directly to output wiring, thus circumventing and nullifying the effects of shielding and filtering. Input and output terminal isolation is most easily accomplished by using a filter that mounts through a bulkhead or chassis. In all cases where bulkhead mounting isolation is not feasible, isolation by shielded wiring is mandatory. It is highly desirable to locate suppression components in or on the device generating the unwanted emission. The RF impedance between filter case and ground must be as low as possible. The methods of mounting a filter become very critical at high frequencies. If complete isolation is effected between input and output, filter insertion loss will approach the design figure. See figure 7-58 for correct mounting techniques.

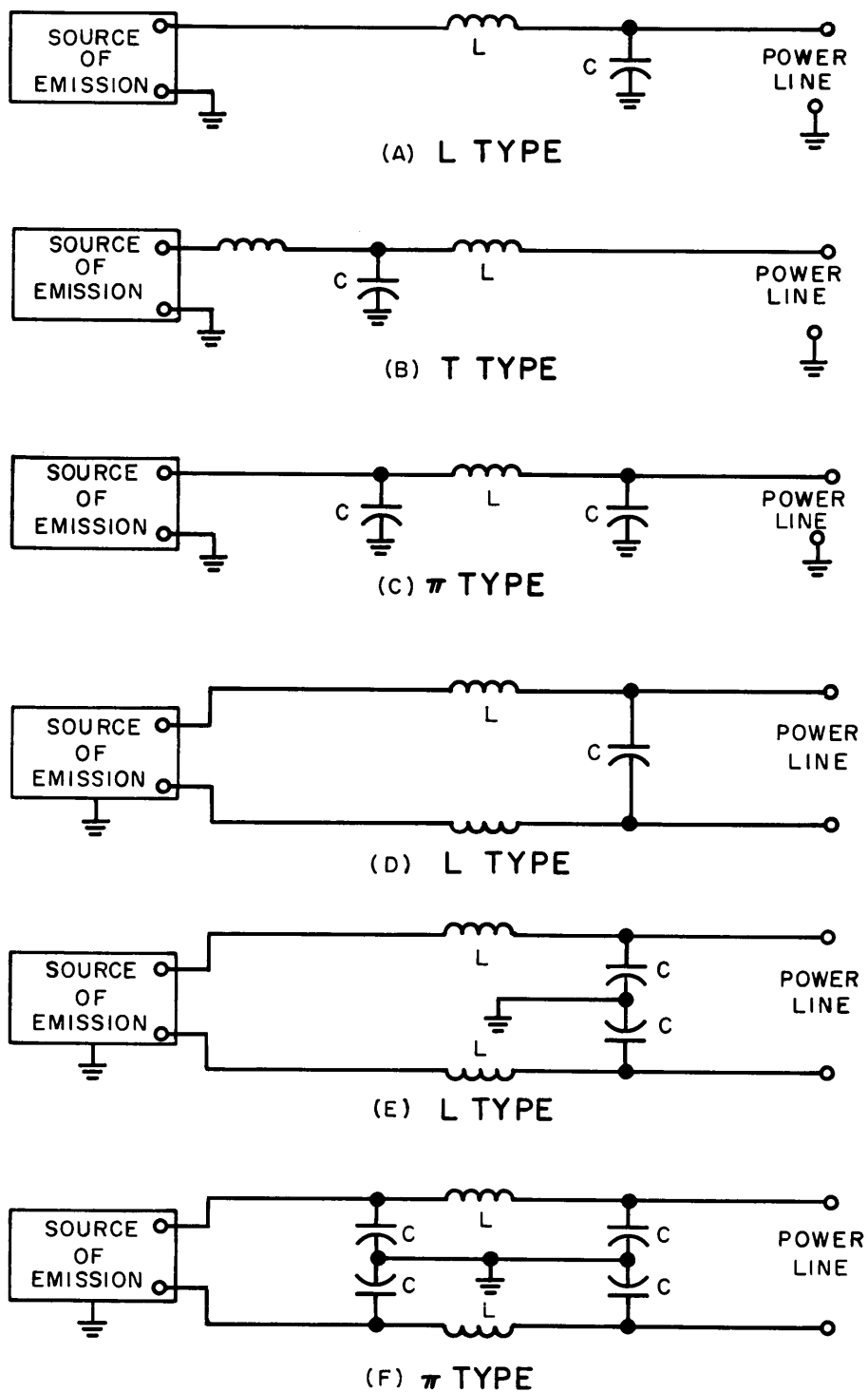
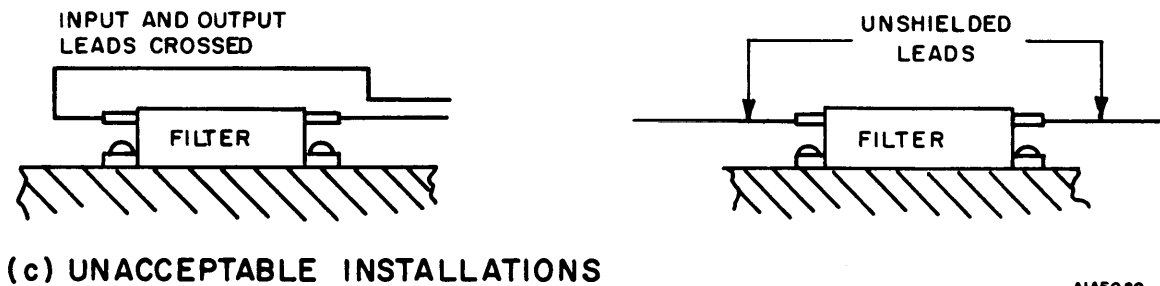
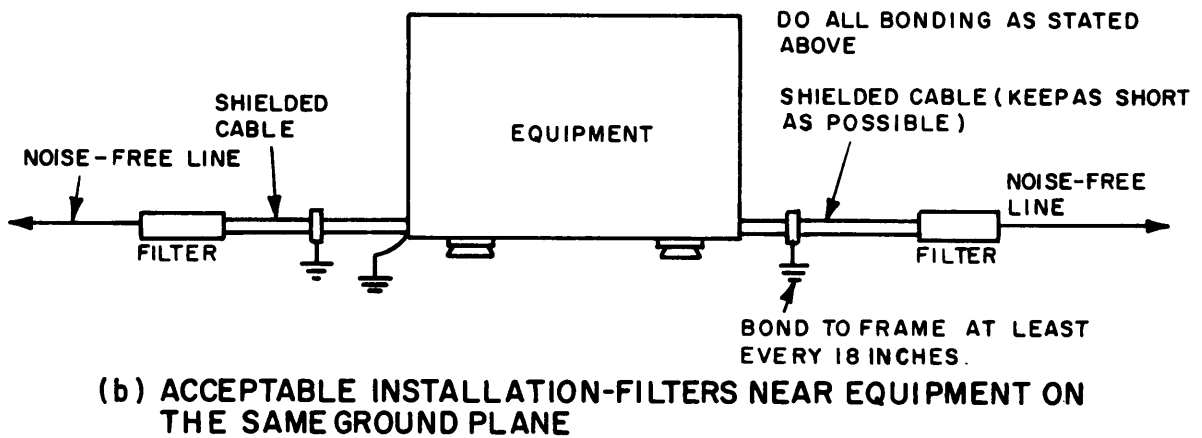
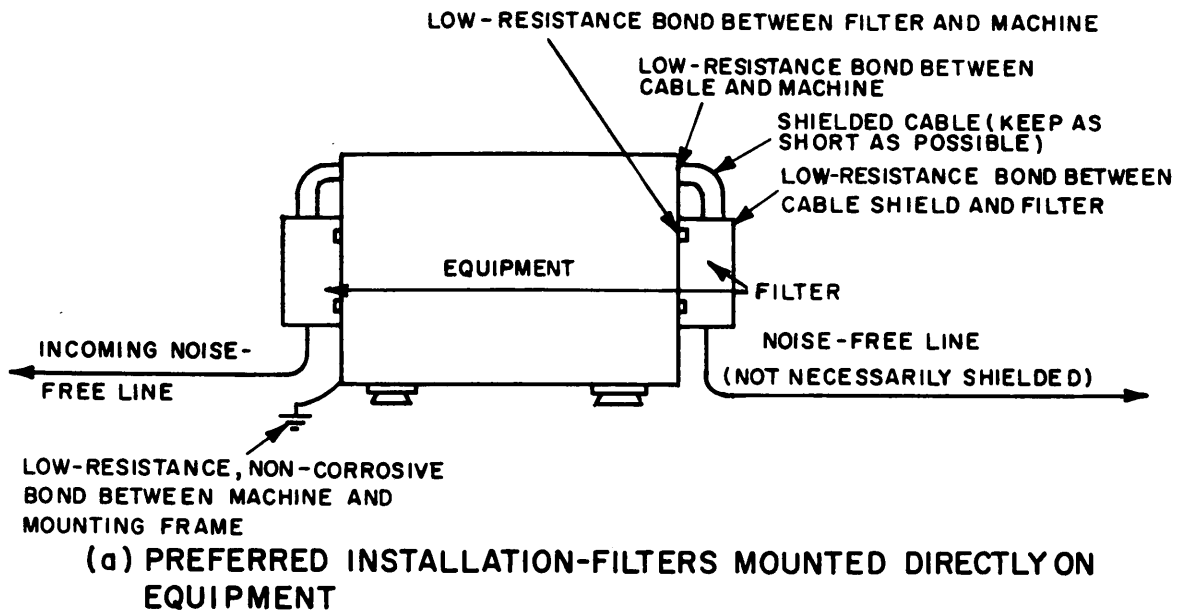


Figure 7 - 57. Applications of L, Pi, and T-Type Filters

The following installation procedures should be observed:

- (1) A filter should be shielded with the output leads isolated from the input leads.
- (2) Metal-to-metal contact must be made between the metal cover and all mounting surfaces of the shielded enclosure.
- (3) The size of the filter terminals should be sufficient to carry the required current.
- (4) There should be low-impedance between the filter unit and the source to permit free flow of the bypassed currents.
- (5) Short leads should be used with capacitors.
- (6) The filter should always be mounted as close as possible to the filtered equipment with shielded leads used as the coupling medium.
- (7) All leads should be run close to the ground planes and in opposite directions to avoid coupling between the leads. Never loop them.
- (8) The latest Navy-approved filters and requirements in MIL-F-15733 shall be met where applicable.
- (9) Both the filter and equipment must be well grounded through low radio-frequency impedances. They should have metal-to-metal contacts at all mounting surfaces and short grounding straps. Ground surfaces should be cleaned as thoroughly as possible when the installation is being made.
- (10) When mounting the filter in a box, insure that the cover and box are thoroughly bonded together by a clean metal-to-metal contact. This isolates the input and output circuits to each end of the filter, thereby reducing to a minimum the coupling across the filter.
- (11) AN type connectors should be used on hermetically sealed filter units in place of an external filter box.
- (12) The low-impedance path which was made in placing the filter into the box must be continued in the installation of the filter box to the equipment. The location of the filter must be such that a low-impedance path back to the ground plane of the equipment is maintained for any current flowing through the capacitors of the filter. Three methods of grounding the filter box with respect to the RF ground connection required are: welding, bolting, and the use of ground straps. In mounting the filter, use a bulkhead, chassis, or equipment case as an isolating shield between the input and output of the filter.
- (13) If a filter is used in the antenna to filter unwanted pick-up, it will often be necessary to add more shielding to the cable between the filter and the equipment. Pick-up is not always caused by inadequate cable shielding or inadequate filtering. In many cases, poor grounding of the cable shield at the filter and at the equipment is the fault.
- (14) A simple capacitor filter is preferred to the more complicated network filters (lattice and ladder) if it provides the required degree of attenuation.
- (15) The filter should be located at the emission source somewhere along the cabling between the source and receiver or at the input to the receiver. The location of the filters is determined by the coupling of the undesired signal to the receiver.



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Figure 7 - 58. Filter Installations

7.6.4 Trade-off Factors

When designing or selecting a filter, a number of parameters must be considered.

a. Impedance Matching. The elements of the filter must be chosen so that the impedance network matches the line into which it is inserted. This is especially true of transmission lines so that the filter does not impair the normal function of the equipment at both ends of this line.

b. Voltage Rating. Consider the voltage rating on the filter used on power lines, and the limits within which electrical power subsystems are to operate. Under some conditions the voltage may deviate by a large amount from the normal line voltage. The filter voltage ratings must be sufficient to provide reliable operation under extreme conditions.

c. Voltage Drop. Determine the maximum allowable drop through the filter and design accordingly. Ensure that the voltage drop caused by a filter does not exceed the total drop permitted by the installation and equipment operating criteria.

d. Current Rating. Current rating should be for the maximum allowable continuous operation of the filter. Calculate the current rating for filter elements, such as capacitors, inductors, and resistors. Whenever possible, the current rating of filters should be consistent with the current rating of the wire, circuit breakers, or fuse with which the filter will be used. A filter with a higher current rating than the circuit in which it is installed will often add to the weight and space penalty. A filter with a lower rating is a safety hazard. The safety factor used in rating filters should also be consistent with those used for other circuit components.

e. Frequency. Consider both the operating frequency of the circuit and the frequency to be filtered (attenuated). In general, do not use sharp filters to reject the power frequencies. If such a filter is required, its rejection characteristic must be wide enough to provide adequate attenuation over the power frequency deviation specified in the installation specification.

f. Insulation Resistance. The insulation resistance of the filter may vary during the life of the filter. Determine the maximum allowable variation of this resistance for proper filter operation.

g. Electrolytic Capacitors. Electrolytic capacitors are sometimes used in low-pass filters. The dissipation factor increases, and the capacitance decreases with age on the wet-type electrolytic capacitor. An RF bypass capacitor should be placed across the output of DC supplies to filter out any HF interference which may be present. The high dissipation factor or series resistance within the wet electrolytic capacitor makes it a poor filter for RF. If space is at a premium and the working voltage of the circuit is low, a solid type tantalum capacitor with a low-dissipation factor may be used.

h. Ground Leads. Ground leads on capacitors and filter enclosures should be as short as possible. Capacitors having metal cases with grounding studs or mounting clamps provide leadless grounds. Feedthrough capacitors and filters are grounded through the metal case and mounting flange.

i. Size and Weight. Size and weight can be the deciding factor in some filter applications. When space is at a premium, adding or subtracting various filter elements may reduce the size and weight of the filter.

j. Isolating and Shielding. Isolating and shielding is the key to good filtering. A filter network may be placed in a shielded enclosure or metal case and grounded accordingly.

k. Transmission Line Filters. These filters are completely shielded in a case and are usually terminated with an input and output coaxial connector.

1. Filters in Connector Contacts. Miniature filters can be constructed into a single-pin contact and placed in a multipin connector receptacle. This connector consists of a group of low-pass filters for the isolation and suppression of RF.

7.7 CONTROL OF EMR HAZARDS

7.7.1 General

Other portions of this handbook discuss potential EMR hazards to personnel, flammable materials, ordnance and electronic hardware, including prediction and measurement techniques. The potentially serious nature of EMR hazards requires the most scrupulous observance of precautions. Positive efforts must be taken to minimize or reduce potential hazards without a reduction in operational requirements. Adequate indoctrination and training in EMR hazard precautions are essential for all personnel engaged in installation design, as well as equipment operation, maintenance and test. It is particularly important that Navy personnel be aware of their specific responsibilities with regard to the execution of safety and protective measures. In addition, rigid control must be exercised to ensure that proper instructions, protective equipments, warning signs and alarms, and other control methods are available to, and utilized by, all involved personnel.

While every effort must be made to protect personnel and materials from exposure to hazardous levels of EMR, it is neither necessary nor desirable to impose restrictions on antenna radiations, Such actions tend to restrict operations, maintenance, and test procedures which could otherwise be carried out in safety, providing adequate precautions are employed.

The following general precautions are to be employed to preclude the potential hazards:

a. Where test procedures require free space radiation, the radiating antenna will be so positioned as to avoid directing the energy beam toward inhabited structures or other personnel groupings, fueling, ordnance, and electronic material handling areas. In the positioning of such radiating antennas, care will be taken to avoid reflecting either the primary beam or associated side lobes in such a manner as to create potential hazards.

b. Aircraft employing high-power radars, vans and other vehicles containing radiating antennas shall be parked, or have their antennas oriented, so that if an equipment is energized, the resultant beam is directed away (or into absorbent chambers) from personnel working areas, fueling areas and electronic equipment and ordnance storage handling and operating areas.

c. Where feasible, all transmitting antennas, i.e., fixed, as well as those on mobile vans and associated with transportable and portable equipments, should be located to minimize exposures in areas adjacent to, or in the installation.

d. All rotating antennas should radiate only when rotating. If necessary, further restrictions can be imposed, such as sector blanking (i.e., installation of cutout devices in the electrical or mechanical components of a system to automatically end transmission when the antenna is pointed in a predetermined direction) or by instructing operating personnel not to transmit in certain azimuths and/or elevations.

e. All non-rotating antennas should be trained and elevated away from inhabited areas, fueling systems, and/or ordnance and electronic equipment operating, storage and handling areas.

f. Appropriate standard radiation hazard warning signs should be available and posted to designate potentially hazardous areas. These signs are described in subsequent portions of this section.

g. Care should be taken so that laser beams are not directed towards personnel, flammable materials, electronic hardware or ordnance.

h. In situations where operations would be unduly restricted by implementation of the above methods, and those described in subsequent paragraphs, suitable attenuation of power density levels may be accomplished by shielding (see section 7.5).

7.7.2 Control Hazards to Personnel

As noted in earlier portions of this handbook, hazards to personnel can result from several causes, i.e., direct exposure to EMR, X-rays inadvertently produced in electronic equipment, and shocks and burns caused by RF potentials induced in various metallic objects that may be contacted by personnel and exposure to laser radiation. The following paragraphs outline precautionary measures which can be employed to minimize or eliminate these hazards to personnel which may result in both direct and indirect injuries.

a. EMR. All areas in which the power density is predicted or measured to be above $10\text{mW}/\text{cm}^2$ should be considered potentially hazardous areas and are subject to the following precautionary measures:

(1) All such areas shall be appropriately posted with the standard warning sign shown in figure 7-59. Personnel should not be permitted in these areas except under emergency conditions. Where the possibility of accidental exposure still exists, a man should be stationed within view of the transmitting antenna and in communication with the radar operator while the antenna is radiating.

(2) Personnel frequently exposed to EMR in connection with their regular duties are subject to the periodic medical examinations in accordance with NCPI 792.11 or NAVMED P-5055, as applicable.

(3) People with metallic implants or medical electronic devices, such as pacemakers, in their body should be extremely careful and perhaps excluded from working in or visiting areas of EMR, because of the susceptability of the devices.

(4) The practice of discharging, under test, the RF output of high power generators which generate average power levels of $10\text{ mW}/\text{cm}^2$ or more, into the surrounding area, is discouraged. Dummy loads, water loads, or other absorptive materials may be used to absorb the energy output of such equipment while being operated or tested.

(5) Visual inspection of feedhorns, open ends of waveguides, and any opening emitting electromagnetic energy will not be made unless the equipment is definitely secured for the purpose of such an inspection.

(6) When operating or servicing radar or high power radiating systems, operating and maintenance personnel shall observe all radiation hazard signs posted in control and operating areas to ensure that the equipments are operating in such a manner that personnel are not subjected to hazardous energy levels.

(7) If, while working in a previously declared safe area, heat is felt coming from the direction of a radar antenna, the area should be evacuated until it can be verified that the heat did not come from the radar beam.

(8) Photographic personnel should be cautioned about the dangers associated with exploding flashbulbs in the main beam of radars, even at considerable distances from the antenna, as severe cuts and burns can occur. Flashbulbs may be safely stored in copper-sheet lined boxes which will shield them from EMR. When using flashbulbs in the vicinity of radars, they should be left in their cartons until used and should be handled with gloves.

(9) Minimum safe distances from radar antennas shall be maintained by all personnel. The minimum safe distance from specific radar antennas and the maximum exposure times within these distances under certain modes of operation are listed in NAVWEPS 16-1-529 and NAVSHIPS 0900-005-8000. Some minimum distances are presented in Table 7-11.

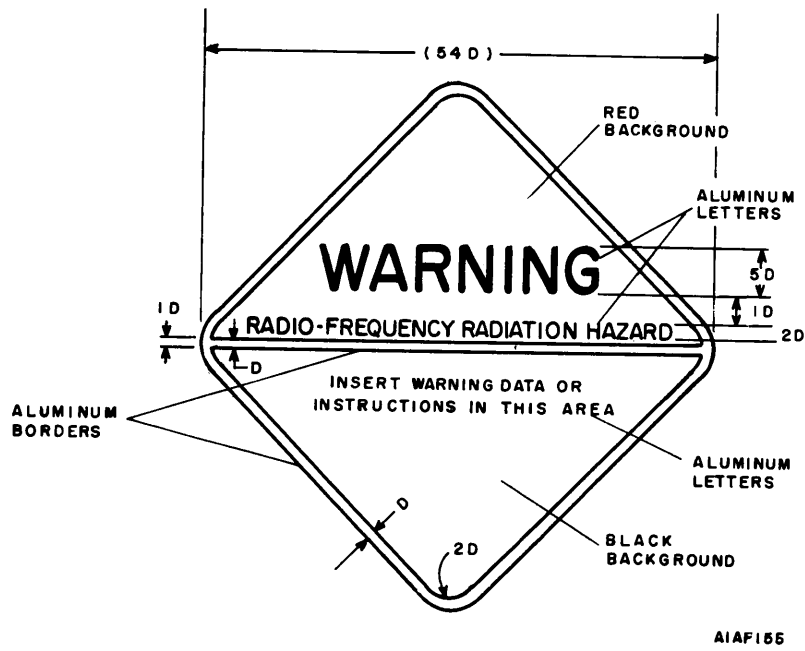


Figure 7 - 59. RF Radiation Hazards Warning Sign

Table 7-11. Distances to 10 mW/cm² Point on the Major Lobe of the Radiating Antenna of Radar Sets (Fixed Beam)

RADAR SETS	ANTENNA DIMENSIONS (Ft.)	DISTANCE TO 10 mW/cm ² (Ft.)
AN/CPN-18	W - 7	182
AN/CPN-18A	H - 9	182
AN/CPS-9	D - 7¾	180
AN/FPN-40		
Azimuth Antenna	H - 3	92
	W - 9	
Elevation Antenna	H - 10	80
	W - 2.5	
AN/FPS-3A		170
AN / FPS-4	H - 3	188
AN/GPS-4		105
AN/MPM-1		30
AN/MPN-11		95
AN/MPQ-21 (10 ft.) antenna dimension		300
AN/MPQ-21 (7 ft.) antenna dimension		210
AN/MPQ-18		175
AN/MPQ-14		45
AN/MPQ-10 S		50
AN/MPQ-10 B		45
AN/MPS-23		530
AN/MPS-22		185
AN/MPS-21		430
AN/MPS-16		50
AN/MPS-14		475
AN/MPS-12		175
AN/MPS-11		100
AN/MPS-10 C		105
AN/MPS-8		105
AN/MPS-7		175
AN/MPS-4		205
AN/PPS-4		2
AN/TPS-1 CD	H - 10	188
AN/FPS-6	H - 30	380
AN/FPS-6A	H - 30	380
AM/MPS-14	H - 30	380
AN/FPS-18	H - 11	400
	W - 17.5	410
AN/FPS-16 (1 MW)	D - 12	400
AN/FPS-16		530
AN/FPS-71	H - 11	280
	W - 40	
AN/MPQ-10	D - 5.7	37
AN/MPQ-10A	D -	
AN/MPQ-12	D - 6	56.5
AN/MPQ-29	D 2.5	21.5
AN/TPS-16	H - 4	33
AN/TPS-1D	W - 15	33
AN/TPS-25	H - 1.67	40
	W - 2.24	40

Table 7-11. Distances to 10 mW/cm² Point on the Major Lobe of the Radiating Antenna of Radar Sets
(Fixed Beam) (Continued)

RADAR SETS	ANTENNA DIMENSIONS (Ft.)	DISTANCE TO 10 mW/cm ² (Ft.)
AJAX acquisition radar	H - 4.4	176
	W - 15.8	176
AJAX missile tracking radar	D - 5.9	97
HAWK continuous acquisition radar	H - 1.58	67
	W - 7.58	67
HAWK high power illuminator	D - 4.0	356
HAWK low power illuminator	D - 4.0	105
HAWK pulse acquisition radar	H - 5.17	55
	W - 22.0	
HAWK range only radar	D - 4.0	148
NIKE-HERCULES acquisition radar	H - 4.4	127
	W - 15.8	
Improved NIKE-HERCULES acquisition radar (HIPAR)	H - 20.8	240
	W - 43.0	
NIKE-HERCULES missile tracking radar	D - 7.7	126
(Ajax mode Basic & improved)		
Improved NIKE-HERCULES target tracking radar (wide pulse)	D - 7.7	230

(10) It is recognized that during the performance of certain functions, Naval personnel may be required, at times, to enter or pass through hazardous areas. Accordingly, the Navy has developed protective devices for such instances which provide coverage and shielding primarily by reflection of the incident energy. A discussion of two such devices follows.

(a) Protective Suit. A protective suit made from metalized heavy duty nylon. The suit contains special features to maintain complete electrical continuity and prevent leakages at interfaces. The suit requires the wearing of an overgarment, such as rubber boots, gloves and coveralls to prevent arcing in the presence of fields exceeding 150 mW/cm² and may be used in the presence of fields between 200 and 10,000 MHz.

(b) Safety Goggles. Safety goggles were developed primarily for use in radar research and may be used over a limited frequency range for eye protection. They are similar to welders' safety goggles and possess lenses having either a metallic film coating or containing a micromesh screen. The goggles are lined with commercially available RF absorbing material, with the exterior coated with a conductive paint designed to reflect the energy.

(c) X-Ray Radiation from Electronic Equipment. As noted in other portions of this handbook, when high velocity electron beams strike metals and certain materials, X-rays are produced which may be hazardous to personnel, especially if the shielding incorporated into the equipment design is not intact. The X-rays produced by accelerating potentials in the order of 15,000 volts are not hazardous beyond approximately a foot from the source and therefore do not require elaborate additional shielding to make the device safe for nearby personnel. However, as the potentials become greater than 15,000 volts, the X-rays have greater energy and therefore require additional shielding. When installing or performing preventive or corrective maintenance on electronic devices that produce X-ray radiation as an undesirable by-product, the following precautions should be observed inasmuch as the required maintenance will usually entail disassembling the microwave generating elements and disturbing the integrity of the shielding.

- o Personnel should not linger near any equipment on which the equipment covers have been removed.

- o Observe all warning signs on the equipment and all written safety precautions in the instruction manuals for the equipment that deals with X-ray hazards. (See figure 7-60.)

- o Do not use jumper interlocks that permit the servicing of operating equipment with the protective X-ray shielding removed, unless such procedures are called for in the instruction manuals.

- o Be sure to replace all protective X-ray shielding when servicing is complete, so that operating personnel or others will not unknowingly be subjected to harmful X-ray radiation.


- o When bench testing X-ray producing electronic devices be sure that adequate X-ray shielding is provided to protect all personnel in the testing area.

- o Determine the latest safety precautions to be observed by maintenance personnel, including the use of the latest approved dosimeters by consulting the installation's industrial hygienist.

b. Lasers. Hazards associated with laser installations and devices are detailed in NAVMED P5052-35. Safety precautions contained in the latest issue of the aforementioned document shall be followed. Some of those safety measures are summarized below for information. In addition, a medical surveillance program shall be established for those individuals whose assignment may result in exposure to laser radiation. Details of the surveillance program are also contained in NAVMED P5052-35.

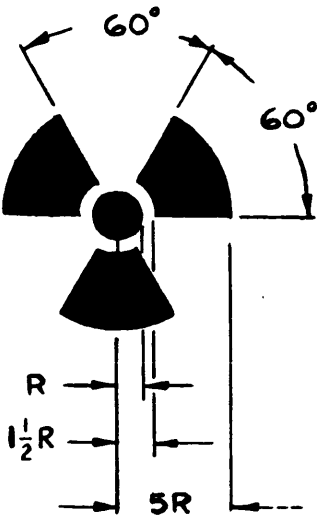
LETTERING TO BE BLACK
BACKGROUND TO BE YELLOW
SYMBOL TO BE PURPLE (MAGENTA)

CAUTION



X - RAYS

THIS DEVICE MAY PRODUCE
X - RAYS WHEN ENERGIZED.
OPERATING PERSONNEL MUST BE
PROTECTED BY APPROPRIATE
SHIELDING. X-RAY CAUTION
SIGNS OR LABELS SHOULD BE
PERMANENTLY ATTACHED TO
EQUIPMENT DIRECTING OPER-
ATING PERSONNEL NEVER TO
OPERATE THIS DEVICE WITHOUT
X-RAY SHIELDING IN PLACE
(SEE USASI-C95.1 OR APPLICABLE
PUBLIC HEALTH STANDARDS)



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Figure 7 - 60. X - Ray Radiation Caution Label

(1) Laser Installations

(a) Wherever feasible laser equipment should be located in a room separated from general laboratory areas or contained in a light-proof enclosure. Laser with power outputs (mega and gigawatt range) exceeding the capabilities of protective devices shall be housed in an area to which personnel will not be allowed access during operation.

(b) Laser spaces shall be free of reflective surfaces or objects, particularly in the target area.

(c) Work with lasers shall be done in areas of high general illumination, except where accomplishment of a mission would be impaired.

(d) A warning sign or signs such as that of figure 7-61 shall be permanently posted at all entrances of the laser enclosure.

(e) Pulsed and CW laser installations with reflected intensities exceeding the maximum allowable safe levels shall:

- o Have safety interlocks at entrances of the laser space such that unauthorized or transient personnel are denied access while the laser power supply is charged and capable of firing. When interlocks are actuated, a fail-safe circuit shall de-energize the laser system within 5 seconds.

- o Have an alarm system including an audible signal and flashing lights (visible through laser safety eyewear) which are actuated when the laser power source is being energized (e.g., capacitor banks begin to charge, CW laser power supply is energized, before laser tube is switched on, or chemical pump energy source is energized).

- o Be free of extraneous reflective surfaces or objects particularly in the target area. Walls and ceilings should be painted with a diffuse nongloss paint, preferably black, near the target area and a light color elsewhere to increase ambient illumination.

- o Have adequate ventilation where inert liquified coolant or toxic gases are used in the system.

- o Have a master electrical power shut-off outside the laser enclosure.

(2) Laser Equipment

(a) Electrical and electronic circuits associated with laser apparatus are to be installed in accordance with the applicable requirements of NAVMAT P-5100 and Requirement 1 of MIL-STD-454, Standard General Requirements for Electronic Equipment.

(b) Firing systems will be designed with fail-safe controls in order to prevent the possibility of firing the laser accidentally.

(c) Laser equipment components that can produce extraneous direct, deflected or reflected radiation of harmful visible, ultraviolet, or infra-red light; X-ray or radio-frequency energy will be shielded. Flash lamps, rotating parts, capacitor banks, and other components that can fail and thereby produce hazardous flying pieces will also be shielded.

(d) A suitable fire-resistant low-reflective material will be provided as a backstop for the beam of carbon dioxide-nitrogen gas lasers.

(e) Safety precautions and safe operating procedures shall be posted in accordance with NAVMAT P-5100.

(f) Systems employing liquid nitrogen as a coolant shall comply with NAVWEPS OP-3199 publication.

(3) Operating Precautions

(a) Wherever possible, aligning the laser beam with the naked eye must be avoided and looking into the primary beam or its reflections is prohibited.

(b) Highly portable lasers shall be turned on only after an alignment check.

(c) The beam shall be discharged into a non-reflective and fire-resistant background. All extraneous reflective objects in path of beam shall be removed.

(d) Laser equipment shall never be left unattended while energized and shall be discharged when shut down.

(e) The countdown procedure shall be employed when firing pulsed and CW laser having reflected intensities exceeding the maximum allowable safe levels.

(f) The operation, maintenance, and repair of laser electrical and electronic circuits shall be performed in accordance with the applicable parts of NAVMAT P-5100.

(4) Personnel Precautions

(a) During the firing of a laser, personnel shall wear protective eyewear in accordance with the criteria of NAVMED P-5052-35. Lenses shall be marked to show the optical density and wavelength for which they are intended to provide protection.

(b) Those in charge of laser facilities shall be competent in laser technology and operation. All personnel assigned to work with lasers shall be fully instructed with respect to the hazards involved, safety precautions, and the use of safety devices.

(c) Only authorized personnel shall be permitted to set up, adjust, or operate laser equipment.

(d) When working on electrical and electronic components of laser equipment, personnel shall observe the safety precautions and use the protective clothing and devices.

(e) When working on liquified nitrogen cooling systems or when handling the liquified nitrogen, personnel shall observe the safety precautions and use the protective clothing and devices stipulated in NAVWEPS OP-3199.

(5) Field Precautions. The environmental and operational controls which are practicable in the laboratory, of necessity, may not be feasible under field conditions. However, the precautions listed above and those following should be enforced in laser exercises in the field wherever practicable:

(a) The laser should be treated as an ordnance piece, and laser operation and test should be confined to gunnery or missile ranges or other sites where similar security and safety measures are in force.

(b) Personnel should be excluded from the beam path to a distance where the energy is within permissible levels. This may be accomplished by the use of physical barriers, administrative control, interlocks, or by limiting beam traverse.

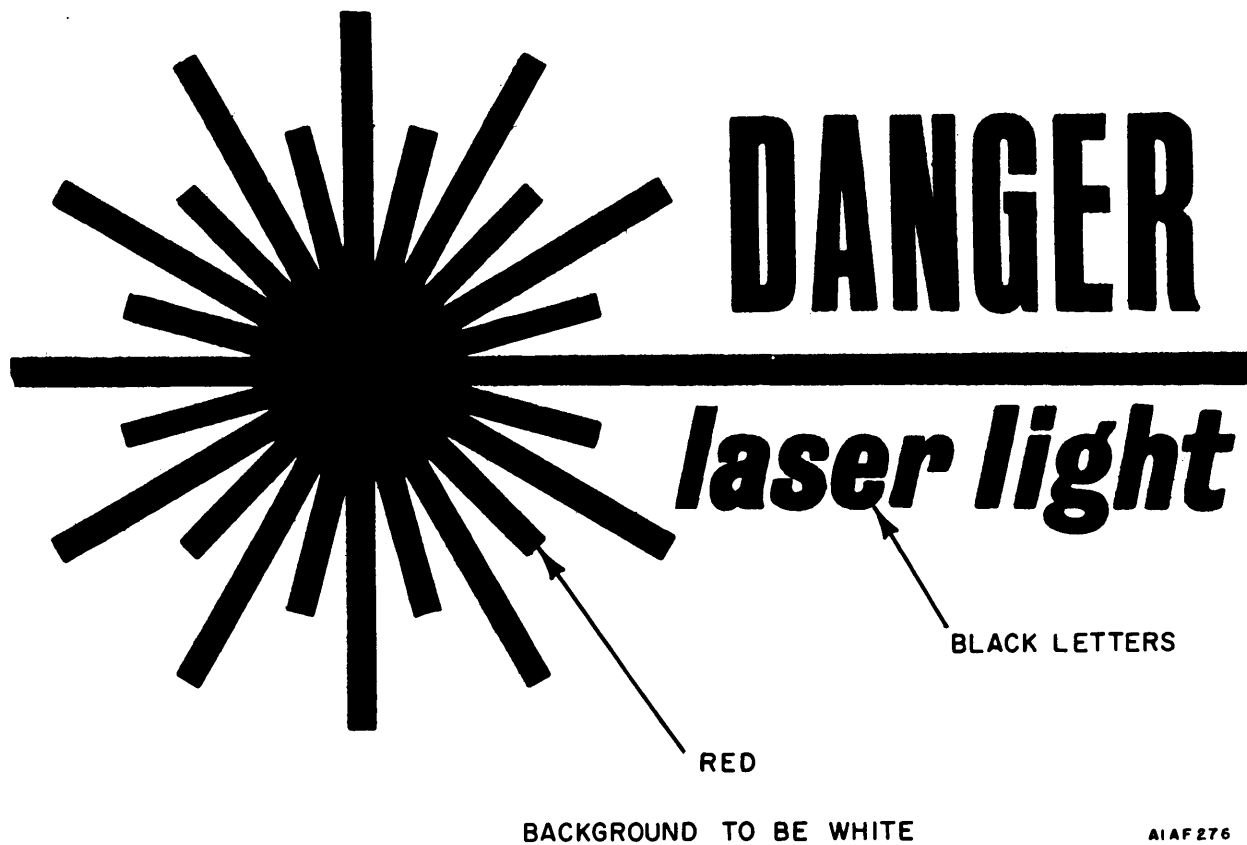


Figure 7 - 61. Laser Warning Sign

(c) Tracking of non-target vehicular traffic or aircraft should be prohibited if within calculated hazardous distances.

(d) The beam path should be devoid of objects or area capable of producing hazardous reflections.

(e) A permanent log should be maintained, including date, time, place, type of device fired, bearing of beam, and roster of participating personnel.

c. Burns and Shock Hazards Due to EMR. As noted in other sections of this handbook, EMR from antennas of electronic equipment can induce voltages in a variety of metallic objects (such as smokestacks, railings, aircraft, ladders, transmitting and receiving antennas, cranes, booms, etc.) normally found on a naval shore installation, which can result in shocks or burns to personnel. Personnel should be alert at all times to the possibility of burns and shocks from the aforementioned examples and other similar objects not specifically mentioned, as well as the undesirable effects that might result from such an accidental shock, such as violent reactions which can cause a fall from an elevated position or an injury due to striking an object. In addition, the following safety precautions should also be taken:

(1) Only authorized personnel should be permitted in the vicinity of transmitting antennas and on nearby ladders, railings etc.

(2) Personnel working in the vicinity of EMR fields should not wear loose clothing, jewelry or other metallic objects.

(3) Circuits in electronic equipment should be grounded to protect against shocks or burns. If the location of the protecting ground is not in the immediate vicinity of working personnel, suitable warning tags should be employed to prevent unauthorized removal of the protective grounds.

(4) Aircraft should be grounded in accordance with the latest such requirements as should mobile vans containing transmitting antennas.

(5) When cranes, booms or cargo handling equipments are used in the vicinity of transmitting antennas, insulated hooks and other safety devices should be used.

7.7.3 Control of Hazards to Fuels

Possible hazards to flammable mixtures as a result of EMR have been discussed in other portions of this handbook as well as many other publications, such as NAVMAT P-5100, NAVORD OP-3565/NAVAIR 16-1-529, NAVAIR 06-5-502, NAVSHIPS 0900-005-8000, and NAVFAC and NAVAIR documents, instructions and directives. These documents contain minimum safe distances for handling fuels. While these restrictions reflect what is known of the hazard to date, present efforts are being directed towards the elimination of all conditions conducive to arcing during fueling operations. These efforts include the development of fueling nozzles and receptacles providing non-metal-to-metal contact with the aircraft or vehicle being refueled, the use of insulated coatings on areas immediately adjacent to fueling receptacles and vents, and the replacement of metal parts with non-metal parts.

Until, and unless, otherwise required, the precautions in 7.7.1 above and the following precautions should be met during the design, operation and maintenance of fueling and transmitting antenna installations:

a. In areas where gasoline is to be handled, avoidable sources of EMR which may cause ignition should normally be located to a distance determined by safety and good practice; this is usually at least 200 feet for gasoline and at least 50 feet for other flammables. Such sources of EMR include cargo handling vehicles, locomotives, power equipment, electrical equipment not specifically approved for use in hazardous atmospheres, all motor vehicles, and electronic and transmitting equipment and antennas.

b. Fueling sites and operations should not be located in the proximity of antennas. An ungrounded automobile, ungrounded filling nozzle, or merely the attendant's body in close proximity to transmitting antennas may produce sparks sufficient to ignite gasoline vapor when the nozzle comes in contact with the tank opening. Pump nozzles must be grounded at all times, and motor vehicles, when fueling, must also be grounded before opening the tank.

c. No flammable mixtures/materials shall be located or handled in an area where the EMR radiation level exceeds the 10 mW/cm² personnel exposure level. In addition, all transmitters having antennas within a certain minimum distance of shore based handling or fueling areas shall be de-energized as follows:

(1) Transmitters with 250 W radiated output or under shall be de-energized if their antennas are 50 feet or less from handling or fueling areas.

(2) Transmitters with over 250 W radiated output shall be de-energized if their antennas are within 200 feet of handling or fueling areas.

(3) Radar transmitters, having antennas within 200 feet of the handling area regardless of their output power, shall be de-energized if it is possible for the center of the main beam of radiated electromagnetic energy from their antennas to fall directly on any part of the handling or fueling area.

d. In instances where space limitations may occasion the erecting of fueling stations, parking ramps or other structures near an antenna site, the following precautions are to be observed:

(1) All metal used in building wooden structures, within 200 feet of fixed antennas radiating 250 watts or more, shall be bonded together where feasible and grounded to reduce interference and fire hazards.

(2) During gasoline or JP-4 fueling operations within the vicinity of shore based transmitting antennas, especially high power transmitting antennas, particular care should be taken to adequately ground all automobiles, aircraft and other gasoline, JP-4 or LPG powered machines while they are being fueled. In addition, refueling trucks, pumps, filling nozzles, and tanks will also be grounded prior to any delivery of fuel.

e. Radiating antennas (i.e., rotating, scanning, and fixed) shall be positioned, if possible, so as to prevent illumination of fueling areas while in operation. Otherwise, minimum distances, as given above, shall be employed.

f. Additional guidance for potential fuel hazards may be found in NAVELEX 0101,103.

7.7.4 Control of Hazards to Ordnance

This handbook does not attempt to outline in great detail the requirements, restrictions, and procedures for handling ordnance in the presence of EMR. Details on the above, as well as measurements and theoretical analyses, may be found in NAVORD OP-3565/NAVAIR 16-1-529, NAVWEPS OD 30393, MIL-P-24014 and other documents. For the purpose of this handbook, it is sufficient to say that weapons systems and associated subsystems, equipments and devices may be tactically deployed on shore stations and therefore may be transported, stored, handled, loaded in launchers, launched, serviced, disassembled, checked and tested in the vicinity of EMR generating equipments. Accordingly, in the planning and design of shore installations and operation and maintenance of ordnance devices, the following precautions, in addition to those in the aforementioned documents and paragraph 7.7.1 of this handbook, are to be met:

a. Weapons and weapon-launcher systems should be grounded according to MIL-B-5087 or the applicable weapon system specification.

b. Access doors should not be opened if the system, or associated subsystems, are located in an EMR field.

c. The handling of weapons, EED's, etc., should not be carried out in the presence of known EMR fields; safe distances as determined by NAVAIR and NAVORD should be used in a manner similar to that for fueling operations.

d. When working in the vicinity of weapons, systems personnel should not touch conductors that lead into the actual weapon.

e. In an EMR field, the launcher and weapons are very likely to be at different voltage potentials which, therefore, increases the possibility of generating an arc when mating the umbilical. After the weapon has been secured to the launcher, the potentials are almost the same and the possibility of an arc is reduced. The latest weapon system design criteria promulgated by NAVORD will reduce the possibility of EMR hazards to ordnance.

f. If an ordnance site is located near a transmitter antenna installation and a weapon is transported in a susceptible condition, partially assembled or with exposed wiring, the shipping crate should be made of sheet metal and should completely enclose the weapon.

g. Since EMR energy of any type may cause inadvertent ignition of ordnance components, motor vehicles equipped with radio transmitters shall not transport electric blasting caps or other electrically fired ordnance. Radio transmitters in any motor vehicle are not to be operated within 25 feet of any area where electric blasting caps are to be located and transmitters with an output of 250 watts or more shall not be operated within 100 feet of such areas.

h. Activity regulations concerning electrical blasting shall take into account the location and characteristics of electronic transmitters both within and outside the confines of the activity. Regulations to minimize this hazard shall comply with precautions described in The American National Standards Institute Guide C95.4 of March 1971, "Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Electric Blasting Caps."

i. All future planning for shore based communications transmitters, radars, or other such installations transmitting high energy electromagnetic fields are to be based on locating such transmitting installations not closer than 1000 feet from any ammunition magazine, ammunition operating building, road used for transporting ammunition, or any area where ammunition or explosives are regularly handled.

7.7.5 Control of Hazards of Electronic Devices

Protection measures to safeguard electronic devices from damage due to EMR should be considered from the initial design stages of the equipments and carried through the installation design and operation phases. Grounding, bonding, shielding, circuit design, chassis layout and other techniques are now being employed to minimize equipment degradation due to EMR. These are treated in the EMC portion of this handbook and may be applied to prevent equipment damage. However, equipment damage is not, as yet considered in the design. Accordingly, the selection of equipment locations to prevent illumination from radiating antennas becomes increasingly important, as does the installation criteria.

Particular attention should be paid to the location of medical electronic devices in relation to transmitting antennas as EMR from the antennas can cause damage to the sensitive medical devices. Relative location of medical monitoring devices (i.e., electrocardiographs, cardiac monitors etc) must also be considered.

When using some of the medical electronic devices described above, such as the EEG, the ground integrity should be checked just before a patient is connected to any line operated device. The use of molded line plugs should be abandoned because they cannot be inspected for broken ground connections.

Hospitals on naval installations must also plan for and establish maintenance programs, such as performing routine checks and measurements of leakage currents so that early symptoms of equipment failure can be identified.

When shipping electronic components for subsequent use in electronic equipments and systems care must be exercised to avoid transporting them in EMR fields. If this cannot be avoided, the components should be packed in a suitable shielded container.

7.7.6 Special Safety Precautions During EMR Measurements

The measurement of a potentially hazardous field implies that some danger will exist for measurement personnel. The first step that should be taken to minimize such danger is to operate the radiating systems at a known reduced power. The field pattern may then be defined and the reduced power density values recorded. Proportional relationships are then used to calculate the maximum power density at the same point in the pattern when the radiator is operated at its maximum power.

A second precaution should also be exercised in all radiation measurements. The site plan and predicted radiation pattern should be studied by the measurement personnel so that a suitable starting point well away from the radiator(s) is chosen. This starting point should have less than the maximum predicted power density and subsequent measures should be made by moving toward the radiating source(s). Personnel should be cautioned that the maximum power density will exist at some calculated distance from the radiator in order that they will be constantly alert for abrupt energy level changes in the near field.

Most radiation measuring devices use a directional antenna which must be pointed toward the source to be measured. Users of such devices must be instructed to scan potential reflectors as well as the primary radiators when measuring the reflected energy, especially when operating at reduced power. The tendency may be to neglect such secondary sources due to an apparently low power density, forgetting that when the same reading is used to establish the maximum power level, a hazardous condition might be indicated.

The measured power density levels should be recorded on a site plan for comparison with those levels resulting from the prediction process. Considerable care should be exercised to picture the site in three dimensions when comparing levels and assigning hazardous labels to particular areas. Highly directive antennas may have their major beams crossing a particular area such that a hazard appears to exist but upon considering a difference in vertical angles the hazard may completely disappear.

Any extreme difference between measured and predicted levels should not be disregarded since inaccuracies in the prediction process are present. In any such case where doubt arises, the measured value should be given precedence in decision making. The combination of the measured and predicted results should remain as real factors in the final determination of existing hazards.

Upon completion of a radiation hazard survey and analysis, certain discrete areas may be defined on the site plans as being hazardous, either to personnel, fueling operations, or to electronic or ordnance devices. Steps must then be initiated to convey the warning of the danger to using personnel as well as to itinerants. Such warning is commonly provided by the standard warning signs described earlier. Fences and other obstacles or more active measures are taken to alleviate the hazardous condition by installing interlocks, cut-outs, or delay mechanisms. Care must be exercised in the employment of these methods since some of them may have direct bearing on the functional utility of the systems involved.