ORDER

6950.19A

PRACTICES AND PROCEDURES FOR LIGHTNING PROTECTION, GROUNDING, BONDING, AND SHIELDING IMPLEMENTATION

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U.S. DEPARTMENT OF TRANSPORTATION
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FOREWORD

This order provides design guidelines for implementation of effective lightning protection, grounding, bonding, shielding, and surge and transient protection for use by Headquarters and Region Design Engineers in designing new FAA electronic facilities and electronic equipment installations. A survey procedure for existing electronic facilities is also included, and is for use by Headquarters, Regional and System Management Office (SMO) personnel in evaluating the effectiveness of the lightning protection, grounding, bonding, shielding, and surge and transient protection presently in use. The survey procedures also provide guidance for the evaluation of deficiencies discovered during accomplishment of the survey in determining whether or not corrective action is warranted and for the inspection and acceptance or rejection during the Joint Acceptance Inspection (JAI).

THE MATERIAL IN THIS ORDER PROVIDES GENERAL DIRECTION AND GUIDANCE TO FACILITATE EFFECTIVE DESIGNS IN THE AREAS NOTED ABOVE. HOWEVER, IT IS NOT POSSIBLE TO SPECIFICALLY DETAIL, ON AN ITEM-TO-ITEM BASIS, EXACT DESIGN PROCEDURES TO BE USED. THEREFORE, THE USER MUST BECOME FAMILIAR WITH THE CONTENTS OF THE ORDER, AND SUBSEQUENTLY APPLY THE KNOWLEDGE GAINED TO SPECIFIC AND DETAILED DESIGN METHODS AND PRACTICES.

Stanley Rivers, Acting Director of
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CHAPTER 1. GENERAL

1. PURPOSE. This directive describes practices and procedures to provide effective lightning protection, grounding, bonding, shielding, surge and transient protection for FAA facilities and electronic equipment that make up the National Airspace System (NAS). This Order requires compliance with FAA-STD-019, Lightning Protection, Grounding, Bonding, and Shielding for Facilities, and FAA-STD-020, Transient Protection, Grounding, Bonding and Shielding Requirements for Equipment.
This mandate provides the recommended grounding, bonding, transient protection and shielding practices in the design of the electrical power distribution and grounding subsystems for both old and new electronic equipment and facilities. It provides guidelines for surveying existing facilities, and recommendations for the correction of deficiencies. Fundamental theory and technical background supporting this order are contained in a FAA Order 6950.20, Fundamental Considerations of Lightning Protection, Grounding, Bonding and Shielding. FAA-STD-019 and FAA-STD-020 provide the standard configuration for new construction, major modification to existing facilities, and new electronic equipment.

2. DISTRIBUTION. This order is distributed to division level in Airway Facilities, Associate Administrator for Research and Acquisition in Washington Headquarters; to branch level at the Mike Monroney Aeronautical Center and the William J. Hughes Technical Center; to branch level in the regional Airway Facilities divisions; and all Airway Facilities System Management Offices.

3. CANCELLATION. Order 6950.19, Practices and Procedures for Lightning Protection, Grounding, Bonding, and Shielding Implementation, dated July 28, 1978 is hereby canceled.

4. BACKGROUND. National Airspace System solid-state electronic equipment has been severely damaged by lightning induced surges and transients entering facilities on AC power lines feeding the facility and on externally exposed landlines terminating at electronic equipments. Structures have been damaged by close proximity and direct lightning strikes to the structure. Electromagnetic interference (EMI) has caused electronic equipment to fail to operate properly. There are conflicts with National Fire Protection Association (NFPA) 70, National Electrical Code (NEC), in the electrical installations at some existing facilities and with NFPA 780, Lightning Protection Code, in the installation of the lightning protection system in and on the structures, thereby introducing hazards to personnel safety

and property. Incorrect grounding or the lack of grounding is often the cause of improper operation of the electrical, electronic and lightning protection systems as well as the cause for electromagnetic interference.

a. Cause of Problems. The widespread use of solid-state equipment has increased the frequency of problems due to lightning related incidents. Additionally, solid-state equipment has become more sensitive to noise because of the low operating voltages typical in its use; therefore, effective grounding needs to be maximized for reliable operation.
Damage to structures from lightning strikes usually occurs because the structure does not have a physical lightning protection system, or an effective ground system, properly installed and bonded to each other. Most NEC violations exist because of a general lack of knowledge of the requirements of the NEC and its latest changes, and the importance of the NEC installation requirements to the safe operations of the facility.

b. Minimizing Problems. This order provides procedures which will minimize problems caused by poor lightning protection, grounding, bonding and shielding practices. Procedures are also provided for complying with the requirements of the National Electrical Code and the Lightning Protection Code. Chapter 3 provides a survey for use in determining if existing electronic facilities meet the requirements for new facilities, together with procedures for correcting deficiencies when considered necessary.

5. ACTION.

a. The practices, procedures, and design guidance given by Chapter 2 for new electronic facilities and by Chapter 4 for new electronic equipment shall be used to facilitate compliance with lightning protection, grounding, bonding, shielding and surge and transient protection requirements.

b. The survey procedures provided by Chapter 3 shall be used as guidance for identifying and correcting deficiencies at existing electronic facilities and for the Joint Acceptance Inspection (JAI). The inspection procedures provided by Chapter 3 shall be used as guidance for identifying and correcting deficiencies at existing electronic facilities. Where applicable, the design checklists of Appendix 1 may be utilized for the inspections at existing facilities to verify the integrity and effectiveness of the various systems. The inspection checklists of Appendix 3 may be used to assist personnel in determining the adequacy of the lightning and the lightning induced surge and transient protection systems, and the various grounding systems (earth, power, and electronic). It may also be used in aid and guidance in the JAI.

6. DEFINITIONS. The definition for some of the words and terminology used in the text of this order are provided in this paragraph. Definitions are included only for words and terminology not of wide and ordinary use, or when the meaning of words is different than ordinary or normal usage.

a. Absorption Loss. The attenuation of an electromagnetic wave as it passes through a shield. This loss is primarily due to induced current and its associated I^2R loss.

b. Access Well. A small opening in the earth using concrete, clay pipe or other wall material for the purpose of providing access to earth electrode system connections.

c. Air Terminal. An air terminal is that component of a lightning protection system that is intended to intercept lightning flashes.

d. Ampacity. The current in amperes that a conductor can carry continuously under normal conditions without exceeding its temperature rating.

e. Aperture. An opening in a shield through which electromagnetic energy passes.

f. Arc Voltage. The voltage that appears across the terminals of a spark gap when the spark gap is ionized and in full conduction.

g. Arrester. Component(s), device(s), or circuit(s) used to attenuate, suppress, and conduct surge and transient energy to ground. The terms arrester, suppressor and protector are generally used interchangeably except the term arrester which is used herein for components, devices and circuits at the service disconnecting means.

h. Balanced Line. A line or circuit using two conductors instead of one conductor and ground (common conductor). The two sides of the line are symmetrical with respect to ground. Line potentials to ground and line currents are equal but of opposite phase at corresponding points along the line.

i. Bond. The electrical connection between two metal surfaces established to provide a low-resistance path between them.

j. Bond, Direct. An electrical connection utilizing continuous metal-to-metal contact between the members being joined.

k. Bond, Indirect. An electrical connection employing an intermediate electrical conductor between the bonded members.

l. Bond, Permanent. A bond not expected to require disassembly for operational or maintenance purposes.

m. Bond, Semipermanent. Bonds expected to require periodic disassembly for maintenance, or system modifications, and that can be reassembled to continue to provide a low-resistance connection.

n. Bonding. The joining of metallic parts to form an electrically conductive path which will assure electrical continuity and the capacity to conduct safely any current likely to be imposed between the metallic parts.

o. Bonding Jumper. A reliable conductor to assure the required electrical conductivity between metal parts required to be electrically continuous.

p. Branch Circuit. The circuit conductors between the final over-current device protecting the circuit and the outlet(s).

q. Brazing. A joining process using a filler metal with working temperature above 800 degrees F, but below the melting point of the base metal. The filler material is distributed by capillary attraction.

r. Building. The fixed or transportable structure which provides environmental protection.

s. Cabinet. A protective housing or covering designed either for flush or surface mounting with a frame, mat or trim in which a swinging door or doors are or may be hung.

t. Case. A protective housing for a unit or piece of electrical or electronic equipment.

u. Chassis. The metal structure that supports the electrical or electronic components that make up the unit or system.

v. Circular Mil. A unit of area equal to the area of a circle whose diameter is one mil (1 mil = 0.001 inch).

w. Clamp Voltage. The maximum voltage that appears across a surge arrester or transient suppressor when discharging a surge or transient current to ground.

x. Common Mode Voltage. The amount of voltage common to both input terminals of a device.

y. Common Mode Rejection. The ability of a device to reject a signal which is common to both its input terminals.

z. Conducted Interference. Undesired signals that enter or leave an equipment along a conductive path.

aa. Conductor, Bare. A conductor having no covering or electrical insulation.

bb. Conductor, Insulated. A conductor encased within material of composition and thickness that is recognized by the National Electrical Code as electrical insulation.

cc. Conductor, Main, Lightning. A conductor intended to be used to carry lightning currents between air terminals and ground terminals. See Roof Conductors and Down Conductors, Lightning hereinafter.

dd. Coupling, Conducted. Energy transfer through a conductor.

ee. Coupling, Free-Space. Energy transfer via electromagnetic fields not in a conductor.

ff. Crowbar. Crowbar is the method of shorting a surge current to ground in surge protection devices. This method provides protection against more massive surges than other types, but lowers the clamping voltage below the operational voltage of the electronic equipment causing noise and operational problems. It also permits a follow current which can cause damage.

gg. Cutoff Frequency. The frequency below which electromagnetic energy will not propagate in a waveguide.

hh. Degradation. A decrease in the quality of a desired signal (i.e., decrease in the signal-to-noise ratio or an increase in distortion) or an undesired change in the operational performance of an equipment as the result of interference.

ii. Discharge Voltage. Same as clamp voltage.

jj. Down Conductor, Lightning. Part of the main conductor installation of a lightning protection system that connects the roof conductors and air terminals to the ground electrode system.

kk. Earth Electrode System. A network of buried electrically interconnected ground rods, plates, pipes, mats, or grids installed for the purpose of establishing a low resistance contact with earth. (Also known as the Grounding Electrode System).

ll. Electric Field. A vector field about a charged body. Its strength at any point is the force which would be extended on a unit positive charge at that point.

mm. Electromagnetic Compatibility (EMC). The capability of equipment or systems to be operated in their intended operational environment at designed levels of efficiency without causing or receiving degradation owing to unintentional interference. EMC is the result of an engineering planning process applied during the life cycle of equipment. The process involves careful considerations of frequency allocation, design, procurement, production, site selection, installation, operation, and maintenance.

nn. Electromagnetic Interference (EMI). Any emitted, conducted, radiated or induced voltage which degrades, obstructs, or repeatedly interrupts the desired performance of electronic equipment.

oo. Electromagnetic Pulse (EMP). A large impulsive type electromagnetic wave generated by man-made or natural explosions.

pp. Electronic Multipoint Ground System. An electrically continuous network for high frequency electronic systems consisting of interconnected ground plates, equipment racks, cabinets, conduit, junction boxes, raceways, duct work, pipes and other normally non-current carrying metal elements. It includes conductors, jumpers and straps that connect individual items of electronic equipment to the multipoint ground system. This system is most effective for frequencies above 100 kHz.

qq. Electronic Single Point Ground System. A single point reference in the facility for low frequency signals, which are installed in a trunk and branch arrangement to prevent conductive loops in the system. Isolated from all other ground systems except for the interconnection, where applicable, to the electronic multipoint ground system at the main ground plate. The single point ground system consists of insulated conductors, copper ground plates mounted on insulated stands, and insulated ground plates, buses or signal ground terminals in the electronic equipment which are isolated from the frame of the equipment. This system is most effective for signals below 100 kHz. Lightning protection is complicated by the use of single point grounding schemes.

rr. Equipment Grounding Conductor. The conductor used to connect non-current carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service disconnecting means or at the source of a separately derived system. This conductor must be routed in the same raceway or cable as the phase and neutral conductors.

ss. Facility Ground System. Consists of the complete ground system at a facility including the Earth Electrode System, Electronic Grounding Systems (Electronic Multipoint Ground System and/or Electronic Single Point Ground System), Fault Protection Grounding System (Grounding Electrode Conductor and Equipment Grounding Conductors), and the Lightning Protection System.

tt. Far Field. The region of the field of an antenna where the radiation field predominates and where the angular field distribution is essentially independent of the distance from the antenna.

uu. Fault. An unintentional short-circuit or partial short-circuit (usually of a power circuit) between energized conductors or between an energized conductor and ground.

vv. Ground. A conducting connection, whether intentional or accidental, between an electrical or electronic circuit or equipment and the earth, or to some conductive body that serves in place of the earth.

ww. Grounded Conductor (neutral). A system or circuit conductor that is intentionally grounded at the service entrance disconnecting means or at the source of a separately derived system.

xx. Grounded Effectively. Permanently and continuously connected to earth from circuits, equipment, and conductor enclosures through a ground connection having sufficient ampacity to conduct safely any fault current likely to be imposed on it, and having sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.

yy. Grounding Conductor. A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes. (Note: In this Order, grounding conductors, not related to or not to be used as part of the electrical system grounding as required by the NEC, are used for the electronic equipment grounding systems.)

zz. Grounding Electrode Conductor. The conductor used to connect the grounding electrode system to the equipment grounding conductor and/or to the grounded conductor of the circuit at the service disconnecting means or at the source of a separately derived system.

aaa. Grounding Electrode System. See Earth Electrode System (Par. 6 kk).

bbb. Interface. Any electrical connection (encompassing power transfer, signaling, or control functions) between two or more items of equipment or systems.

ccc. Isokeraunic. Statistics showing average annual number of days with thunderstorms.

ddd. Isolation. Physical and electrical arrangement of the parts of equipment, system, or facility to prevent uncontrolled electrical contact within or between the parts.

eee. Landline. Any conductor, line, or cable installed externally above or below grade to interconnect electronic equipment in different facility structures or to connect externally mounted electronic equipment.

fff. National Electrical Code (NEC). The purpose of this code is the practical safeguarding of persons and property from hazards arising from the use of electricity. This code covers the installation of electrical conductors and equipment within or on buildings and other structures including mobile units and floating buildings; and other premises such as yards, parking and other lots. It is sponsored by the National Fire Protection Association (NFPA 70) and has been approved by the American National Standards Institute (ANSI).

ggg. Near Field. The region of the field immediately surrounding an antenna where the inductive and capacitive fields predominate. In this region, the angular distribution of the field varies with distance from the antenna.

hhh. Neutral. The AC power system circuit conductor that is intentionally grounded on the supply side of the service disconnecting means. It is the grounded conductor of a single phase, 3-wire system or of a three phase, 4-wire system. This conductor is identified by white or natural gray insulation along its entire length, or where larger than No. 6 AWG, by white markings at its terminations and at all accessible places such as pull boxes. (Note: Green insulated conductors are not to be re-identified and used as the neutral conductor.)

iii. Overshoot Voltage. The fast rising voltage that appears across transient suppressor terminals before the suppressor turns on (conducts current) and clamps the input voltage to a specified level.

jjj. Penetration. The passage through the partition or wall of an equipment or enclosure by a wire, cable, or other conductive object.

kkk. Plane Wave. An electromagnetic wave which predominates in the far field region of an antenna, and with a wavefront which is essentially in a flat plane. In free space, the characteristic impedance of a plane wave is 377 ohms.

lll. Radiation resistance. The resistance which, if inserted in place of an antenna, would consume the same amount of power that is radiated by the antenna.

mmm. Radio Frequency Interference (RFI). Synonymous with electromagnetic interference.

nnn. Reference Plane or Point, Electronic Signal (Signal Ground). The conductive terminal, wire, bus, plane, or network which serves as the relative zero potential for all electronic signals referenced thereto.

ooo. Reflection Loss. The portion of the transition loss, expressed in decibels (dB), that is due to the reflection of power at a barrier or shield. Reflection loss is determined by the magnitude of the wave impedance inside the barrier relative to the wave impedance in the propagation medium outside the barrier.

ppp. Response Time. The time required for a surge arrester or transient suppressor to turn on (conduct) and clamp surge or transient after turnon or sparkover voltage is impressed across the device terminals

qqq. Reverse Standoff Voltage. The maximum voltage that can be applied across a surge arrester or transient suppressor without causing the arrester or suppressor to turn on and conduct. Sometimes referred to as maximum operating voltage, primarily for spark gap arresters. Also referred to as maximum allowable voltage for metal oxide varistor (MOV) devices.

rrr. RF-Tight. Offering a high degree of electromagnetic shielding effectiveness.

sss. Roof Conductor (Lightning). The lightning protection system conductors on the roof of a structure that interconnect all the air terminals to form a two way path to ground from the base of each air terminal.

ttt. Secondary Lightning Bonding Conductor. A conductor used to bond a metal object within the zone of protection, that is subject to potential build-up different from the lightning current, to the lightning protection system.

uuu. Shield. A housing, screen or cover which substantially reduces the coupling or electric and magnetic fields into or out of circuits or prevents the accidental contact of objects or persons with parts or components operating at hazardous voltage levels.

vvv. Shielding Effectiveness. A measure of the reduction of attenuation in the electromagnetic field strength at a point in space caused by the insertion of a shield between the source and that point.

www. Signal Return. A current-carrying path between a load and the signal source. It is the low side of the closed loop energy transfer circuit between a source-load pair.

xxx. Supporting Structures, Electrical. Non-electrified conductive structural elements near energized electrical conductors such that a reasonable possibility exists of accidental contact with the energized conductor. Examples are conduit and associated fittings, junction and switch boxes, cable trays, electrical and electronic equipment racks, electrical wiring cabinets, and metallic cable sheaths.

yyy. Transducer. A device which converts the energy of one transmission system into the energy of another transmission system.

zzz. Thunderstorm Day. A local calendar day on which thunder is heard.

aaaa. <u>Transient Suppressor</u>. Component(s), device(s), or circuit designed attenuate, suppress or divert conducted transient(s) and surge energy to ground to protect electronic equipment.

bbbb. <u>Turn-On Voltage</u>. The voltage level that must be applied across the terminals of an arrester or suppressor to cause the device to turn on and conduct current. For solid-state and MOV devices, the specified voltage is normally that required to cause the device to conduct 1 milliampere of current. The turn-on voltage for MOV devices is normally specified as a varistor voltage. The turn-on voltage for spark gaps is normally referred to as sparkover voltage, and varies greatly for different types of spark gaps.

cccc. <u>Undesired Signal</u>. Any signal which tends to produce degradation in the operation of equipments or systems.

dddd. <u>Wave Impedance</u>. The ratio of the electric field strength to the magnetic field strength at the point of observation.

eeee. <u>Zinc Oxide Nonlinear Resistor (ZNR)</u>. A specific type of metal oxide varistor (MOV) with a specified voltage-current relationship.

7. <u>AUTHORITY TO CHANGE ORDER</u>. The Program Director, NAS Transition and Implementation (ANS-1), shall approve all changes to this order.

8. - 10. <u>RESERVED</u>.

CHAPTER 2. NEW FACILITIES DESIGN CRITERIA

11. GENERAL. This chapter presents the design, implementation, test, and check-out practices and procedures for effective grounding, lightning protection, bonding, shielding and lightning-induced surge and transient protection in a new facility. A new facility is one of new construction or one that is to undergo major renovation. The major elements of the facility covered here are the earth electrode system, power system fault protection network, lightning protection system, the electronic system grounding networks, i.e., single point and multipoint grounding systems, overall facility grounding system, facility shielding, system bonds, and lightning-induced surge and transient protection methods. Designs and construction steps for these eight elements are contained in Sections 1 through 6.

Supplemental measures that need to be incorporated into a new facility are contained in Sections 7 through 9. Reduction in common-mode and instrumentation noise problems in a facility are presented in Section 7. The special construction practices recommended to reduce facility vulnerability to the electromagnetic pulse (EMP) threat are contained in Section 8. And finally, new facility inspection and test procedures are provided in Section 9 to assist in verifying proper execution of recommended practices and procedures, and in establishing a performance baseline for comparison against future measurements.

To obtain optimum performance of electronic equipment, while providing proper protection against power system faults (as per NFPA 70, National Electrical Code) and lightning strikes (as per NFPA 780, Lightning Protection Code), thorough consideration must be given to the grounding system for the building; to the bonds needed and the method of their implementation; and to the shielding needed throughout the building for personnel safety and equipment interference control. For a new facility, the requirements in each of these areas are defined and appropriate design steps set forth to assure that the necessary measures are incorporated into the final construction.

SECTION 1. EARTH ELECTRODE SYSTEM

12. GENERAL. The earth electrode system (grounding electrode system) establishes the electrical connection between the facility and the body of the earth. This connection is necessary for lightning protection, power fault protection, and the minimization of noise between interconnected facilities. The system should be tailored to reflect the characteristics of the site and the requirements of the facility. It must be properly installed and steps taken to assure that it continues to provide a low resistance connection throughout the life of the structure. To achieve these objectives, first determine the electrical and physical properties of the site, design an electrode system appropriate for the site, install the system in accordance with the recommended procedures, and finally, measure the earth resistance of the system to verify that it meets the recommended goals or design specifications.

13. DETERMINATION OF SITE PARAMETERS. Before beginning the design of the Earth Electrode System, conduct a survey of the site where the earth electrode system is to be installed. Through this survey, determine the resistivity of the soil, identify significant geological features, gather information on architectural and landscape features which may influence the design of the system, and review local climate effects. If possible, conduct this survey in advance of the final site selection in order to avoid particularly troublesome locations.

a. Soil Resistivity. Soil (earth) resistivity is the resistance of a cubic centimeter of earth measured between opposite surfaces expressed in ohm-centimeters. Soil resistivity varies due to the type of soil, its temperature, moisture content, compactness and homogeneity. Resistivity will vary as a function of seasonal changes such as freezing, or lengthy dry periods. Mixtures of materials in the soil (sand, loam, gravel, or rock), may be encountered which will cause the resistivity of the soil to vary. The four-probe method is the most accurate method in practice for measuring the resistivity of large volumes of undisturbed earth. This will allow for mapping soil resistivity to specific depths, as determined by the spacing distances between the probes. It will also allow for locating the depth of the most homogeneous, moist layer of the soil.

b. Soil Resistivity Measurement. A four-terminal earth resistance test set is used to measure the soil resistivity. The measurement shall be made a minimum of 72 hours following measurable rainfall. In this test four small probes, normally furnished with the earth resistance test set, are used. These probes shall all be driven to the same depth and shall be equally spaced in a straight line as indicated in Figure 2-1. Four separate lead wires shall be connected from the four probes to the four terminals on the instrument, hence the name, "Four Probe" or "Four Terminal" Method. The wires are generally connected to the probes with clamps. The depth of the penetration (B) of the short probes must be small in comparison to the distance (A) between the probes. For convenience, a distance of 10 feet (3 meters) and a depth of penetration of not

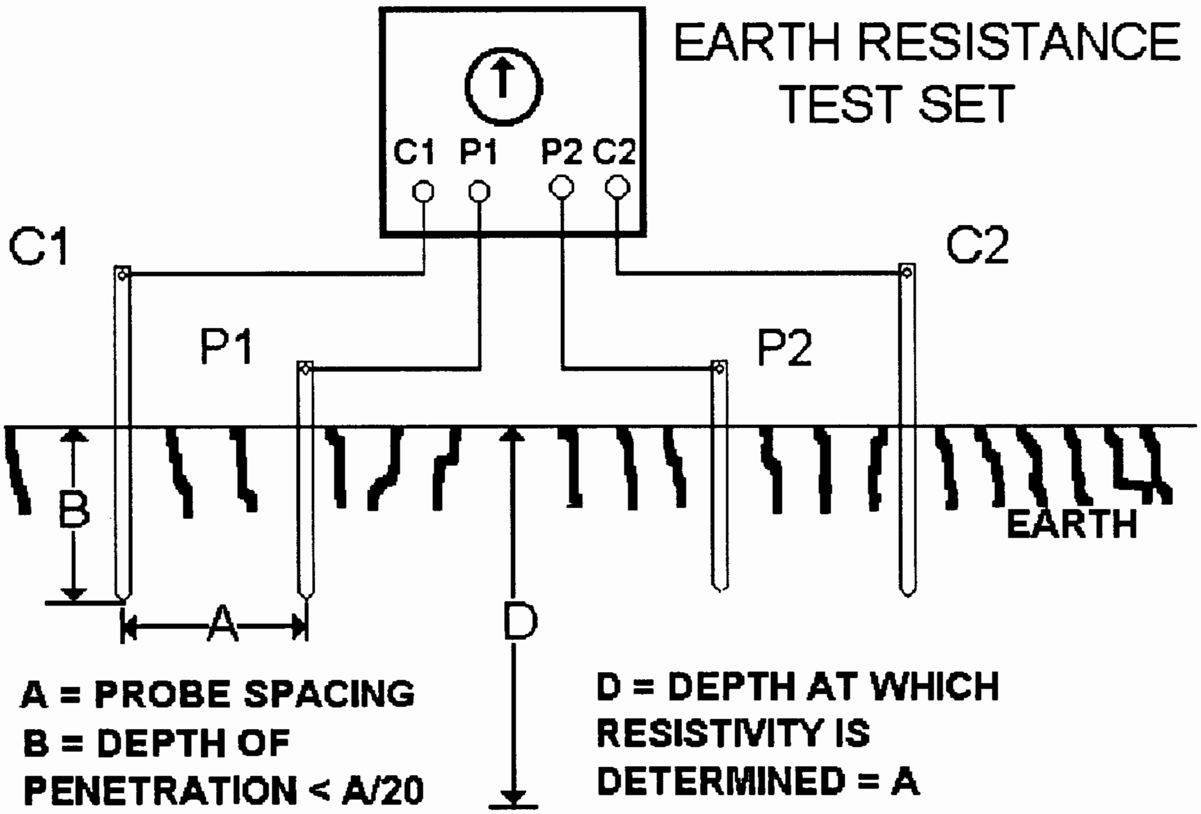


FIGURE 2-1. MEASUREMENT OF SOIL RESISTIVITY

more than 6 inches are recommended as a start. For small sites up to 2500 square feet (232 square meters), make at least one measurement at the center of the site and at each of the four corners of the site. Figure 2-2 shows this for a square site, 50 feet (15 m) on each side. These measurements should be made at distances between probes of 10, 20, 30, and 40 feet. Drive a stake or marker at the location shown (Figure 2-2). Position the potential and current probes in a straight line with the stake or marker centered between the probes. Make a resistance measurement at each of the locations shown and record the resistance. The average of the five readings for each spacing of probes is used to calculate the resistivity for the soil of the site. For large areas, make measurements every 100 to 150 feet (30 to 45 meters) over the site area. Include in the site area the location of the support elements such as the transformer banks, towers, engine-generator buildings, etc. Choose a sufficient number of test points to give an indication of the relative uniformity of the soil composition throughout the area. For each spacing of probes, a value (R ohms) will be recorded. (NOTE: If the probes are not available with the test set, four metal rods (of steel, copper, or aluminum) 1/4 to 3/8 inch (6 to 10 mm) in diameter and 12 to 18 inches (30.5 to 46 cm) in length may be used.)

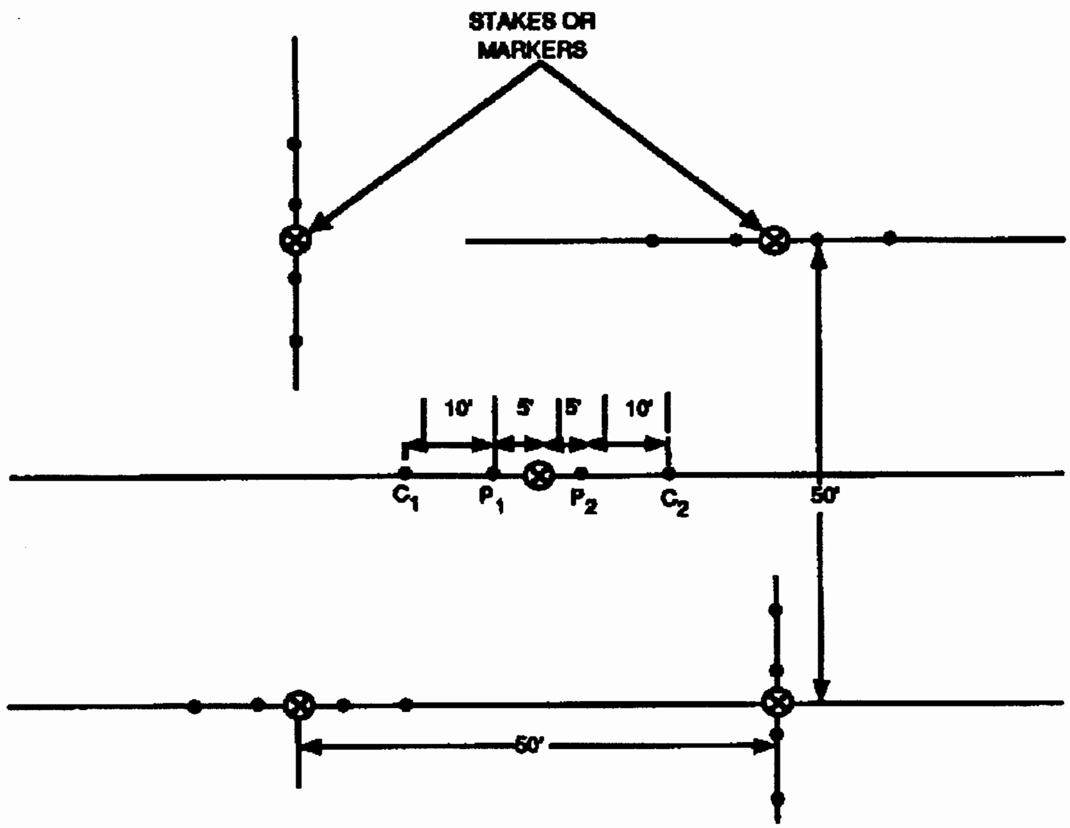


FIGURE 2-2. RESISTIVITY DETERMINATION OF A SMALL SITE

The following formula applies where the probe depth is kept small in comparison to the distance between the probes:

$$p = 2\pi AR$$

where p is the average soil resistivity in ohm-centimeters (ohm-cm) to a depth A, which is the spacing of the probes in centimeters (cm), π is the constant 3.1416, A is the distance between probes in cm and R is the resistance reading of the test instrument in ohms.

c. Soil Resistivity Calculations. Assume that the distance between probes is 20 feet (610 cm) and that a resistance of 2 ohms is measured. The resistivity can be calculated from the above formula. Substitute the values of 3.1416 for π, A = 610 for 20 feet in cm, and R = 2 ohms.

$$p = 2\pi A \times R$$
$$p = 2 \times 3.1416 \times 610 \times 2 = 7662 \text{ ohm-cm.}$$

The reading obtained indicates the average soil resistivity in the immediate vicinity of the test area, at a depth of 20 feet.

d. Resistivity Profile. The information above may be used in determining what type of earth electrode system is most appropriate for the facility (complex, building, tower structure, transformer bank, substation, etc.). A plot of either ohm-cm, or R (ohms) versus depth or spacing can be used to determine the best rod lengths to be used. The soil resistivity is considered low when less than 2000 ohm-cm., average when between 2000 and 20,000 ohm-cm., and high when greater than 20,000 ohm-cm. The higher the soil resistivity, the more complex (and expensive) will be the earth electrode system necessary to achieve the desired resistance. Thus, take maximum advantage of the low resistivity soils wherever they exist.

e. Calculation of Earth Resistance. From the soil resistivity calculations and the plot layout, the lowest achievable resistivity (p) value can be selected and the resistance of a single rod driven to a depth determined by the spacing between the probes on the plot layout. The resistance of a single driven ground rod can be approximately calculated from the formula:

$$R_s = 0.366p/\ell \times \log_{10} 3\ell/d$$

where R_s is the resistance of a single ground rod in ohms, p is the soil resistivity in ohm-cm, ℓ is the length of the ground rod in cm and d is the diameter of the ground rod in cm. Thus if the design goal is a resistance of 10 ohms, the total number of ground rods spaced to fit the system, but spaced no closer together than the length of one ground rod can be approximated from the formula:

$$R_t = \frac{R_s K}{N} \quad \text{or,} \quad N = \frac{R_s K}{R_t}$$

where R_t = total (Goal) resistance, R_s = resistance of a single ground rod, N is the number of ground rods and K is the resistance ratio. The resistance ratio (K) can be determined from Figure 2-3. If it is desired to include the effects of the buried interconnecting conductor and the mutual effects of rod to wire, use the equations in FAA Order 6950.20.

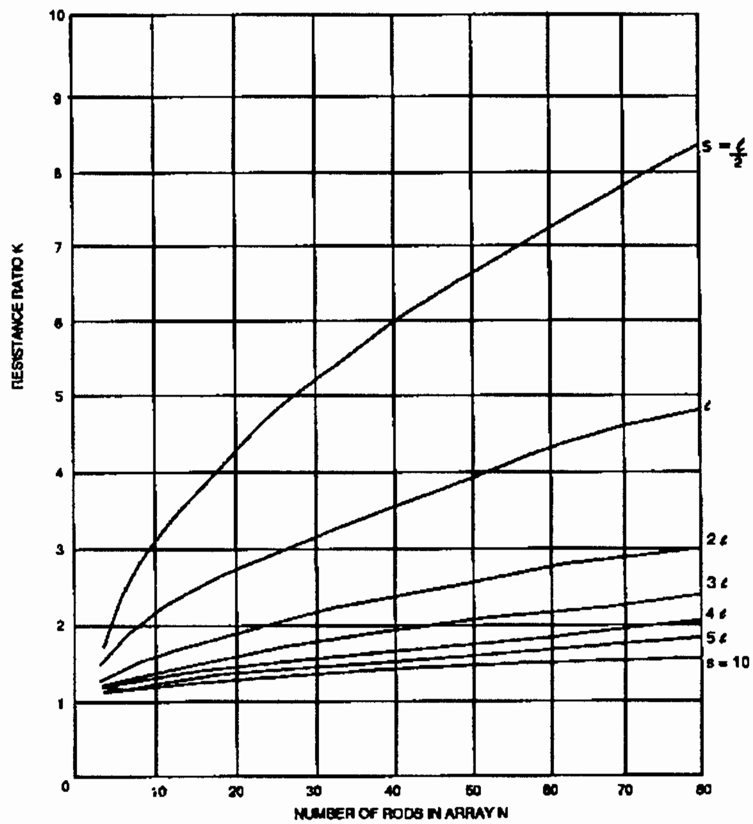


FIGURE 2-3. RATIO OF THE ACTUAL RESISTANCE OF A ROD ARRAY TO THE IDEAL RESISTANCE OF N RODS IN PARALLEL

14. GEOLOGICAL EFFECTS IDENTIFICATION.

a. Geological Features. Identify the significant geological features of the site. Specifically, attempt to establish:

(1) Distribution of major soil types to include the locations of sand and gravel deposits.

(2) Major rock formations.

(3) Presence of water sources to include underground streams.

(4) Depth of the water table.

b. Information Source. Utilize test borings, on-site inspections, studies of local maps, and interviews with local construction companies, well drillers, power companies, and other local personnel to obtain the desired information.

c. Evaluation. Evaluate the information provided by these sources for indications of particularly troublesome, or particularly helpful, characteristics that may influence the design or installation of the earth electrode system of the facility.

15. PHYSICAL FEATURES. Locate and identify other physical features that will influence the general placement of the earth electrode system, the location of the test and access points, physical protection requirements, and the cost of materials and installation. For example, indicate on the general site plan:

a. The planned physical layout of the building or structure.

b. Locations of paved roads and parking lots.

c. Drainage, both natural and man-made.

d. The location of buried metal objects such as pipes and tanks.

16. LOCAL CLIMATE.

a. Review local climatic conditions and determine the annual amount and seasonal distribution of rainfall, the relative incidence of lightning, and the depth of freezing (frostline) typical for the area. Obtain the rainfall and frostline information from the local weather service; project the relative lightning incidence from the isokeraunic maps given in Order 6950.20, Fundamental Considerations of Lightning Protection, Grounding, Bonding and Shielding.

b. Record the data and make it a part of the facility files for the site. Use the information to aid in the design of the earth electrode system for the facility to be constructed at the site.

17. DESIGN PROCEDURE.

a. Selection of Electrode Configuration. Determine what type of electrode system is most appropriate for the facility (complex, building, structure, transformer bank, substation, etc.). Establish the primary functional requirements to be met by the electrode system. For example:

(1) Lightning. For a facility located in an area of high lightning incidence or a high degree of exposure to lightning, or both, the earth electrode system must safely dissipate the lightning energy without melting conductors or overheating the soil.

(2) Fault Current Magnitude. Where very large fault currents are likely (in power substations, for example), the electrode system must be capable of restraining hazardous step voltage levels, and must be capable of transporting the current into the soil while maintaining temperatures to less than the boiling point of water.

(3) Impulse Impedance Characteristics. Where EMP protection is necessary, low impulse impedance should be incorporated into the electrode system. Refer to Chapter 2, Section 8.

(4) Mobility. Mobile facilities or temporary transportable facilities will generally not justify the installation of an extensive fixed electrode system. For such facilities, install only a basic system capable of providing the minimum acceptable lightning and personnel fault protection. Refer to Section 3.

(5) Resistance. The desired value for the resistance of the earth electrode system is 10 ohms or less unless otherwise required in the design criteria. In high resistance soils this may not be economically feasible. In cases where the soil resistivity is very high, but will allow for deeper driven rods, the electrode system should be comprised of deeper buried rods

driven to reach the low resistivity soil levels. The minimum spacing of rods shall not be less than the driven length of the rods. Where the soil is not suitable for the installation of driven rods, such as in rock formations, vertical plates, grids or horizontal conductors of sufficient sizes and quantities shall be installed and spaced so that any current imposed on the system will be dissipated over a large area.

b. Evaluation of Local Conditions.

(1) Soil Resistivity. Is soil resistivity low (<2000 ohm-cm), average (2000-20,000 ohm-cm) or high (>20,000 ohm-cm)? The higher the soil resistivity, the more complex (and expensive) will be the electrode system necessary to achieve 10-ohms resistance. Thus, take maximum advantage of low resistivity soils wherever they exist.

(2) Moisture Content. Is the water table near the surface or far below grade, and is it subject to large seasonal variations? Design the earth electrode system so that it makes and maintains contact with soil that stays damp or moist year round if at all possible. Penetration of the permanent water table is highly desirable.

(3) Frostline. How deep does the frostline extend, even during coldest periods? The resistivity of soil rises greatly as the soil temperature drops below 32 degrees Fahrenheit. Thus for maximum stability of electrode resistance, the system should penetrate far enough into the soil so that the contact is always maintained with unfrozen soil. In permafrost, fault protection must be provided through the use of metallic returns accompanying the power conductors to insure the existence of a return path to the transformer or generator. Personnel protection in permafrost requires an even greater emphasis on the bonding of all metal objects subject to human contact together and to the power system neutral. Because of the high resistance of permafrost, stray earth currents can be expected to be minimal with consequently reduced concern with interfacility power frequency noise problems. In the event that earth-current-related noise problems exist, the common-mode rejection techniques should be applied. Refer to Order 6950.20.

(4) Rock Formations. Are major rock formations near the surface and are they large enough to influence the design and layout of the electrode system? In regions of shallow bedrock, vertical ground rods may not be usable and horizontal grids, wires, or plates, sloped downward away from the facility, must be used. Large rock outcroppings or subsurface boulders may force the alternate routing of conductors or the placement of rods.

There is no need to incur the expense of drilling holes in rock to insert rods or lay wires because the resistivity of rock is so high that generally the rods or wires would be ineffective.

(5) Architectural Layout. Design the electrode system so that it will not be materially influenced by the weather shielding effects of parapets or overhangs on the building. Lightning down conductor placement and routing will frequently be influenced by architectural considerations. Design the electrode system to accommodate such consideration by providing convenient connection points to ground rods in the earth electrode system near the lightning protection system down conductors to avoid any lengthy extensions between the down conductors and the effective grounding point. Configure the electrode system such that convenient connections are possible between the earth electrode system and the power grounding conductors and signal ground system conductors originating inside the facility.

(6) Landscape Features. Locate ground system conductors under sodded areas or those otherwise covered with vegetation. Locate conductors to take maximum advantage of the wetting effects of run-off or drainage water from the roof, parking lots, etc. Try to avoid placing major portions of the earth electrode system under extensive paved areas such as paved walkways, roads and parking lots.

c. Electrode Type. Consider the relative advantages and disadvantages given in Table 2-1, and choose a basic type of electrode most appropriate for meeting the functional requirements of the facility at the site under construction.

d. Cost. Estimate the relative costs to meet the objectives with the different types of configurations. Include the cost of materials, installation costs, and relative maintenance and upgrading costs.

18. ALTERNATE CONFIGURATIONS. Non-ideal sites will frequently be encountered. For example, large rock formations may be present which prevent the uniform placement of ground rods around the site; bedrock may be relatively near the surface; the water level may drop to several feet below grade; the soil resistivity may be very high; or architectural and landscape requirements may preclude locating ground rods at particular points. In such cases, modify the electrode configuration to conform to the constraints while achieving the desired resistance. Typical suggested alternatives are:

a. Change Number of Ground Rods. In many cases, fewer rods could be used and still meet a required earth resistance goal.

Thus, if rock outcroppings were present at certain points around the perimeter, it may be permissible to omit some of the rods. On the other hand, if the soil resistivity is very high, more ground rods would be necessary.

b. Use Longer Ground Rods. Ground rods longer than 10 feet (3 m)(can be realized by assembling 10-foot sections) may be used in high-resistivity soil in place of a larger number of 10-foot ground rods. Where the ground water table is greater than 10 feet below the surface at any season of the year or where the frostline is greater than 10 feet, use the longer rods to maintain contact with the permanent moist, unfrozen soil. When longer rods are used, the spacing between rods should be increased so as to maintain minimum spacing between rods and the length of the rods should be preferably two to three times the length of the ground rod.

c. Use Horizontal Wires and Vertical Plates Instead of Vertical Rods. Where bedrock or other obstacles prevent the effective use of vertical rods, horizontal wires, vertical plates, grids, or radials should be used. (See Order 6950.20 for design data and equations.) Rectangular grids should also be used in substations or any other locations where very high ground currents may be encountered. Star radials are required for EMP grounding and as antenna counterpoises. Radials may be desirable if the proposed ground rod location is in an area of high resistivity. Where horizontal wires radials are used, they shall be installed so as to slope downward away from the structure. Where plates are used, they shall be installed to be vertical. Where this is not feasible, the plates shall be installed to slope to the maximum extent practicable.

d. Lower the Soil Resistivity Through Chemical Enhancement (Salting). Where the above alternatives are not possible or are not cost effective, chemical enhancement is frequently the only choice left. Any chemical enhancement used must comply with local environmental regulations.

19. DESIGN GUIDELINES.

a. At each facility supplied by commercial electric power, at least one ground rod of the Earth Electrode System should be installed near the service disconnecting means. If the transformer is located on the site, a bare wire sized the same as the counterpoise wire of the Earth Electrode System, normally No. 4/0 AWG, should also interconnect the ground rod driven adjacent to the transformer with a ground rod in the related facility Earth Electrode System.

TABLE 2-1. RELATIVE ADVANTAGES AND DISADVANTAGES OF THE PRINCIPAL TYPES OF EARTH ELECTRODES

TYPE	ADVANTAGES	DISADVANTAGES
Vertical Rods	Straightforward design. Easiest to install (particularly around an existing facility). Hardware readily available. Can be extended to reach water table.	High impulse impedance. Not useful where large rock formations are near surface. Step voltage on earth surface can be excessive under high fault currents or during direct lightning strike.
Horizontal Grid	Minimum surface potential gradient. Straightforward installation if done before construction. Can achieve low resistance contact in areas where rock formations prevent use of vertical rods. Can be combined with vertical rods to stabilize resistance fluctuations.	Subject to resistance fluctuation with soil drying if vertical rods are not used.
Plates	Can achieve low-resistance in limited areas.	Most difficult to install.
Horizontal Wires (Radials)	Can achieve low-resistance where rock formations prevent use of vertical rods. Low impulse impedance. Good rf counterpoise when laid in star pattern.	Subject to resistance fluctuations with soil drying.
Incidental Electrodes (Utility pipes, building foundations, buried tanks)	Can exhibit very low-resistance (if electrically continuous). Generally lowest initial cost (borne by others).	Little or no control over future alterations.

b. For lightning protection purposes, very small facilities (ie. less than 10 sq ft) located in areas of low earth resistivity and very low lightning incidence may require only one ground rod. In regions of low earth resistivity and high lightning incidence and at those facilities having structural extensions or equipment protrusions (such as antenna elements or towers) extending above the surrounding terrain, a minimum of two ground rods located on opposite corners of the facility should be installed.

c. Most installations will require more than two ground rods. A type of configuration similar to that shown in Figure 2-4 is adequate for most facilities.

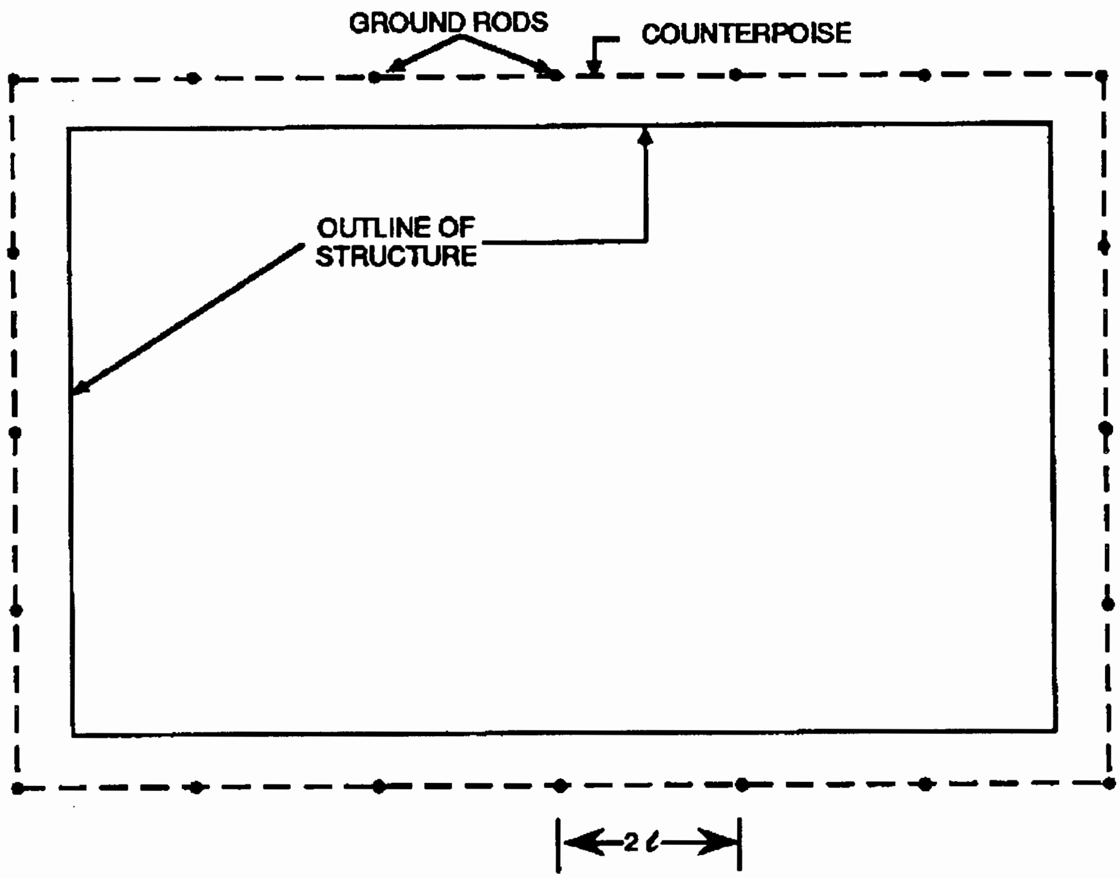


FIGURE 2-4. TYPICAL EARTH ELECTRODE SYSTEM CONFIGURATION FOR RECTANGULAR SHAPED FACILITY

The number of ground rods actually required at a given location will be determined by the resistivity of the soil and the configuration of the installation. Ten-foot (3 m) ground rods installed at 20-foot (6 m) intervals around the perimeter of the structure provide good utilization of the effective radius of the rod while providing several points of contact with the earth. If longer rods are required to penetrate the lowest resistance as determined by the soil survey (see Paragraph 12), greater spacings shall be employed. The nominal spacing between ground rods should be between two and three times the length of the rod and in no case shall the spacing between ground rods be less than the length of the ground rod. Spacings may be predetermined by the size of the electrode system. A ground rod shall be installed at each corner of the earth electrode system, and in between as required.

d. Ground rods and their installation shall be in accordance with the following:

(1) Material and Size. Ground rods shall be of copper or copper clad steel and shall be a minimum of 10 feet (3 m) in length and 3/4-inch (19 mm) in diameter. Where corrosive soils are not compatible with copper or copper clad ground rods stainless steel rods may be used. If cladded rods are used, the copper cladding shall not be less than 1/64 inch (0.4mm) in thickness. Where deeper penetration is required, either additional ground rods exothermically butt welded together or sectionalized ground rods, complete with couplings and driving bolts (studs), shall be used. Ground rods shall bear the manufacturer's name, trade mark, and catalog number. Longer rods may be used to penetrate the frost line, or in high resistivity soil, in lieu of interconnecting 10-foot rods.

(2) Spacing. Ground rods shall be as widely spaced as practical, but in no case spaced closer together than the length of one ground rod. Nominal spacing between ground rods should be between two and three times the rod length.

(3) Location. Ground rods shall be located 2 to 6 feet (0.6 to 2 m) outside the foundation or exterior footings of the structure. At buildings with overhangs, the ground rods shall be located beyond the dripline of the structure to insure that rain, snow, and other precipitation wets the earth around the ground rods.

(4) Interconnection of ground rods. Ground rods shall be interconnected by means of a buried, bare, No. 4/0 AWG copper cable. The cable shall be buried at least two feet six inches below the finished grade level and the connections to the ground rods shall be made with exothermic welds. The interconnecting cable shall close upon itself forming a complete loop (counterpoise) with the ends exothermically welded together. Other connections to the ground rods and to the earth electrode system will be as indicated in other sections of this order.

e. For facilities which do not conform to a rectangular or square configuration, lay out the rod field to generally follow the perimeter of the structure as illustrated in Figure 2-5. Note that a ground rod is installed at each corner or change in direction of the earth electrode system.

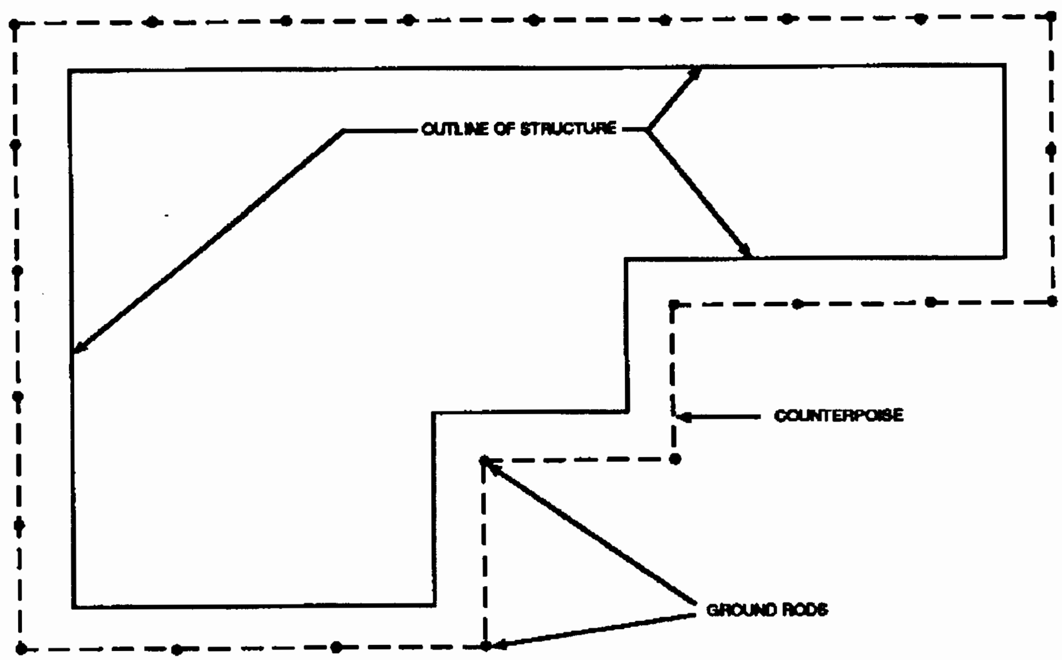


FIGURE 2-5. ELECTRODE CONFIGURATION FOR IRREGULAR SHAPED FACILITY

f. Where two or more structures or facilities are located in the same general area and are electrically interconnected with AC power, signal, control and/or monitor circuits, either provide a common ground rod counterpoise system, or interconnect the separate earth electrode systems with buried bare copper cables sized the same as the counterpoise cable of the earth electrode systems.

A common example of an installation where two separate structures are involved is a radar or communications site where the equipment shelter is adjacent to the antenna tower. Signal cables, both coaxial and waveguide, control cables (electronic and/or power, and AC power conductors typically run between the tower and the shelter. The tower being taller than the shelter, is more susceptible to lightning strikes. To minimize voltage

differentials between the two structures, the facilities should effectively share a common ground.
Separate structures spaced closer than 15 feet (4.5 m) should have a common-rod system installed that encircles both facilities as shown in Figure 2-6a. When the separation is between 15 and

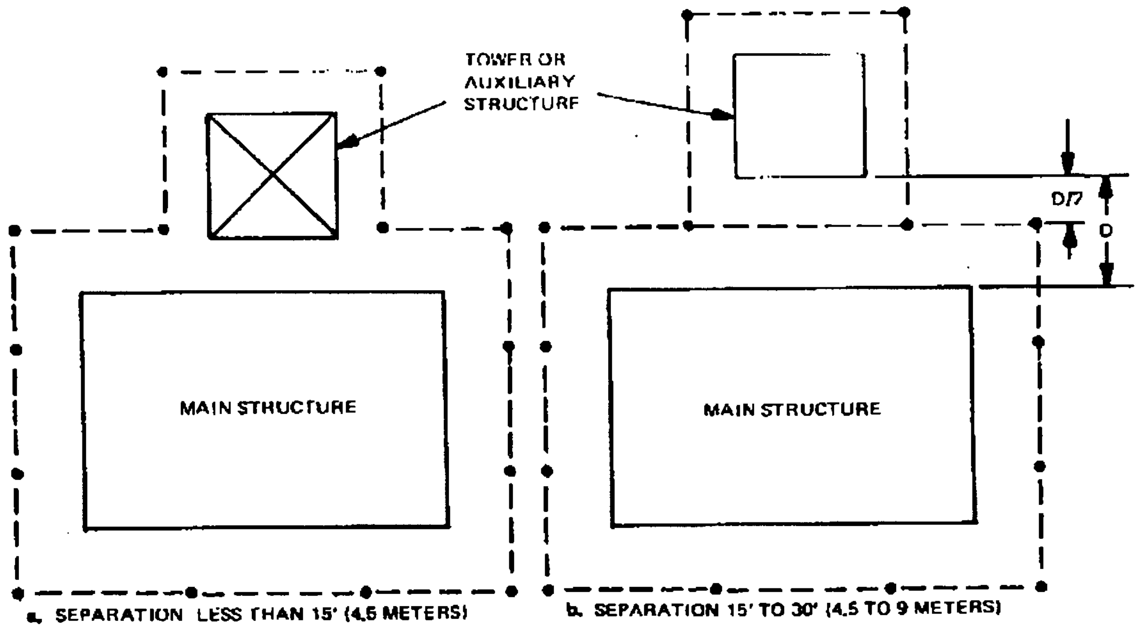


FIGURE 2-6. ELECTRODE CONFIGURATION FOR ADJACENT STRUCTURES

30 feet (4.5 and 9 m), they may share a common side of the earth electrode systems as shown in Figure 2-6b. Figure 2-7 shows the recommended arrangement when the separation is greater than 30 feet (9m). A typical site installation involving three widely separated structures, such as a Radar Installation, is illustrated in Figure 2-8. The counterpoise wire noted may also serve as a guard wire for the buried power and electronic cables.

g. There may be a number of incidental, buried, metal structures in the vicinity of the earth electrode system. These structures should be connected to the system to reduce the danger of potential differences during lightning strikes or AC power faults. Their connection will also reduce the resistance to the earth of the electrode system. Such additions to the earth electrode system may include the rebar in concrete footings, and buried tanks and pipes. These objects shall be connected to the earth electrode system by a bare copper cable not smaller than No. 2 AWG utilizing exothermic welds or FAA approved type connectors. Exothermic welds shall not be used where hazards may exist, i.e., near fuel tanks.

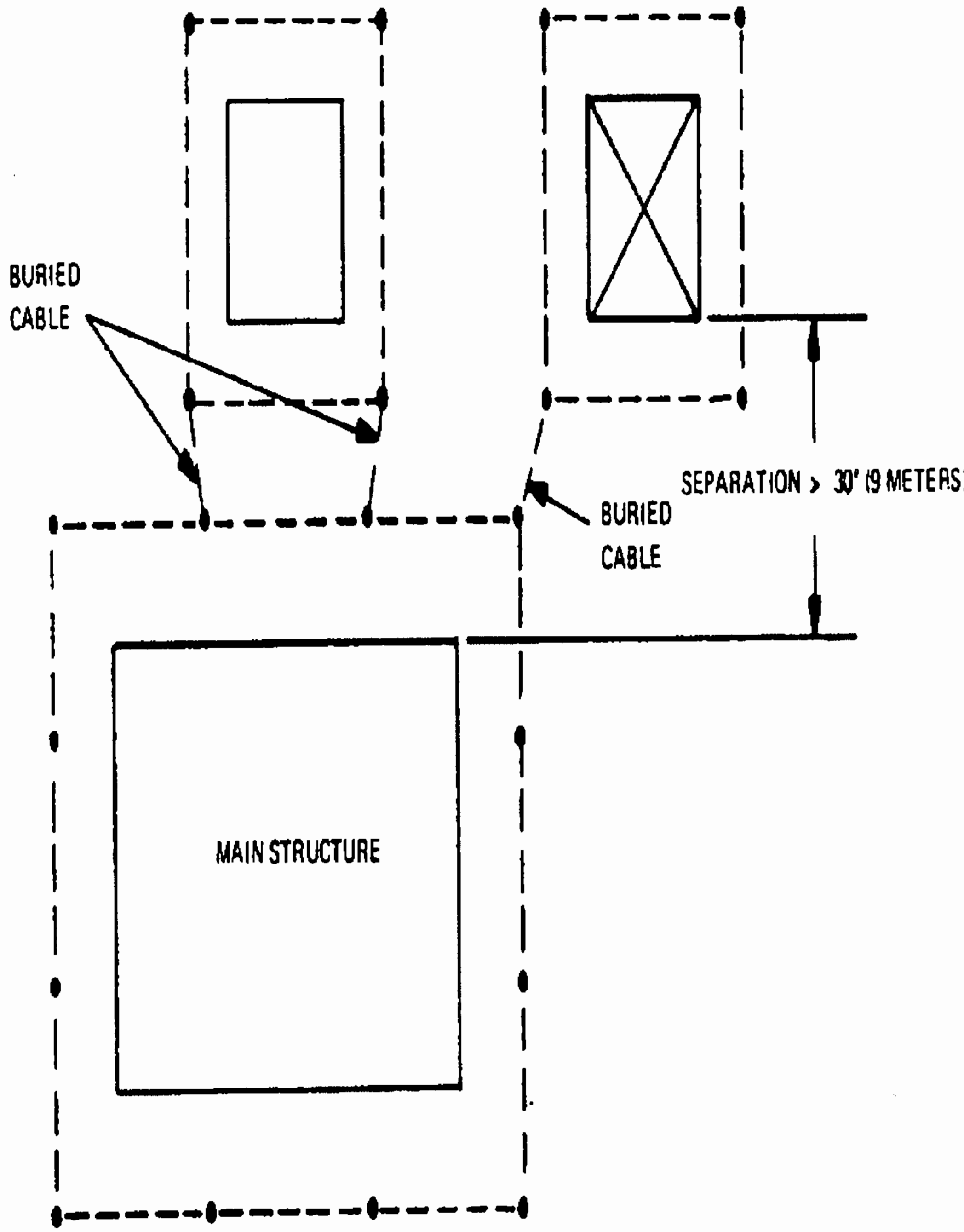


FIGURE 2-7. ELECTRODE CONFIGURATION FOR CLOSELY SPACED STRUCTURES

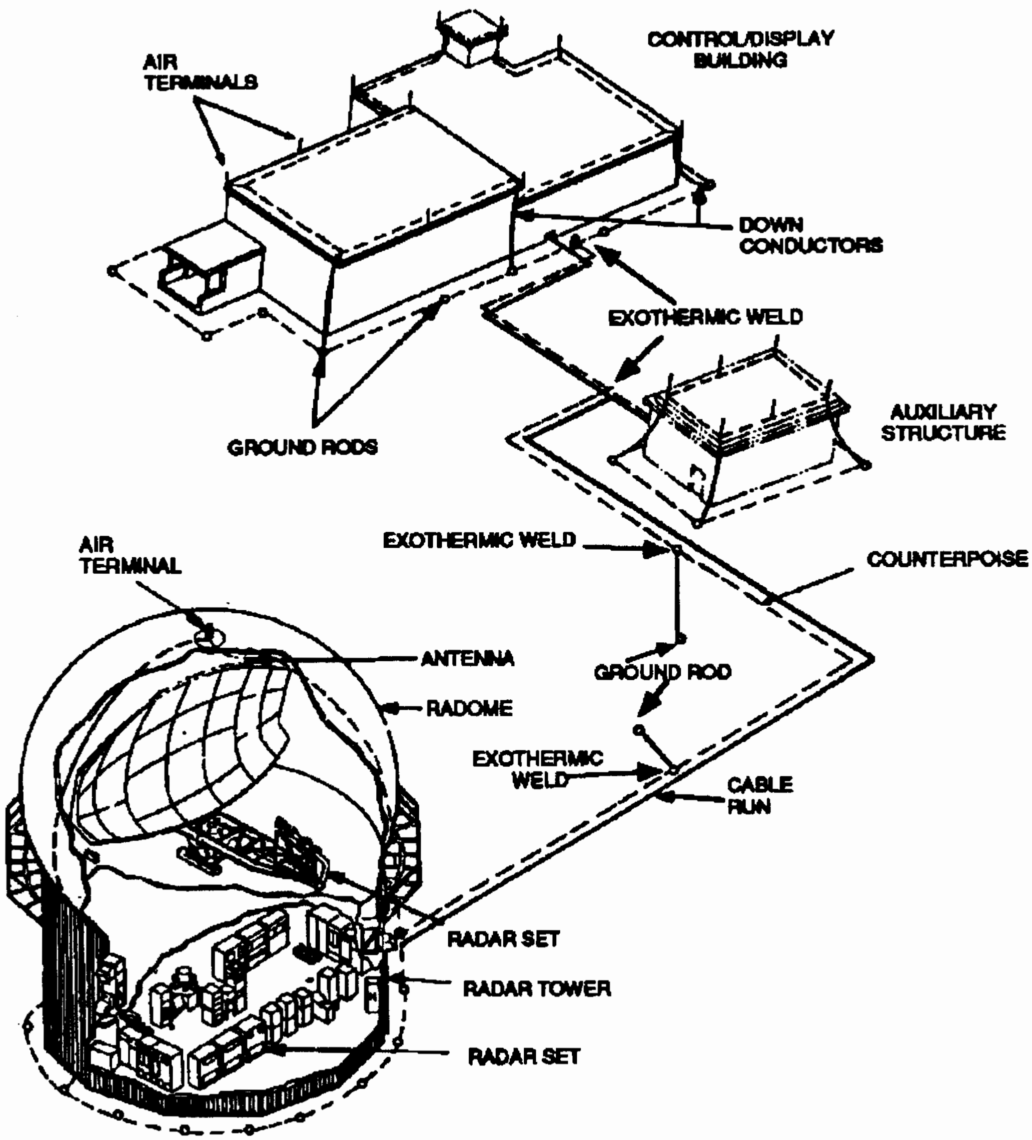


FIGURE 2-8. GROUNDING SYSTEM FOR TYPICAL RADAR INSTALLATION

(1) <u>Where rebar in the footings</u> or foundations is intentionally designed to be a significant portion of the facility grounding system, the rebar system interconnects shall have a bond resistance of 1 milliohm or less.

(2) Where corrosion problems make it undesirable to ground fuel tanks and piping, an isolating section or bushing must be inserted in lines which feed FAA facilities. When this is accomplished the tank and piping system outside the isolating element need not be grounded. Any metallic pipe which enters the facility must be bonded to the earth electrode system to minimize transient entry.

h. <u>To minimize resistance variations</u> caused by surface drying of the soil and by freezing of the soil during winter and to minimize the possibility of mechanical damage to ground rods, connections, and interconnecting cables, the tops of the ground rods should be at least 1 1/2 feet below the finished grade level. The recommended practices are illustrated in Figure 2-9.

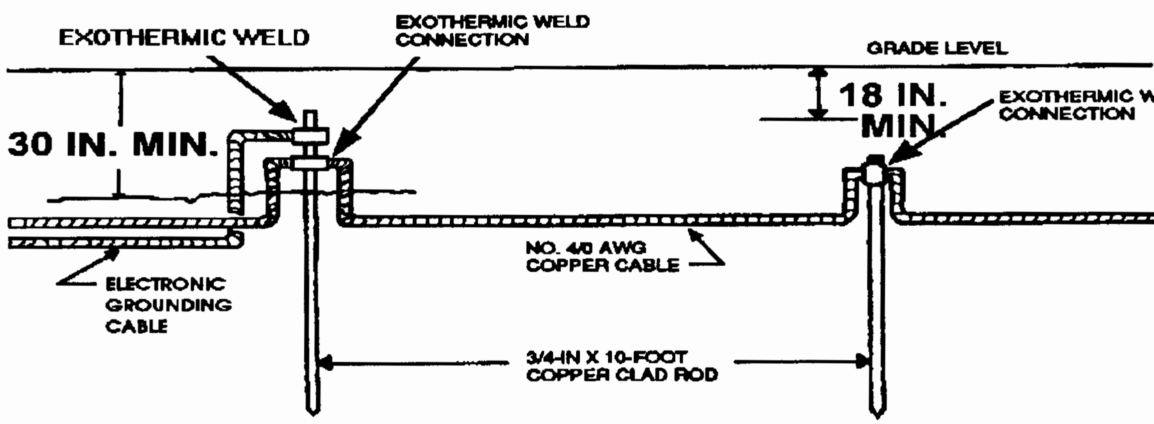


FIGURE 2-9. DETAILS OF GROUND ROD/COUNTERPOISE INSTALLATION

i. <u>If the Earth Electrode System is installed</u> after foundations are poured, cables are installed, utility pipes installed, etc., make proper provisions for performing the needed interconnections between the water system piping, lightning down conductors, structural steel, buried lines and cables, and the electrodes.

j. <u>Access to the earth electrode system</u> may be provided through the installation of one or more access wells at each

site. An acceptable type of access well is illustrated in Figure 2-10. Access wells shall be of a non-conductive material

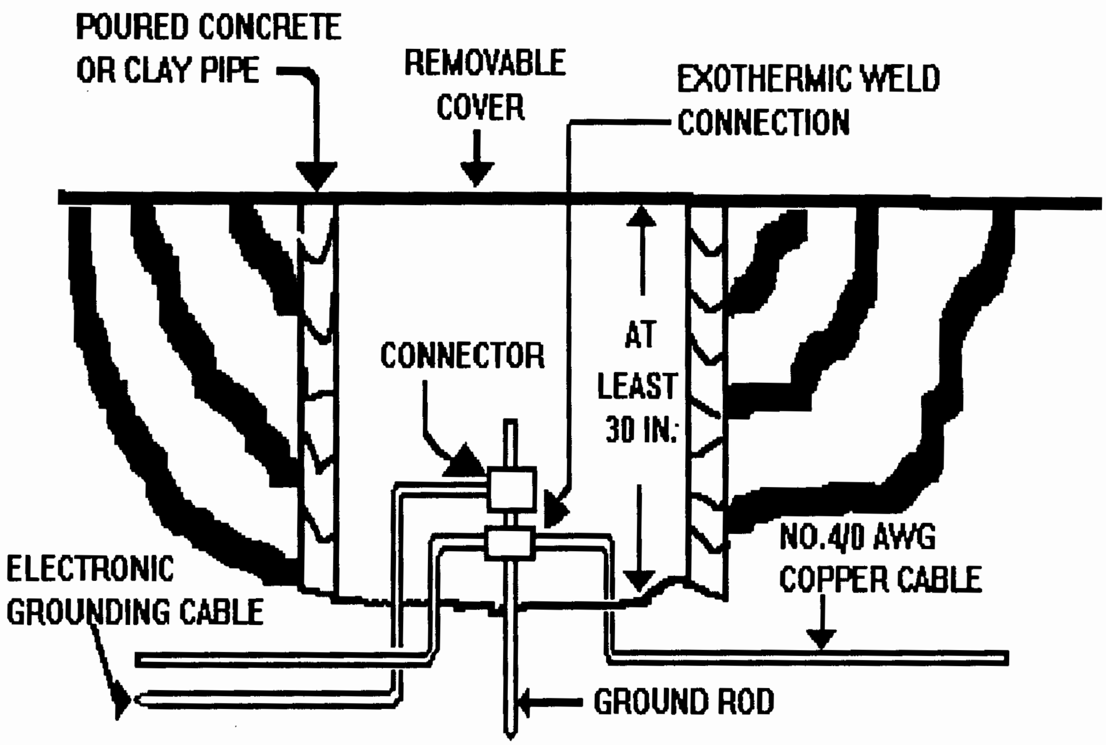


FIGURE 2-10. ACCESS WELL

and have a minimum opening area of 175 square inches. Removable access covers must be provided. In very large structures, particularly those in which grounding grids are installed underneath, the access well or wells may be located inside the building in an accessible location. More than one access well may be necessary depending upon the size of the facility, the extent of the electrode system, and the degree of accessibility to the electrodes deemed desirable. Locate at least one of the access wells in the area with access to open soil so that the resistance checks of the earth electrode system can be made once the building is in use.

The top view of a representative ground rod installation is shown in Figure 2-11 illustrates the required connections to the electronic signal reference network, the lightning protection

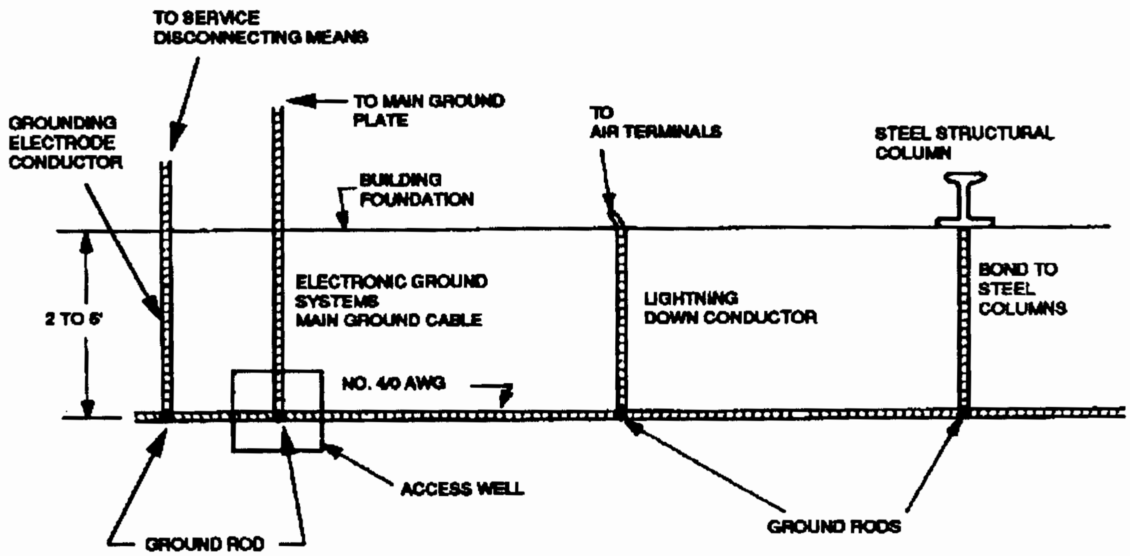


FIGURE 2-11. CONNECTIONS TO EARTH ELECTRODE SYSTEM

system and the facility power ground system. Connection to ground rods in access wells, except for the counterpoise conductor, may be by means of FAA approved connectors in lieu of exothermic welds. The counterpoise conductor connections to the ground rods shall be exothermically welded. Lightning protection down conductor and the grounding electrode conductor connections shall be exothermically welded to buried ground rods.

20. INSTALLATION PRACTICES.

a. Schedule the installation of the earth electrode system so that any needed excavation, such as hole and trench digging, can be performed while other excavating, clearing, and earth moving operations associated with construction of the facility are in progress. If the system is installed prior to completion of the other earth moving operations, take the precautions necessary to assure that the components are not damaged or broken.

b. Take special care to ensure that all underground metallic lines such as water and sewer pipelines, armored cable, etc., are carefully bonded to the earth electrode system with a bare No. 2 AWG (minimum) copper conductor.

c. Before covering the electrode system with backfill dirt or otherwise rendering it inaccessible, make checks of all joints and connections to check mechanical integrity, to verify the absence of voids or other indications of poor bonding, and to see that all required interconnections are made.

d. All bonds in concealed locations must be exothermically welded. Any bonds between dissimilar metals, such as between a copper wire and cast iron or steel pipe, must be thoroughly sealed against moisture to minimize corrosion.

e. Drive rods only into undisturbed earth or into thoroughly tamped or compacted filled areas. Rods and cables should be placed in the backfill around foundations only after the soil has been compacted or has adequate time to settle. Do not drive or lay ground rods in gravel beds which have been installed for drainage purposes unless the rods extend through such beds far enough to provide at least 8 feet (2.4m) of contact with the undisturbed earth underneath. Do not lay horizontal in such beds under any circumstances.

f. Rods may be driven either by hand sledging or with the use of power drivers. Where a limited number of rods are installed in the earth of moderate compactness, hand sledging may be preferable. Use driving nuts to prevent damage to the driven end, particularly if the rods are of the sectional type. Deep driven rods or those driven into hard or rocky soil generally require the use of power drivers with special driving collars to prevent damage to the rod.

g. As the earth electrode system is installed, and prior to covering the counterpoise and ground rods, make a resistance check of the overall earth electrode system. If the measured resistance is less than the calculated resistance, the system as installed is acceptable. On the other hand, if the measured resistance of the ground rods is greater than calculated, additional rods or deeper driven rods should be installed during the construction stage rather than waiting until the facility is completed to add additional rods.

h. Where vertically driven ground rods are not practical, due to geological formations, rods may be slanted. The more vertical a rod is driven, the more effective it is. Plates are best mounted vertically to ensure the greatest possible soil contact.

21. - 29. RESERVED.

SECTION 2. LIGHTNING PROTECTION FOR STRUCTURES

30. PRINCIPLES OF LIGHTNING PROTECTION.

a. Lightning Protection Requirements. A structure, for the purpose of lightning protection, is defined as a building, mast, tower, or similar self-supporting object other than power lines, power stations, and substations. To protect structures against direct lightning strikes, three requirements must be fulfilled:

(1) A conductive object must be provided to intentionally attract the lightning leader.

(2) Paths must be established that join this conductive object to earth with such a low impedance that the discharge follows the paths in preference to any others.

(3) A low resistance connection must be made with the body of the earth.

b. Protection Methods. These conditions are met when a lightning discharge is permitted to enter or leave the earth while passing through only conducting parts of a structure, and without causing damage to the facility or injury to personnel. The conditions can be satisfied by one of two methods, each meeting the requirements of The National Fire Protection Association, NFPA 780, Lightning Protection Code, and having specific applications. These methods are:

(1) The installation of an integral protection system consisting of air terminals interconnected with roof conductors and down conductors utilizing approved type connectors and fittings to form the shortest practical low impedance paths to a ground rod in an earth electrode system suitable for the purposes.

(2) The installation of a separately-mounted protection system of one of two types:

(a) A mast type consisting of a pole, either metal or of a non-conductive material, which acts as a support for a lightning air terminal may be used. The air terminal shall be mounted on the pole so that it is supported in accordance with the requirements of NFPA 780. The down conductor shall be connected to the air terminal and shall be run down the pole to the earth electrode system. The down conductor shall be run on the exterior of the pole and shall be fastened to the pole at intervals not exceeding three feet. The mast or pole supporting the air terminal shall NOT be used as a substitute for the down conductor.

(b) Two or more poles supporting an overhead ground wire connected to the earth electrode system with a down conductor at each pole.

31. INTEGRAL PROTECTION SYSTEM. When designing and installing an integral lightning protection system, perform the following:

a. Provide a lightning protection system that shall meet the requirements of NFPA 780, Lightning Protection Code; UL 96A, Underwriter's Laboratories (UL) Installation Requirements Master Labeled Lightning Protection Systems; and as specified herein. All equipment shall be UL approved for use as part of a master labeled lightning protection system, and marked in accordance with UL procedures.

b. Provide air terminals for all parts of a structure that are likely to be damaged by direct lightning strikes. Air terminals shall be erected on the structure as required by NFPA 780 and hereinafter in this order. Metal parts of a structure that are exposed to direct lightning strikes and have a metal thickness of 3/16 inches (4.8 mm) or greater are connected to the lightning protection system with main size conductors and bonding plates which have a minimum of 3 square inches of contact.

c. Install roof and down conductors so that they provide a two way path from each of the air terminals (except where NFPA 780 permits one way paths and dead ends) and offer the least possible impedance to the passage of stroke currents between the air terminals and the earth and provide the most direct path to the earth electrode system.

d. Distribute ground connections symmetrically about the perimeter of the structure rather than grouping to one side.

e. Interconnect all metal objects within six feet of the discharge path to prevent side flashes. Representative connections are shown in Figure 2-12.

32. AIR TERMINALS. The intent of air terminals is to intercept any lightning stroke that might otherwise strike the building or structure being protected.

a. Size and Materials. Air terminals shall be UL approved and shall be solid copper, aluminum, or bronze. Copper air terminals may be nickel plated. The minimum sizes are 1/2-inch

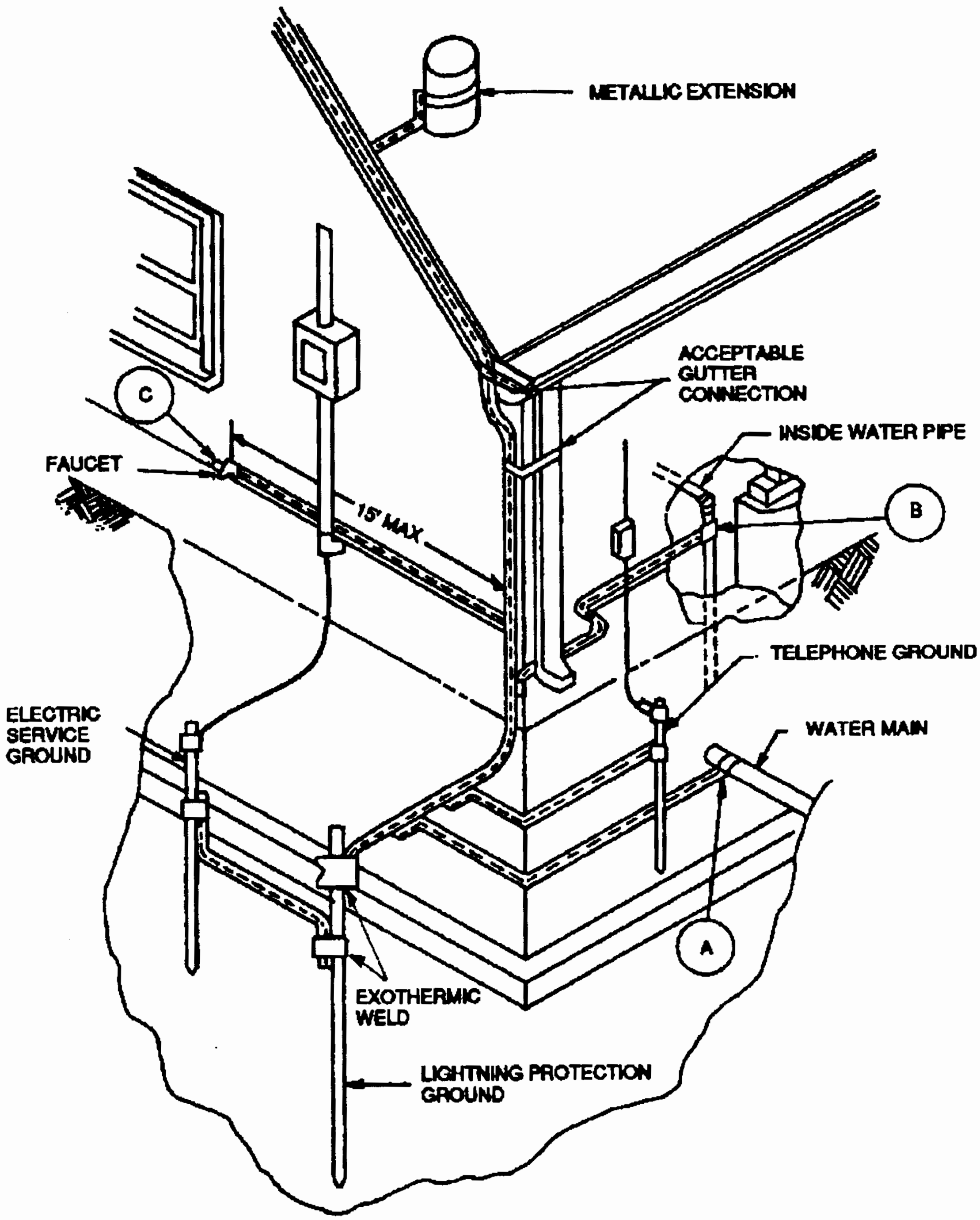


FIGURE 2-12. GROUNDING PRACTICES FOR LIGHTNING PROTECTION

(12.7 mm) in diameter for solid copper or bronze air terminals and 5/8-inch (15.9 mm) in diameter for solid aluminum air terminals. Air terminals shall have rounded or blunted tips for safety.

(1) Air terminals must extend at least 10 inches (250 mm) above the object being protected. Rather than arbitrarily choosing the shortest terminal which will provide this minimum height, all parts of the structure must be checked graphically or analytically in the manner described in the next section to determine if the zone of protection provided by the air terminal is adequate. Likewise a longer air terminal should not be arbitrarily selected. Where taller air terminals are required to provide complete protection, support and bracing as required by NFPA 780, Lightning Protection Code must be provided.

NOTE: Where a personnel injury risk exists, such as areas where maintenance activities are regularly performed, the tip of the mid-roof air terminals shall be not less than 5 feet above the walking or working surface.

(2) All air terminals shall be secured against overturning either by attachment to the object to be protected or by means of braces which shall be permanently and rigidly attached to the building. An air terminal exceeding 24 inches (0.6 m) shall be supported at a point not less than one-half its height.

(3) An ornament or decoration on a free-standing, unbraced air terminal shall not present, in any plane, a wind-resistance area in excess of 20 square inches (0.01 square meter). This will permit the use of a copper or aluminum ball 5 inches (127 mm) in diameter to be mounted at the top of the air terminal as a means to prevent the electrostatic discharge from interfering with communications equipments in facilities.

b. Location.

(1) Locate air terminals along the ridges of gable, gambrel, and hip roofs in the manner illustrated in Figure 2-13.

(2) Place air terminals on corners and along the edges of gently sloping roofs as shown in Figure 2-14. Gently sloping roofs are defined as (1) having a span of 40 feet (12 m) or less with a pitch (rise-to-run ratio) of less than one-eighth or (2) having a span of greater than 40 feet (12 m) and a pitch of less than 1/4. Where gently sloping roofs exceed 50 feet in

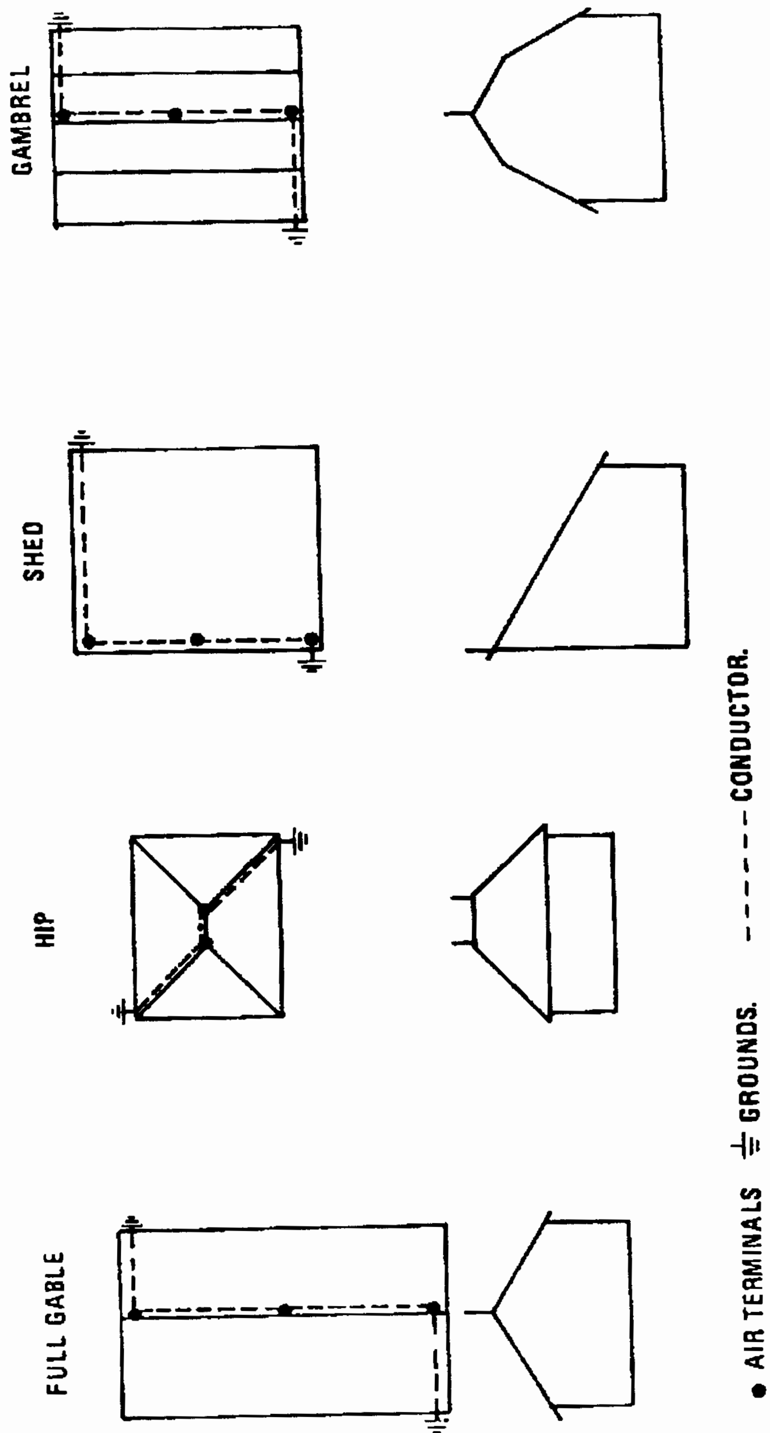


FIGURE 2-13. LOCATION OF AIR TERMINALS FOR COMMON ROOF TYPES

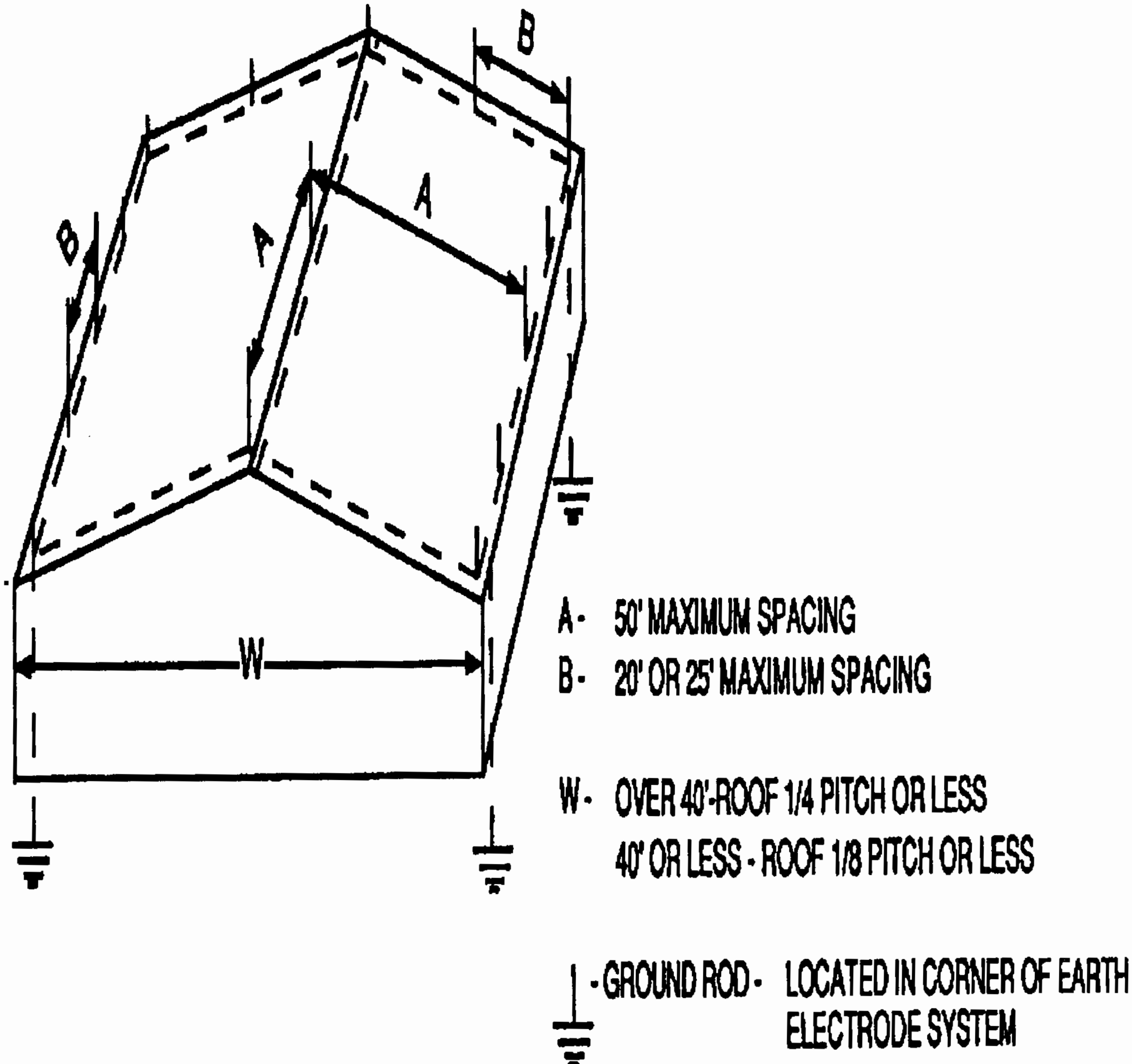


FIGURE 2-14. LOCATION OF AIR TERMINALS ON GENTLY SLOPING ROOFS

length or width, provide additional air terminals located at spacings not to exceed 50 feet (15 m) on the gently sloping area. In addition, if the roof has a width of over 20 feet, an air terminal shall be located at the ridge ends regardless of the pitch or span.

(3) On flat roofs, position air terminals around the perimeter in the manner shown in Figure 2-15. Provide additional air terminals placed at 50 foot (15 m) intervals over the

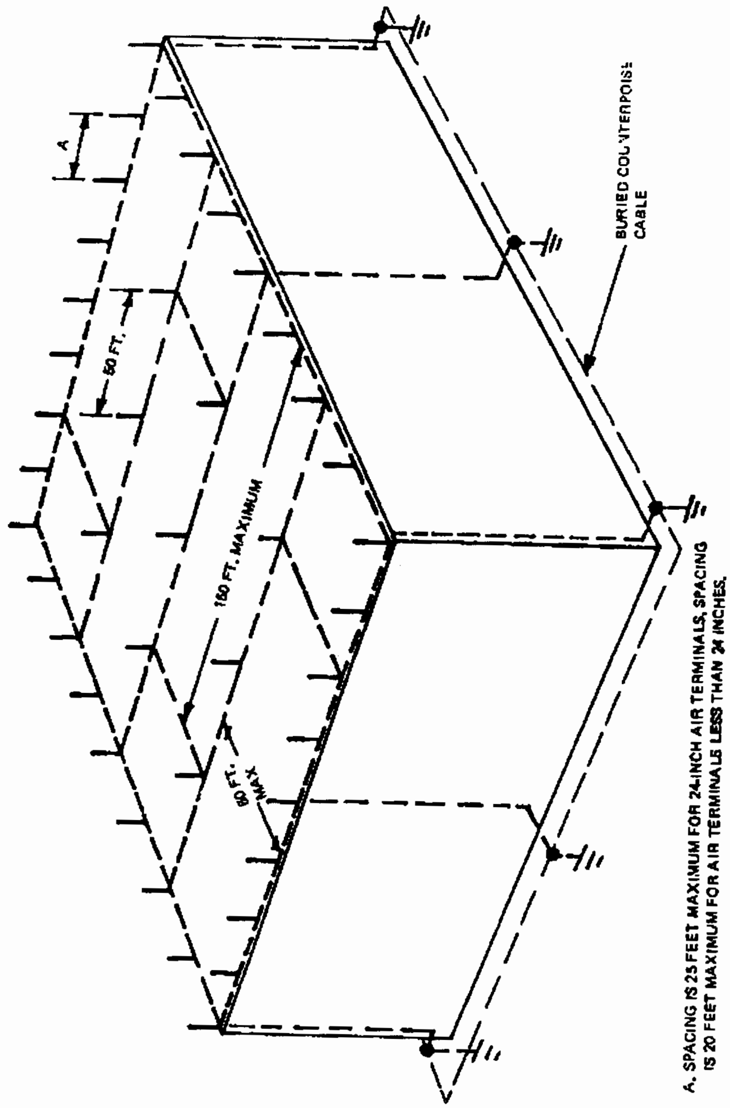


FIGURE 2-15. AIR TERMINAL PLACEMENT ON FLAT-ROOFED STRUCTURES

interior of the flat roofs which exceed 50 feet in length or width. (SAFETY NOTE: Where a personnel injury risk exists, such as areas where maintenance activities are regularly performed, the tip of the mid-roof air terminals shall be not less than 5 feet above the walking or working surface.)

(4) Air Terminals shall be placed at or within 2 feet (0.6 m) of the ends of ridges or ends and corners of roofs.

(5) The height of air terminals shall be such as to bring the tip of the air terminal not less than 10 inches (254 mm) above the object to be protected for 20 foot (6 m) maximum intervals and not less than 2 feet (0.6 m) above the object to be protected for 25 feet (7.6 m) maximum intervals.

c. Zones of Protection. The zone of protection is that space adjacent to a lightning protection system that is substantially immune to direct lightning flashes. Ensure that no part of the structure extends outside the zone of protection established by the air terminals. Determine the zone of protection using the criteria in NFPA 780, Lightning Protection Code (additional guidance may be found in Standard of Practice LPI-175 of the Lightning Protection Institute). Structures that do not exceed 50 feet (15 m) above the earth may utilize the following:

(1) Protection for structures that do not exceed 25 feet above earth are considered to protect lower portions of a structure located in a one-to-two zone of protection and structures that do not exceed 50 feet (15 m) above earth are considered to protect lower portions located within a one-to-one zone of protection.

(2) Prominent projections, such as dormers, which are as high or higher than the main ridge shall be protected with air terminals, conductors and grounds as normally specified for a roof installation. Roof projections and dormers below the main ridge may be protected by a "dead ended" air terminal with only one path to a main conductor, provided the run from the air terminal to a main conductor is not more than 16 feet (4.9 m) in total length and maintains a horizontal or downward coursing.

(3) To determine if protection is provided for all parts of a flat roofed structure such as vents, pipes, cabling or raised extensions, use the method illustrated in Figure 2-16 to calculate the zone protected by two vertical air terminals. This method can also be used to determine the coverage provided by vertical masts or horizontal wires. In Figure 2-16, point P represents the point of discrimination (that is, the point of departure of the final stepped leader) of the downward traveling stroke. To determine if the air terminals are actually the nearest objects to point P, use P as a center and swing an arc of radius X through the tips of the terminals. Let the value of this radius X be 150 feet (45 m) as required by NFPA 780. Because of the large differences between the height of typical terminals and the striking distance X, graphical determination of

the protected zone will usually be awkward. For greater accuracy, calculate the critical distances through the use of the

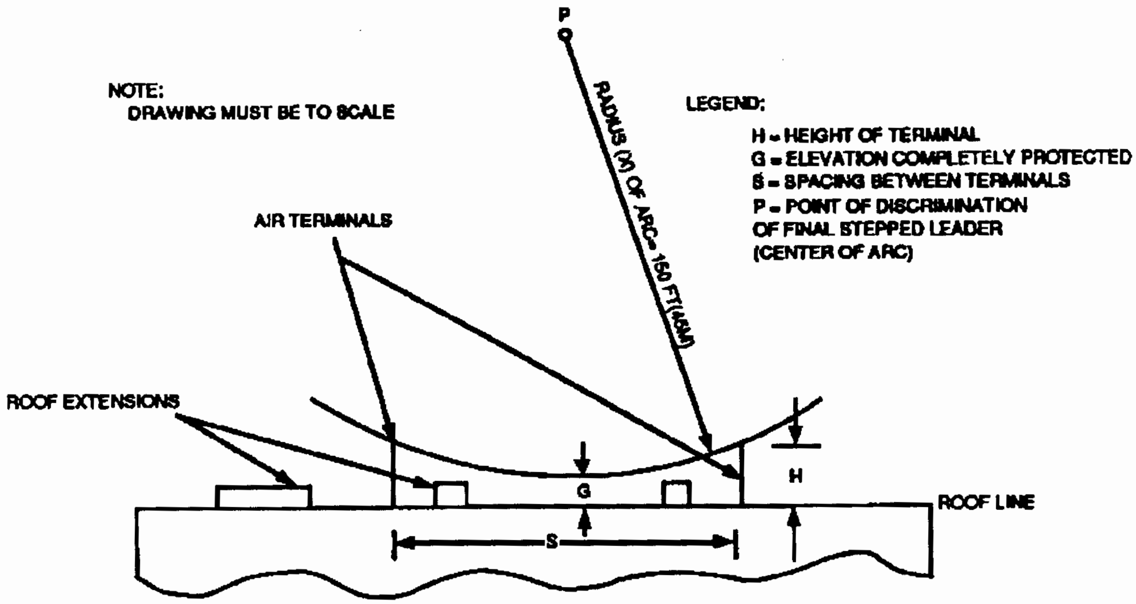


FIGURE 2-16. ILLUSTRATION OF METHOD FOR DETERMINING THE PROTECTION OF FLAT SURFACES AS PROVIDED BY AIR TERMINALS

following equation which is valid for $s \leq 2X$:

$$G = H - X + [X^2 - (S/2)^2]^{1/2}$$

In this equation, G is the height between the two terminals that is completely protected, H is the height of the terminals, S is the spacing between the terminals, and X is the radius of the arc.

(4) Receiving and transmitting antennas, used for air to ground (A/G) communication, shall be included within the zone of protection. The inclusion of all antennas within the zone of protection is a design goal. If it is not technically feasible to include all antennas within the zone, then those antennas not included should have their bases or mountings bonded to the structural lightning protection system. This bond shall be accomplished with main conductors.

33. LIGHTNING PROTECTION CONDUCTORS. Provide each air terminal with a two-way path to earth through the installation of main (roof and down) conductors conforming to the appropriate tables in NFPA 780, Lightning Protection Code; Class I Materials for

structures not exceeding 75 feet (23 m) in height and Class II Materials for structures exceeding 75 feet (23 m) in height. Exceptions to the two-way path are allowable one-way paths (See Par. 34 c) and "dead ends" as defined in NFPA 780. Bonding Conductors shall be sized in accordance with the same tables defining the main cables noted above.

34. ROOF CONDUCTORS.

a. Course roof conductors are situated along ridges of gable, gambrel, shed, and hip roofs; around the perimeter of flat roofs; behind or on top of parapets; and across flat or gently sloping roof areas as required to connect all air terminals. Conductors shall be coursed through or around obstructions (such as cupolas, ventilators, etc.) in a horizontal plane with the main conductor. Roof conductors shall interconnect all air terminals including those on any roof projection (such as chimneys, air handling units, cooling towers, etc.) and shall provide a two way path to ground from the base of the air terminal except where noted in Paragraphs 33 and 34(c) herein.

b. On flat or gently sloping roofs that exceed 50 feet, (15 m) cross-run conductors (main conductors) are required to interconnect the air terminals. For example, roofs from 50 feet (15 m) to 100 feet (30 m) in width require one cross-run; roofs 100 feet (30 m) to 150 feet (46 m) in width require two cross runs; etc. Cross-run conductors shall be connected to the main perimeter cable at intervals not exceeding 150 feet (46 m). See Figure 2-15.

c. One-way path. Air terminals on a lower roof level that are interconnected by a conductor from a higher roof level only require one horizontal or downward path to ground (one-way path), provided the lower roof conductor run does not exceed 40 feet (12 m).

d. Maintain a horizontal or downward coursing with conductors, free from "U" or "V" (down and up) pockets. Such pockets, often formed at low positioned chimneys, dormers, or other projections on sloped roofs, or at parapet walls, shall be provided with a down conductor from the base of the pocket to ground, or to an adjacent down lead conductor. (See NFPA 780 for examples).

e. Route conductors through or around obstructions which lie in a horizontal plane with the main conductor (See Figure 2-17(b), (c), and (e)).

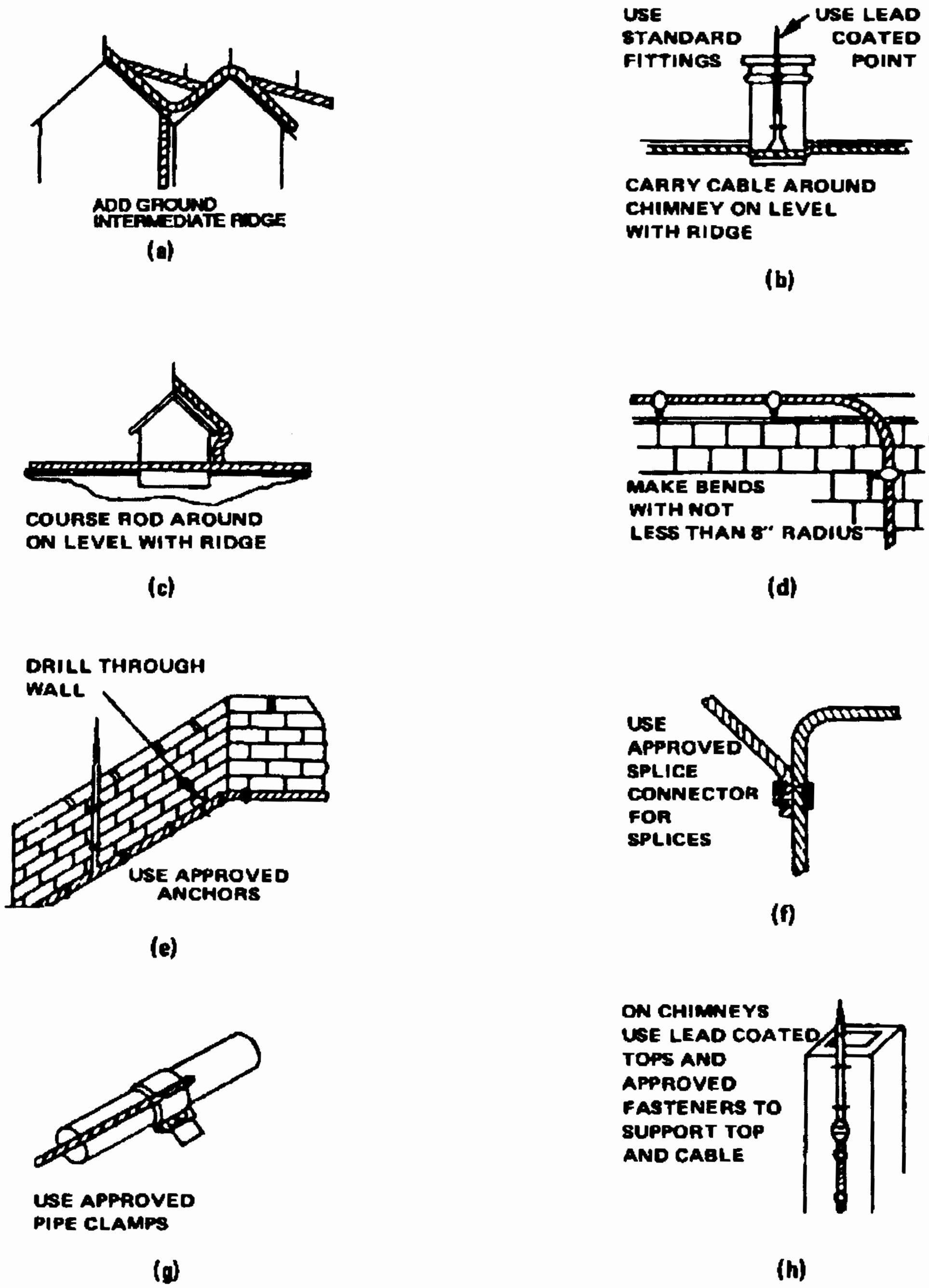


FIGURE 2-17. RECOMMENDED CONSTRUCTION PRACTICES FOR INTEGRAL LIGHTNING PROTECTION SYSTEMS

f. Bends in conductors shall not form an included angle of less than 90 degrees; nor shall it have a radius of less than 8 inches (203 mm). In particular, re-entrant loops shall be avoided. When routing around obstacles, wide gradual bends are preferred.

g. Securely attach the conductors directly to the building or other object upon which they are installed with UL-approved fasteners at intervals not exceeding 3 feet (0.9 m).

h. Conductors may be coursed through air without support for distance not to exceed 3 feet (0.9 m). When conductors must be coursed through air for greater distances, they shall be supported with a positive means of support that will prevent damage or displacement of the conductor.

35. DOWN CONDUCTORS.

a. Course down conductors over the extreme outer portions of the structure and separate them as far as practicable. Their location depends on such considerations as: the placement of air terminals; the most direct coursing of conductors; earth conditions; security against displacement; the location of large metallic bodies; and the location of underground metallic piping systems. Down conductors shall be run on the exterior of the structure, and shall not penetrate or invade the structure except as indicated in Paragraph 38, Antenna Towers. Where deemed necessary for the appearance of the structure, the down conductors may be installed in PVC conduits.

b. Locate down conductors as close as practical to air terminals that provide the most direct coursing of the down conductors from the air terminals to ground rods in the earth electrode system of the structure and security against displacement.

c. At least two down conductors shall be provided on any kind of structure except on slender objects such as flag poles, antenna masts, light poles, and pole type towers.

d. Structures exceeding 250 feet (76 m) in perimeter shall have a down conductor for every 100 feet (30 m) of perimeter or fraction thereof. The total number of down conductors on structures having flat or gently sloping roofs shall be such that the average distance between all down conductors does not exceed 100 feet (30 m). Irregular-shaped structures may require additional down conductors in order to provide a two-way path from each air terminal. Only the perimeter of the roof requiring protection will be measured in determining the perimeter of a structure. Lower roofs or projections that are located within a zone of protection are to be excluded.

e. Maintain down conductors in a downward course with the routing around or through any obstruction which may lie in its path. Sharp bends or turns shall be avoided with necessary bends limited so that the included angle shall not be less than 90 degrees nor shall the radius of the bend be less than 8 inches (200 mm). This radius requirement is not applicable where approved clamps or connectors are used to accomplish the cable bend.

f. On structures with overhangs such as antenna towers with extended platforms run the down conductors vertically through the platform and down the inside edge of the tower leg where practical.

g. Protection shall be provided for down conductors located in runways, driveways, public walks, or other similar locations to prevent damage or displacement. The down conductor shall be protected for a minimum distance of 6 feet (1.8 m) above grade level. Down conductors shall be run through footings such as at the base of radar or communications towers in 1" heavy wall plastic conduits.

h. Where UL-approved down conductors are installed in corrosive soil precautions are needed to prevent deterioration of these conductors. The UL approved cable, because of the size and type of strands utilized, is more susceptible to corrosion than the 4/0 AWG copper cable used in the counterpoise. The down conductor may be protected against corrosion in the following ways:

NOTE: The following types of installations shall only be made in locations where the soil is known to be corrosive. It is the exception, not the rule and SHALL NOT be utilized in areas where the soil is not corrosive.

(1) Provide a protective coating to the down conductor from 3 feet (0.9m) above grade level and extending for its entire length below grade in accordance with NFPA 780.

(2) A 4/0 AWG bare stranded copper cable may be substituted for the underground portion of the UL approved down conductor from the ground rod to 18 inches (0.45 m) above ground level. Exothermic welds shall be used at both ends of this 4/0 AWG cable. The mold for welding the 4/0 AWG cable to the lightning protection cable shall be specifically designed for the welding of these cables. Molds for standard AWG stranded copper cable are not satisfactory and shall not be used to weld these types of cables together.

36. FASTENERS.

a. Conductors shall be securely fastened to the building or other object upon which they are placed, at intervals not exceeding 3 feet (0.9 m) with approved type fasteners. The fasteners, attached by nails, bolts, or adhesives as necessary, shall not be subject to breakage and shall be of the same material as the conductor or of a material equally resistive to corrosion as that of the conductor. No combination of materials shall be used that forms an electrolytic couple of such nature that, in the presence of moisture, corrosion will be accelerated. Galvanized or plated materials shall not be used.

b. Masonry anchors shall have a diameter of not less than 1/4 inch (6.4 mm) and shall be set in correctly sized holes made with proper tools and preferably made in the brick or stone rather than in mortar joints. The anchors shall be installed to fit tight so as to exclude the accumulation of moisture and the possible resultant effects of frost.

c. Connector fittings shall be used on all lightning conductors at "end-to-end", "tee", or "Y" splices. They shall be attached so as to withstand a pull test of 200 pounds (890 N). Fittings for connection to metal tracks, gutters, downspouts, ventilators, or other metal parts of the structure shall be made tight to the object by compression under bolt heads or by exothermic welds. High compression, bolted or welded connectors are acceptable for splices. Crimp type fittings shall not be used.

37. SEPARATELY MOUNTED PROTECTION SYSTEM.

a. Mast Type.

(1) No part of the structure being protected shall extend outside of the protected zone of the lightning protection mast. This zone of protection shall be as calculated by the procedure defined in NFPA 780, Lightning Protection Code for Rods and Masts under Protective Measures.

(2) Where it is impractical for a common mast to provide protection for an entire structure, additional masts or other means of protection shall be provided.

(3) An air terminal shall be mounted on the pole so that it extends not less than 2 feet (0.6 m) nor more than 3 feet (0.9 m) above the top of the pole. The air terminal shall be attached and supported on the pole with appropriate fittings and shall have an UL approved terminal for connection to the down conductor.

(4) <u>A down conductor</u> shall be run from the connector on the base of the air terminal to the earth electrode system of the protected structure. The down conductor shall be fastened to the pole with appropriate fittings at intervals not exceeding 3 feet (0.9 m). (Steel or other metal poles shall be considered a support for the air terminal and NOT a part of the air terminal).

b. <u>Overhead Ground Wire Type</u>.

(1) <u>Overhead ground wires shall</u> be installed so as to provide the Zone of Protection as defined in NFPA 780. Overhead ground wires shall be main conductor cables as required for the class of structure. If the poles are of a non-conducting material, an air terminal shall be mounted on the top of each pole, extending not less than 2 feet (0.6 m) nor more than 3 feet (0.9 m) above the top of the pole. Down conductors shall be run from the fittings on the bottom of the air terminal to the earth electrode system. These down conductors shall be fastened to the pole at intervals not exceeding 3 feet (0.9 m). Overhead ground wires shall be dead-ended on the pole and shall be connected to the down conductor with an appropriate UL approved connector. Where a guy wire is used on the pole installation, it shall also be connected to the down conductor and overhead ground wire, as shown in Figure 2-18. Where masts are of conducting materials, the air terminal may be omitted. However the overhead ground wire, down conductor, and where required, the guy wire shall be utilized and connected together as for the non-conducting pole. Additional guidance is provided in the Lightning Protection institute Standard of Practice LPI-175, Section on Masts and Overhead Cables.

(2) <u>The height of the poles</u> shall be sufficient to provide a clearance of not less than 6 feet (1.8 m) between the overhead ground wire and the highest projection of the structure being protected.

(3) <u>Poles shall be placed</u> not less than 6 feet (1.8 m) from the structure for either the mast type or the overhead ground wire type of system. This distance shall be increased as necessary and defined by NFPA 780 to prevent side flashes to the structure being protected.

38. <u>ANTENNA TOWERS</u>. Antenna towers shall be provided with lightning protection in accordance with the following:

a. <u>Number of down conductors</u>. Metal pole type towers shall have one down conductor. The down conductor shall be bonded to the metal antenna pole near its base on the tower with an approved type bonding plate or clamp. Towers which consist of multiple, parallel segments or legs which sit on a single pad, or

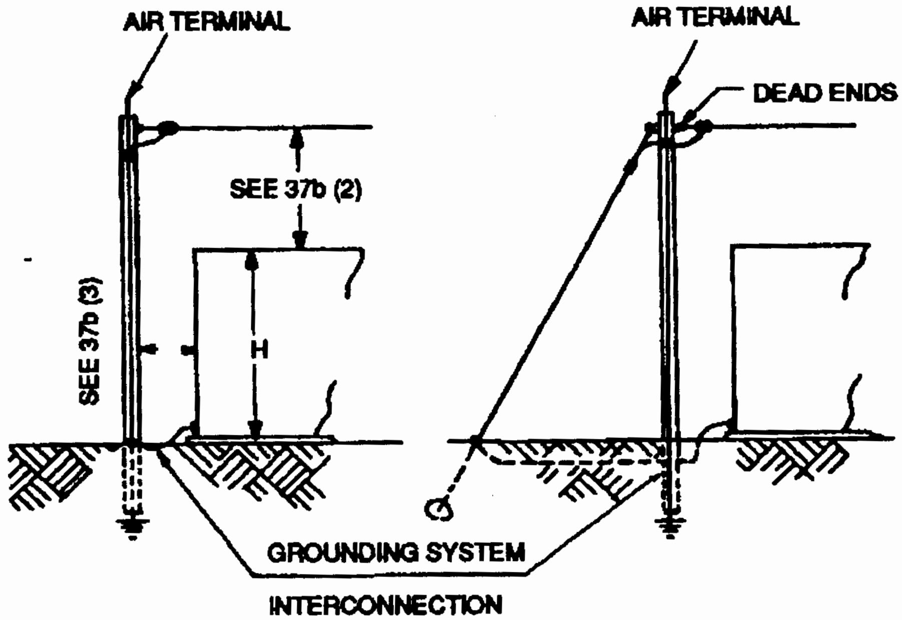


FIGURE 2-18. OVERHEAD GROUND WIRE LIGHTNING PROTECTION SYSTEM

footing, less than 9 square feet in area, are considered as pole type towers. Three and four leg towers shall have two down conductors. Down conductors shall be routed down the inside of tower legs wherever possible. The down conductors shall be fastened at intervals not exceeding 3 feet (0.9 meter) in accordance with Paragraph 36.

b. Towers without radomes. Towers without radomes shall be protected by one or more air terminals as required to provide a Zone of Protection that is in accordance with NFPA 780 for all antennas on the tower. Protection may be provided for large radar antennas by extending structural members above the antenna and mounting the air terminals at the top of the structural members with appropriate clamps and fittings. The structural member shall be braced as required and shall not be used as part of the air terminal or in lieu of the down conductor. The air terminal shall have an UL approved type fitting on its base for connection to a down conductor. The down conductors from the air terminals shall be bonded to a conductor installed around the perimeter of the antenna platform. Two down conductors shall be connected to the tower platform perimeter conductor and run down opposite legs of the tower on the inside of the tower leg where practicable, to the earth electrode system. The down conductors shall be fastened to the air terminal structural support and to the tower legs at intervals not exceeding 3 feet (0.9 m) with approved type fasteners. All connections between the main size conductors shall be with approved type connectors. All conductors shall be UL approved and shall be main size conductors meeting the requirements of NFPA 780.

c. Towers with spheroidal radomes. Regardless of the specific orientation of air terminals used to protect a radome two absolute requirements must be met: 1) an air terminal must be mounted within 2 feet of the apex of the radome unless protected by a system external to the radome, and 2) the entire radome must lie within the "zone of protection" established by the air terminals. Specific data on calculating the "zone of protection is in NFPA-78. Depending upon the overall height and configuration of the structure this may be accomplished with a single 2 foot air terminal at the radome peak and four additional air terminals placed around the structure to establish a zone of protection based on a 150 foot radius arc which includes all portions of the radome structure. A minimum of two down conductors shall be routed from the air terminal at the peak of the radome, following the curve of the radome, to a perimeter cable that forms a closed loop around the base of the radome. Electrically continuous radome framing (not zigzagged) may be used in lieu of these two down conductors.

Air terminals around the base of the radome shall be connected to the perimeter loop. A single run of down conductors shall be routed from each of these air terminals to the perimeter loop. Where dome construction permits, and where advantageous for establishing a zone of protection including all portions of the radome, four additional air terminals spaced around the circumference of the radome may be positioned down from the peak. These air terminals shall be interconnected with main size conductor. This loop, the perimeter loop and the air terminal at the peak of the radome, shall be interconnected with two down conductors. The perimeter cable shall be incorporated as a part of the structural lightning protection system if located on a building. If on a free standing tower it shall be connected to the earth electrode system with two down conductors. All of the above conductors shall be main size conductors meeting the requirements of NFPA 780 for the class of structure. All fittings, connectors, etc., used in the installation of the lightning protection system on towers shall be UL approved. All lightning protection conductors shall be supported with approved fittings at intervals not to exceed three feet (0.9m).

39. FENCES.

a. Fences and Gates.

(1) Fences made of conducting materials; i.e. chain link fabric, metal crossbar, stranded wire, shall be constructed using metal posts which extend a minimum of 2 feet (0.6 m) below grade.

(2) Gates shall be bonded to the adjoining fence posts with a flexible tinned 1 inch (2.54cm) by 1/8 inch (32mm) copper strap. The posts at each side of the gate opening shall be bonded together with a 2/0 AWG bare copper cable. Bonds to these posts shall be made 6 inches (15.25 cm) above grade.

(3) Metallic fence fabric with non-conducting coatings shall not be used.

b. Where overhead power lines cross a fence constructed of conducting material, the fence shall be bonded with a bare #6 AWG copper conductor. This conductor shall be bonded to the top, middle and bottom of any fence fabric and to each strand of security wire above the fabric. On fences constructed of cross bars, stranded wire, etc the conductor shall be bonded to each horizontal element. This bond shall be made a minimum of 20 feet to each side of the power line crossing and the two bonds interconnected with a buried #6 AWG bare copper conductor.

c. In areas having a high (i.e. above 50) isokeraunic level, the following may be used in lieu of the above.

(1) All gates in the fence shall be grounded by connection to a grounded adjoining fence post. The fence post on each side of the gate shall be bonded to a 3/4-inch (190 mm) diameter by 10 feet (3 m) long ground rod with a No. 2 AWG copper conductor. The ground rods on each side of the gate shall be bonded together with a No. 4/0 AWG bare stranded copper conductor. The gate post shall be bonded to the adjoining fence post with a flexible tinned copper strap 1 inch (2.54 cm) by 1/8-inch (32 mm) by length as required for allowing free movement of the gate without damage to the strap. All connections noted above shall be exothermic welds.

(2) Where overhead power lines cross a fence, a bare No. 6 AWG solid copper conductor shall be bonded to the bottom,

middle and top of the fence material, each strand of security wire and at each cross bar. This wire shall be bonded to a No. 2 AWG copper cable which in turn shall be bonded to a 3/4-inch (190 mm) diameter by 10 feet (3 m) long ground rod installed a minimum of 20 feet to each side of the powerline crossing. The ground rods shall be bonded together with a No. 4/0 AWG bare stranded copper conductor. The above ground rod connections shall be made with exothermic welds.

d. Where fences are in within 6 feet of any element bonded to the facility earth electrode system, the fence ground rods must be bonded to the facility earth electrode system with No. 4/0 AWG bare stranded copper conductors. All connections noted above shall be by exothermic welds.

40. GUYED TOWERS. To provide improved lightning protection, all metallic guy wire systems without isolators should be grounded. These provisions prevent primary lightning currents from discharging through reinforced concrete anchors, and from passing through tension adjustment components (i.e. turnbuckles). The intent is to provide a low impedance path to ground; and to prevent damage to the guy wire system.

a. CONCRETE OR OTHER ANCHORS WITH LOW CONDUCTIVITY. A jumper, of the same material as the guy wire, should be mechanically bonded to each guy wire above the lowest turnbuckle. Where there is more than one guy wire to a single anchor point, the single jumper should daisy chain through the guy wires. This jumper is exothermically or conventionally welded to a UL approved 3/4 inch by 10 foot ground rod driven near the anchor point. Mechanically bonded jumpers should also be placed across any intermediate turnbuckles, where feasible.

b. METALLIC ANCHORS. A jumper, of the same material as the guy wire, should be mechanically bonded around the turnbuckle to provide an alternate current path for metallic (screw type, etc.) anchors. Mechanically bonded jumpers should also be placed across any intermediate turnbuckles, where feasible.

c. ALTERNATE METHODS. On existing guyed towers, the jumpers described above can be constructed with any metallic material which will not create a electrolytic cell (dissimilar metals) with the guy wire material, and which can be welded to the required ground rod. Typically these materials include stainless wire rope, galvanized steel rope or cable, or tinned copper wire.

41. BONDS AND CONNECTORS. All metal objects subject to the effects of lightning shall be bonded to the lightning protection

system and all items comprising the lightning protection system (i.e., air terminals, main conductors, secondary conductors, earth electrode system, metal bodies subject to side flashes or direct strikes, etc.) shall be bonded together with connectors approved for the purpose of accomplishing electrical continuity throughout the entire lightning protection installation.

a. Metal Bodies.

(1) Certain metal bodies located outside or inside a structure contribute to lightning hazards because they are grounded or assist in providing a path to ground for lightning currents, or because they may effect the bonding requirements for other metal bodies. Such metal bodies shall be bonded to the lightning protection system in accordance with the requirements of NFPA 780, Lightning Protection Code. The following guidance can be used as a minimum:

(a) Metal bodies subject to a side flash (formerly known as Bodies of Inductance) are metal bodies located within 6 feet of a conductor subject to build-up of potential due to lightning currents and shall be bonded at their closest point to the lightning protection system using secondary UL-approved conductors and UL approved fittings.

(b) Metal bodies at or above the eave or flat roof level of a structure and subject to a direct lightning strike (formerly known as Bodies of Conductance) having a area of 400 square inches (0.26 square meters) or greater, a volume of 1,000 cubic inches (0.016 cubic meters) or greater, or a metallic object of a height equal or higher than adjacent air terminals, shall be bonded to the lightning protection system, unless entirely located within the zone of protection of the structures lightning protection system. The bonding of the metal body shall use main size cables connected to the metal objects with a bonding plate of similar metal having a contact surface area of not less than 3 square inches (1940 square mm) and shall provide a two-way path to ground as required for air terminal.

b. Antennas. Antenna masts of metal, located on a roof of a protected structure, shall be bonded to the lightning protection system with a main size conductor and fittings. Antenna masts shall not be used in lieu of air terminals. In general, communication antennas should be located in the Zone of Protection of the air terminals on the structure. Care must be taken to avoid interference with the communications antennas. Spacing distances between the antennas and the air terminals may be needed to avoid noise problems due to electrostatic fields. The required locations of the air terminals must be maintained.

Where noise problems occur and spacing is a problem, these problems may be reduced by the installation of copper balls (corona balls) not exceeding 5 inches (127 mm) in diameter and mounted at the top of the air terminal. Other static dischargers, consisting of metal rods, supported from metal crossarms mounted near the top of the air terminal, are available and may be used in lieu of the corona balls.

c. Structural Steel Framing. The structural steel framework of a building, can be used as the main conductor, if it is electrically continuous, per NFPA 780 paragraph 3-19-1. Ground connections from the structural steel of the building shall be made at approximately every other steel column around the perimeter of the building and shall not average over 60 feet (18 m) apart, with a bare No. 4/0 AWG stranded copper cable. Ground terminals shall be attached to the steel columns at the lowest possible point, with bonding plates having a surface contact area of not less than 8 square inches (5200 square mm) securely bolted or welded to cleaned areas of the structural steel column.

42. ELECTROLYTIC COUPLES AND CORROSION CONTROL.

a. The materials from which lightning protection systems are made must be highly corrosion resistant. Junctions or contacts between dissimilar metals must be avoided; where such unions are unavoidable, moisture must be permanently excluded from the contact surfaces.

b. Where any part of a copper protective system is exposed to the direct action of chimney or other corrosive gases, the exposed copper elements are to be protected by a continuous hot dip coating of lead. The coating should extend for at least 2 feet (0.6 m) below the top of the chimney or past the vent or flue opening.

c. Copper lightning protection materials shall not be installed on aluminum roofing, siding or other aluminum surfaces.

d. Where aluminum systems are installed, they shall be installed in accordance with the following:

(1) Aluminum materials shall not be used where they come in direct contact with the earth. Fitting for connection of aluminum down conductors to copper risers from the earth electrode system shall be bimetallic connectors. These bimetallic connectors shall be installed not less than 18 inches (457 mm) above finished grade level.

(2) Aluminum lightning protection equipment shall not be installed on copper roofing materials, or other copper surfaces, or where exposed to run-off from copper surfaces.

(3) An aluminum conductor shall not be attached to a surface coated with alkaline-base paint, embedded in concrete or masonry, or installed in a location subject to excessive moisture.

(4) Lightning protection systems utilizing aluminum materials shall not use connectors of copper, copper-covered, or copper-alloy fittings. Where aluminum must connect to copper, only UL approved bimetallic connectors shall be used. Where incidental contact with aluminum surfaces is unavoidable, the use of tinned copper will reduce the galvanic action of the electrolyte couple on the copper.

43. INSTALLATION AND MATERIALS. This section on Lightning Protection is not intended to allow any violations of the Lightning Protection Code, NFPA 780. NFPA 780 shall be used in all designs and installations as the minimum criteria and any differences noted herein are intended to be used where the FAA has definite needs and requirements that exceed the requirements of NFPA 780.

a. All equipment used in the installation of lightning protection systems shall be UL approved and labeled in accordance with UL procedures. Each air terminal shall bear an "A" label and all main conductors shall bear "B" labels at 10 foot intervals.

b. All equipment shall be new and of a design and construction to suit the application where it is used, in accordance with NFPA-78 and UL 96 requirements.

c. All materials shall be copper, bronze, aluminum, or stainless steel of a size, weight and construction to meet the requirements of the class of structure to be protected.

d. All air terminals shall be solid, round, copper, aluminum, or stainless steel bar of 1/2 inch diameter or greater.

e. The installation should be accomplished by an experienced installer listed with UL as qualified.

44. - 49. RESERVED.

SECTION 3. GROUNDING NETWORKS FOR NEW FACILITIES

50. GENERAL. Electronic facilities require separate grounding systems for the electronic equipment and the power distribution system. The electronic equipment grounding systems are to control system noise, electrostatic discharge (ESD), lightning related surges of electromagnetic interference (EMI), and to establish signal return paths between the source and load. The power distribution grounding system is for the protection of the equipment and personnel from hazards, such as direct short or arc faults, in the power distribution system or its related electronic equipment.

The electronic grounding system will consist of a network of conductors, bars and plates configured in a manner to produce the reference plane characteristics most appropriate for the frequencies employed by the electronic equipment. The use of low frequency electronic equipment requiring a single point grounding system shall be avoided where possible. When this is not possible, the single point grounding system shall be as described in Paragraph 51a. The high frequency electronic equipment utilizes a multipoint grounding system as described in Paragraph 51b. The power distribution grounding system will be as described in Paragraph 52 and shall be in accordance with the requirements of the NFPA 70, National Electrical Code (NEC). The electronic systems grounding networks shall NOT be used in lieu of the power grounding systems under any condition. The combined grounding that may be used in a typical facility is described in Paragraph 53.

51. ELECTRONIC EQUIPMENT GROUNDING SYSTEMS.

a. Electronic Single Point Ground System. This ground system provides a single point reference for equipment designs requiring single point grounds to minimize power frequency noise and provide control of static buildup.

Electronic single point ground systems may significantly increase the susceptibility of equipment to lightning related damage in areas of high isokeraunic activity. This increase in susceptibility is due to the possibility of significant differentials in voltage reference levels during lightning incidents. Use of single point grounding may necessitate transient protection on individual equipment.

It is essential that the single point ground system in a facility be designed and installed in a manner that controls interference coupling (Order 6950.20). Not all system noise problems will be solved even with correctly designed ground systems. Additional measures such as reducing the levels of the sources of interference through shielding, filtering, or alternative designs; common-mode rejection techniques; and various other control techniques will frequently be necessary in order to limit the noise level in system circuits to a non-interfering level.

(1) Configuration. Configure the single point grounding system for an electronic facility as an isolated system like that shown in Figure 2-19. The principal components of the network are identified in Figure 2-20. Equipment manufacturers will make final determination of single point ground versus multipoint ground for their equipment.

(a) Install a main ground plate in the electronic facility to provide a single point of interconnection between the single point ground system, the multipoint ground system, and the earth electrode system. (NOTE: The main ground plate is an extension of the earth electrode system (EES) within thefacility. It is not a part of either the electronic single point or the electronic multipoint ground system but rather a part of the facility EES.)

(b) Install a trunk ground cable between the main ground plate and the branch ground plates located throughout the electronic facility.

(c) Provide branch ground cables extending from the branch ground plates to the feeder ground plates centrally located in rooms or areas near electronic equipment.

(d) Connect the single point or points (Chapter 4) within each electronic equipment to the feeder ground plates with insulated conductors. These may be isolated terminals on the electronic equipment case or an isolated ground bus mounted in the electronic equipment.

(e) Adapt the ground system to meet the needs of the facility. If the facility is large and complex with low frequency electronic equipment distributed throughout, then the ground system should be configured to reach into all pertinent areas. On the other hand, if the low frequency electronic equipment is located in one specific limited area, then it is only necessary to extend the ground system into that area. Similarly, a small facility having no low frequency electronic equipment installed would obviously not require such a ground system. The main ground plate is always required.

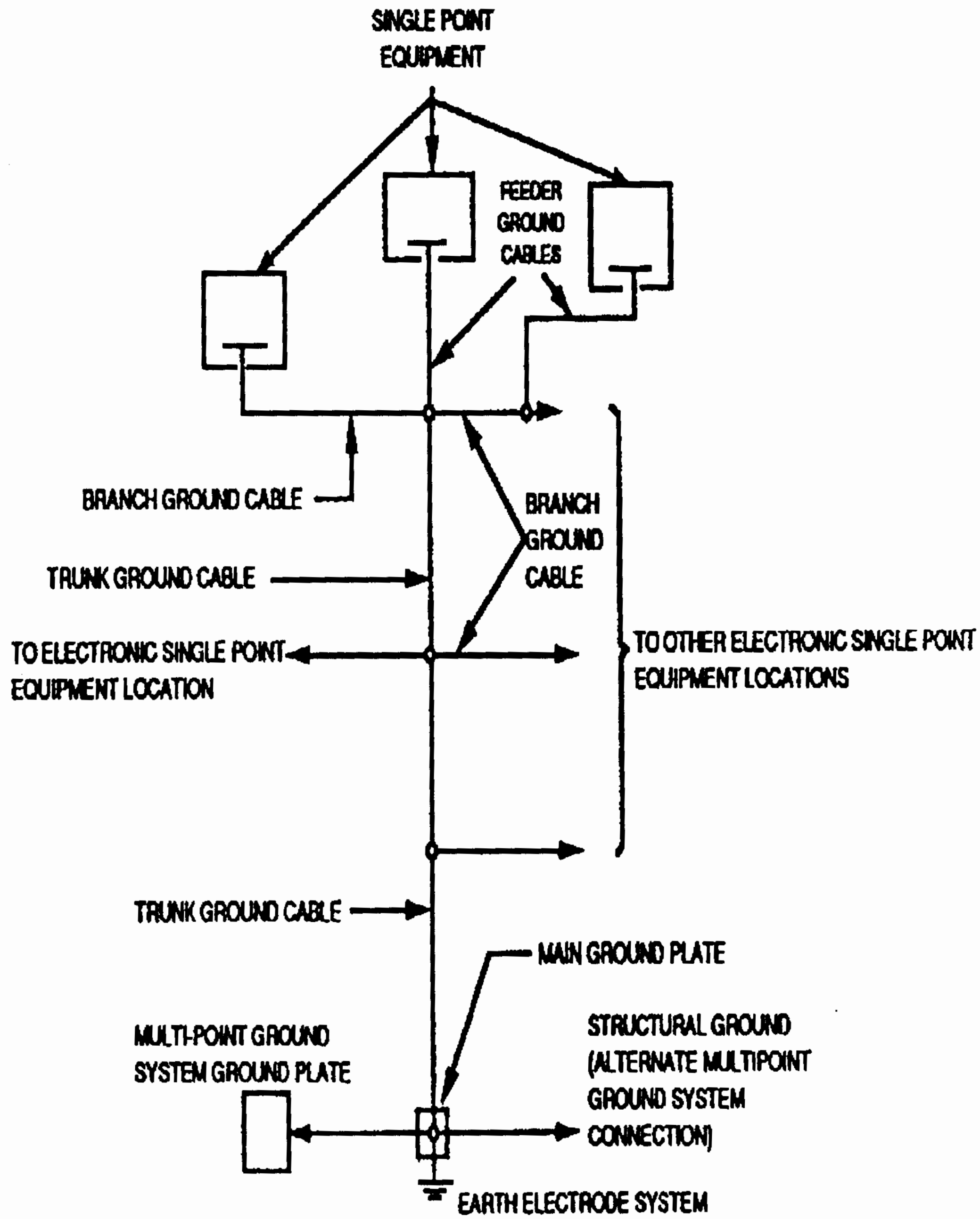


FIGURE 2-19. DIAGRAM OF THE SINGLE POINT GROUND SYSTEM

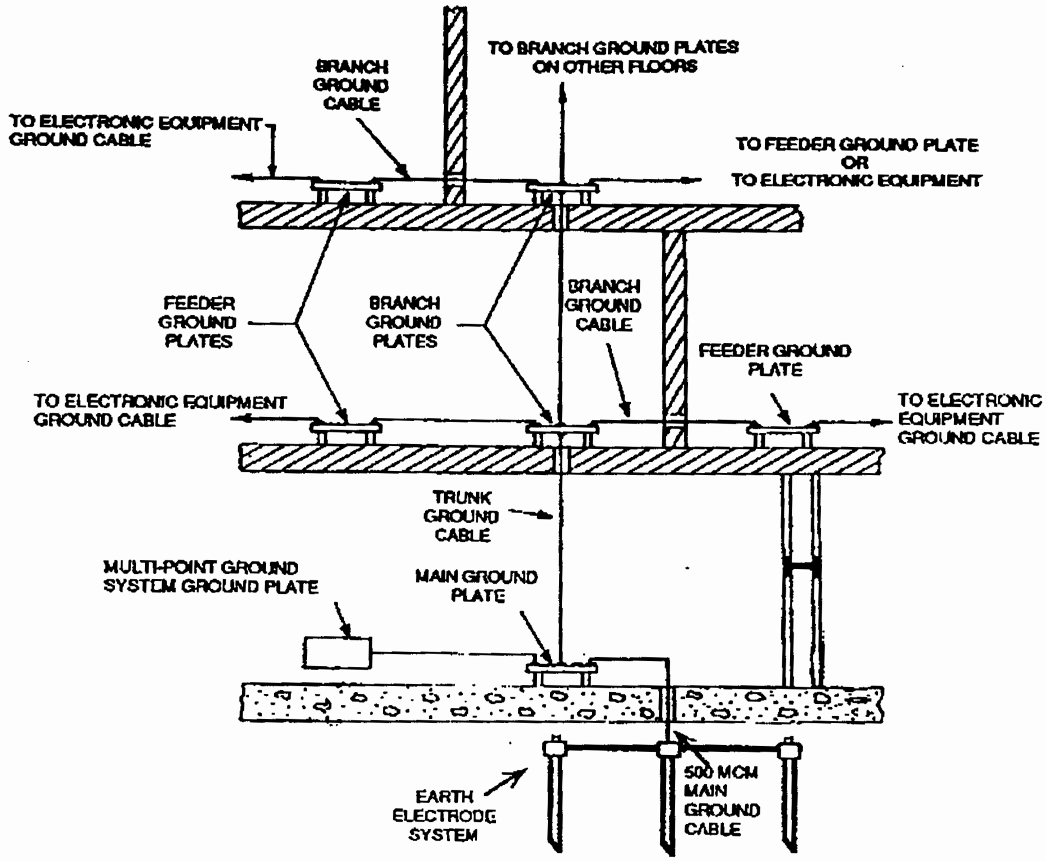


FIGURE 2-20. SINGLE POINT GROUND SYSTEM INSTALLATION

(2) Single Point System Ground Plates. The ground plates of the electronic single point ground system shall be of high conductivity copper. The ground plates must be isolated, and shall be securely mounted on phenolic or other nonconductive material of sufficient cross section to rigidly support the plates, after all ground cables are connected to the plate. Bolts or other devices used to secure the ground plates in place shall be insulated or shall be of a nonconducting material. The ground plates shall be mounted in a manner that provides ready accessibility for future inspection and maintenance. The mounting and minimum size of the ground plates are illustrated in Figure 2-21.

(a) Main Ground Plate. The main ground plate shall be located so as to be readily accessible and convenient for the connection to the earth electrode system, as well as to the branch ground plates.

(b) Branch Ground Plates. The branch ground plate shall be installed in each area containing low frequency electronic equipment to provide a convenient point for interconnecting the trunk ground cable with the branch ground cable. If installed in a multistory building, a branch ground plate shall be installed on each floor or in each major area containing low frequency electronic equipment.

(c) Feeder Ground Plates. The feeder ground plates shall be located near the electronic equipment so as to keep the size of the insulated conductors from these plates to the electronic equipment to a minimum size.

(3) Grounding Cables. The grounding cables shall be insulated copper and shall be isolated from any equipment not part of its respective single point ground system throughout its entire network except for the Main Conductor to the earth electrode system. These ground cables shall be mechanically protected by enclosing each in a polyvinyl chloride (PVC) conduit or by routing it in other nonmetallic material, in floor trenches, or behind permanent structural members. The conductor sizes for the copper single point ground cables should be based on providing a cross-sectional area of 500 circular mils (cmil) per running foot (0.3 m) of conductor, i.e., minimum wire cross section (in cmil) = length of run in feet x 500 cmil/foot. This criteria limits the DC resistance between any two points in the network to 20 milliohms.

NOTE: Where isolated ground systems for frequencies above 100 kHz are installed, the size of the related isolated ground cable may need to be increased based on the operating frequencies.

The total path resistance (in ohms) = 10.4 (approximate resistivity of copper) x length in feet/cross-sectional area in cmil. The resistance per foot (0.3 m) of a wire with a cross-sectional area of 500 cmil is

$$(10.4 \times 1) / 500 = 0.0208 \text{ ohms.}$$

(a) The single point grounding system shall be designed to keep the overall length of the grounding cables, i.e., trunk, branch, and feeder cables as short as practical. The distance from the farthest piece of equipment reached, via a segment of cable to the point of origin of the segment, is

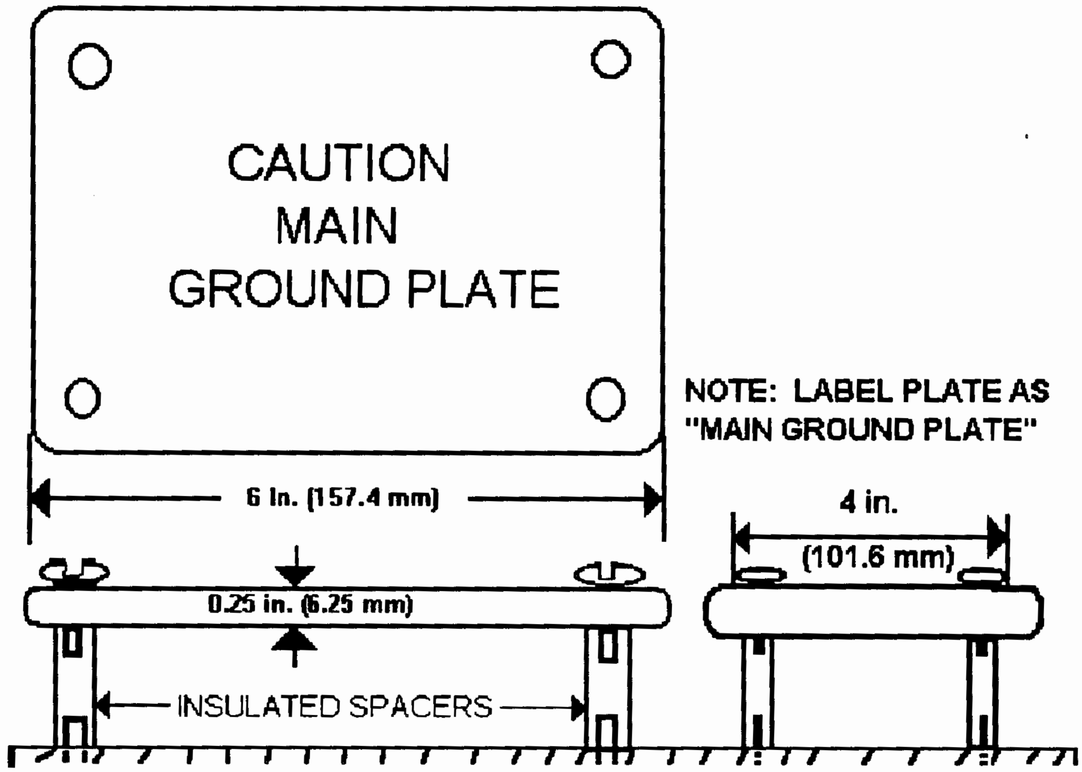


FIGURE 2-21. ELECTRONIC MAIN AND SINGLE POINT PLATES

defined as the running length of the segment. Thus, a 25 foot length of branch cable has a running length of 40 feet if the equipment ground cable from the feeder plate to the equipment is 15 feet long. Thus, there is a requirement for a 20,000 cmil cross sectional area for this branch cable.

(b) Main Ground Cable. The main ground cable shall be an insulated 500 MCM copper cable, or equivalent, 50 feet or less in length, installed between the main ground plate and the earth electrode system.

(c) Trunk Ground Cable. Plan the routing of the insulated trunk ground cable from the main ground plate to the branch ground plates to minimize conductor length. Avoid long runs in parallel with unshielded power cables and locate the trunk ground cables as far as possible from lightning down conductors. Where close routing with powerlines cannot be avoided, either the powerlines or the trunk ground cable should be placed in iron or steel conduit. If at all possible, the power cables should be the conductors installed in the metal conduits, as the integrity of the single point grounding system may be violated if the single point ground system cables are installed in metal conduits and proper isolation is not maintained.

1 The minimum size recommended for the trunk ground cable is 4/0 AWG. For short lengths, a 4/0 AWG cable will provide more than 500 cmil per foot. For example, assume a run length of 200 feet (60 meters). The minimum cross-sectional area for the conductor should be 200 x 500 or 100,000 cmil. The smallest standard AWG cable meeting the requirement is 1/0 (105,500 cmil). However, the extra mechanical strength and the lower resistance offered by the larger 4/0 AWG cable leads to its recommendation over the smaller cable. Further, by initially installing a larger cable, future expansions and modifications can be accomplished in conformance with the 500 cmil criteria without necessitating a change in cable size.

2 To the extent practical, limit the total length of the trunk ground cable to not more than 300 feet (91 m), unless the branch ground cable length is short (see Para. (d) 2 below). If longer lengths are required, install a larger cable or provide parallel or multiple networks within the electronic facility as noted in Paragraph 51a(3)(a) above.

(d) Branch Ground Cable. Branch ground cables, routed to provide the shortest practical path, shall be installed between the branch ground plate and the feeder ground plates located near the electronic equipment.

1 Install branch ground cables to provide the extensions needed between the branch ground plates and the feeder ground plates in the general electronic equipment areas, except as noted hereafter. These cables shall be at least No. 2 AWG copper for lengths less than 75 feet (22.9 m), No. 1/0 AWG copper for lengths between 75 feet and 150 feet (45.7 m), and No. 4/0 AWG. copper for lengths exceeding 150 feet. Where the electronic equipment is located in close proximity to the branch ground plate, a feeder ground plate will not be required and the conductor from the electronic equipment to the branch ground plate shall be sized to meet the requirements of an electronic equipment ground cable (see Para. e below).

2 Do not permit the total length between the main ground plate and the feeder ground plate located near the equipment to exceed 400 running feet (122 m) unless the cable is increased in size.

(e) Electronic Equipment Ground Cable. The cable from the feeder ground plate (branch ground plate if there is no need for a feeder ground plate in the cable run) to the isolated terminal connection on the equipment shall also meet the 500 cmil per running foot requirement. The minimum size cable shall be an insulated No. 16 AWG copper not more than 5 feet (1.5 m) in length. For lengths of cables over 5 feet (1.5 m) in length, the insulated cable size must be increased accordingly. For example, if the feeder plate is 10 feet (3 m) from the electronic equipment, a No. 12 AWG copper cable shall be installed. Care must be taken to locate the feeder ground plates near the electronic equipment, as there may be a problem making connections to the isolated terminal, if the distance between the feeder plate and the isolated terminal requires too large a cable.

(4) Multiple And Parallel Networks.

(a) When multiple and parallel networks are installed, electrical isolation must be maintained between them except at the interconnection at the main ground plate (if one plate serves two or more parallel networks) or through the earth electrode system (if separate main ground plates are used for multiple networks). Ground cables from two separate single point ground systems should not be attached to the same feeder or branch ground plate. Inadvertent interconnections through electronic equipment must also be avoided.

(b) After the complete network is installed, and before it is connected to the main ground plate, or any electronic equipment is connected, the isolation between the network and the multipoint ground should be checked. The isolation should be a minimum of 10 megohms.

(c) After the check required in paragraph 51a(4)(b), connect the electronic equipment, and again check for isolation between parallel single point systems, as well as between single point and multipoint ground systems.

(5) Layout and Routing.

(a) To the extent permitted by operational requirements, electronic equipment should be located to minimize the length of the single point ground system conductors required to reach throughout the facility.

(b) Where flexibility in the location of electronic equipment is limited, the routing of the single point ground system cables may be modified to accommodate the locations. In doing so, however, the isolated network configuration must be maintained in order to ensure that the network does not become a common path for signal currents, stray power currents, and other potential sources of noise. It is not necessary that all branches be installed if no requirement exists. It may be possible, for example, to route the trunk ground cable through an electronic equipment area and avoid the need for branch ground cables to that location. The branch ground plates can then serve as the termination points for the electronic equipment signal ground conductors, instead of the feeder ground plates that would be used otherwise. When routing in this manner, the total trunk cable length must be determined and care taken to ensure that the 400 foot (122 m) limit is not exceeded.

(c) Ensure that the single point ground system does not close back on itself and establish multiple paths between two points.

(6) Labeling and Protection.

(a) Provide mechanical protection for the single point ground system network cables, where they may be subjected to physical damage, by routing them in polyvinyl chloride (PVC) conduit or routing them in other nonmetallic materials, in floor trenches or behind structural members. PVC is not permitted in air handling areas, under raised floors, and above false ceilings.

(b) To maintain the isolation and integrity of the single point ground system network, all cables of the network shall be color coded, and all components clearly identified with color coded labels. The cables shall be color coded green with a bright yellow tracer. Where cables are concealed and not color coded, any exposed portion of the cable and each end of the cable for a minimum of 2 feet (0.6 m) shall be color coded by green tape overlaid with bright yellow tape to form the tracer. Where routed through raceways or wireways, or installed under raised floors, the color coding of the conductor shall be such that by removing or opening any cover, the color coding will be visible. Where conductors are routed through cable trays, color coding for a minimum length of 4 inches (10 cm) shall be accomplished at intervals not exceeding three feet (1 m) between the codings. The equipment grounding, required by the National Electrical Code (NEC) shall not be connected to the single point ground system except at the earth electrode system.

(c) Conduit in which the single point ground system conductors are routed should also be clearly identified using the color coding noted above.

(d) <u>All branch and feeder ground plates</u> shall be provided with a clear plastic protective cover, spaced 3/4 inch from the plate and extending 1 inch beyond each end. This cover provides physical protection; however its main function is to identify these plates as being part of the single point grounding system and to insure that no connections other than those for the single point system are made to the plate. The cover shall have a green label with distinguishing bright yellow slashes attached bearing the caption: "CAUTION, MAIN GROUND PLATE" in black 3/8 inch high letters.

(7) <u>Telephone and Data Switching Systems</u>. Telephone and data switching systems are frequently powered from a battery supply. Traditionally, one side of the battery is connected to chassis, cabinet, or rack which serves as signal ground. A single connection should be made from a point on the equipment to the multipoint ground system. The ground should not be interconnected with the multipoint ground system at more than one point because of potential stray current noise problems. Except for the single connection, the racks and cabinets should be isolated from the structure. It is important that this isolation not be jeopardized, because of either direct contact between the racks and structure, or indirectly through equipment grounding conductors. All signal wiring and cabling should be of a balanced type. Shields of wires and cables should be grounded at one end only, preferably to the isolated rack or chassis.

b. <u>Electronic Multipoint Ground System</u>. The electronic multipoint ground system is a network which provides multiple low resistance paths between various parts of the facility, between electronic equipment within the facility, and between any points within the facility and the earth electrode system, in order to minimize the effects of noise currents that may be present in the ground system, and to control static charge build-up that could cause damage to the electronic equipment or create a hazard to personnel.

The multipoint grounding system consists of electronic equipment ground plates, grounding conductors for the electronic equipment and interconnected structural steel elements, electrical supporting structures, electronic equipment racks and cabinets, utility pipes, etc. (See Figure 2-22). The electronic multipoint ground system shall also provide multiple low resistance paths between the various parts of the facility, between electronic equipment within the facility and between any points within the system and the earth electrode system to minimize the effects of spurious currents that may be present in the ground system. Where the electronic equipment is distant from the earth electrode system or located so as to require several grounding

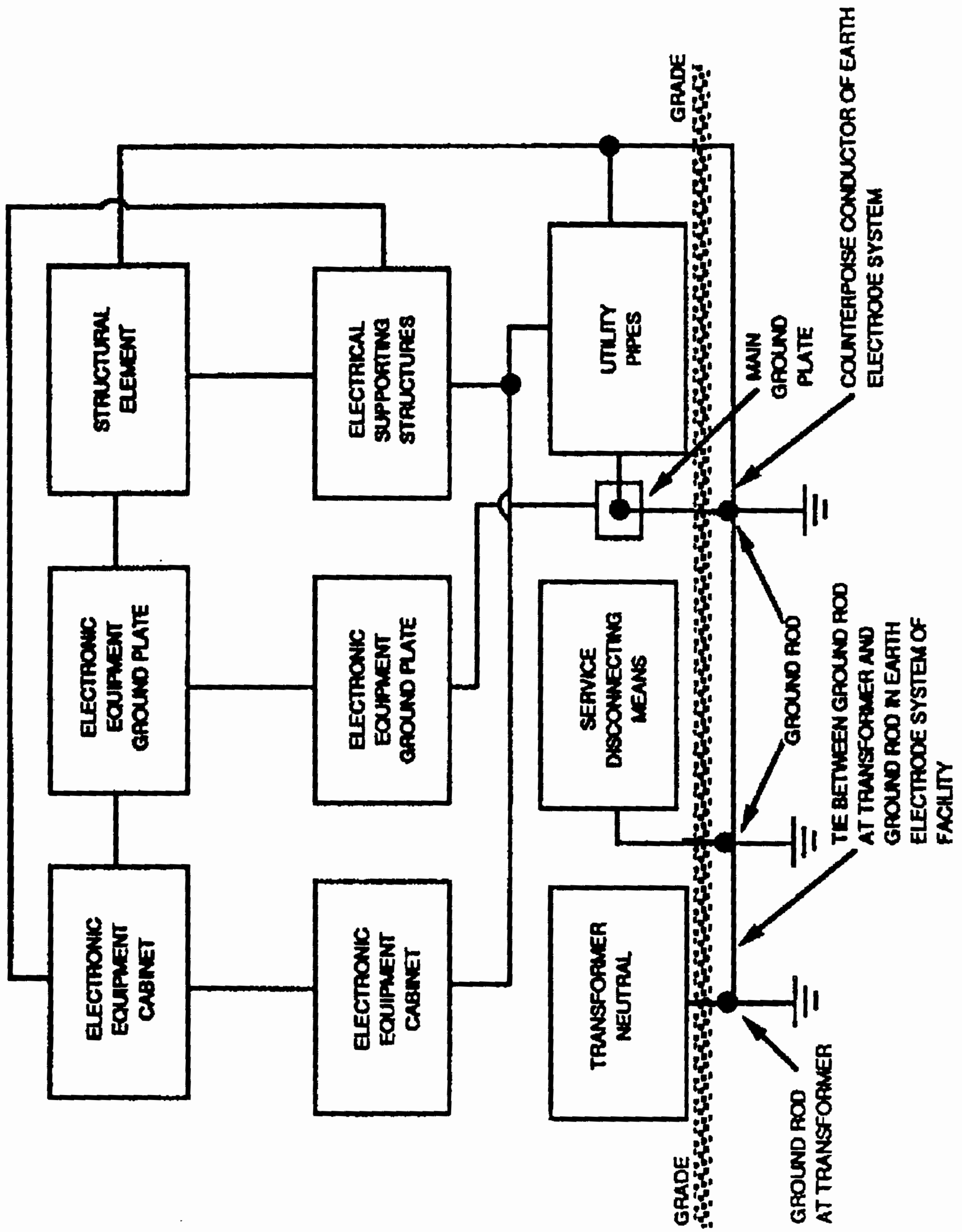


FIGURE 2-22. GROUNDING GRID ESTABLISHED BY MULTIPOINT GROUND SYSTEM

conductors to the ground plates and interconnections thereto, an equipotential ground plane for the system may be used. The multipoint ground system is to be separated and isolated from the single point ground system described previously except for interconnections made at the main ground plate, which is a portion of the earth electrode system (EES).(See Figure 2-20). The main ground plate is connected to the underground portion of the EES with a 500 MCM copper cable. The multipoint ground network shall not be used in place of the equipment grounding conductor required by the National Electrical Code for power system grounding (Paragraph 52).

(1) Interconnections.

(a) In steel frame buildings, make all structural steel members of the building (i.e., buildings columns, wall frames, roof trusses, etc.) electrically continuous by bonding each joint and interconnection with a welded or high compression bolted connection. Where direct bonds of this type are not possible, bridge the joint with a No. 4/0 AWG stranded copper cable and weld or bolt both ends of the cable in place across the joint.

(b) Connect the bonded structural steel network to the earth electrode system with No. 4/0 AWG. copper cables. The ground connections shall be made at approximately every other steel column and shall not average over 60 feet (18 m) apart.

(c) Where steel frame construction is not used, install a system of large copper cables, conforming to sizes specified in Table 2-2 where required. The system of copper cables is necessary to provide low impedance interconnections between the various elements (primarily ground plates) of the multipoint grounding system that are provided by structural steel members in buildings of steel frame construction. Upon completion, the copper cables installed must, in general, replace the building structural members depicted in Figure 2-23. An equipotential ground plane may be utilized where the elimination of or shortening of the lengths of the copper cable grounding cables noted herein is achieved.

(d) Equipment cabinets, electrical supporting structures, and utility pipes are to be connected to this structural steel, copper cable grid, or equipotential plane with cables providing 2000 cmil of cross sectional area per running foot of length. However, No. 6 AWG conductors shall be the minimum size cables used for these connections. Electrical supporting structures include all the conduit, raceways, switch and breaker panels, and other hardware (not energized) commonly associated with the electrical wiring system. Typical

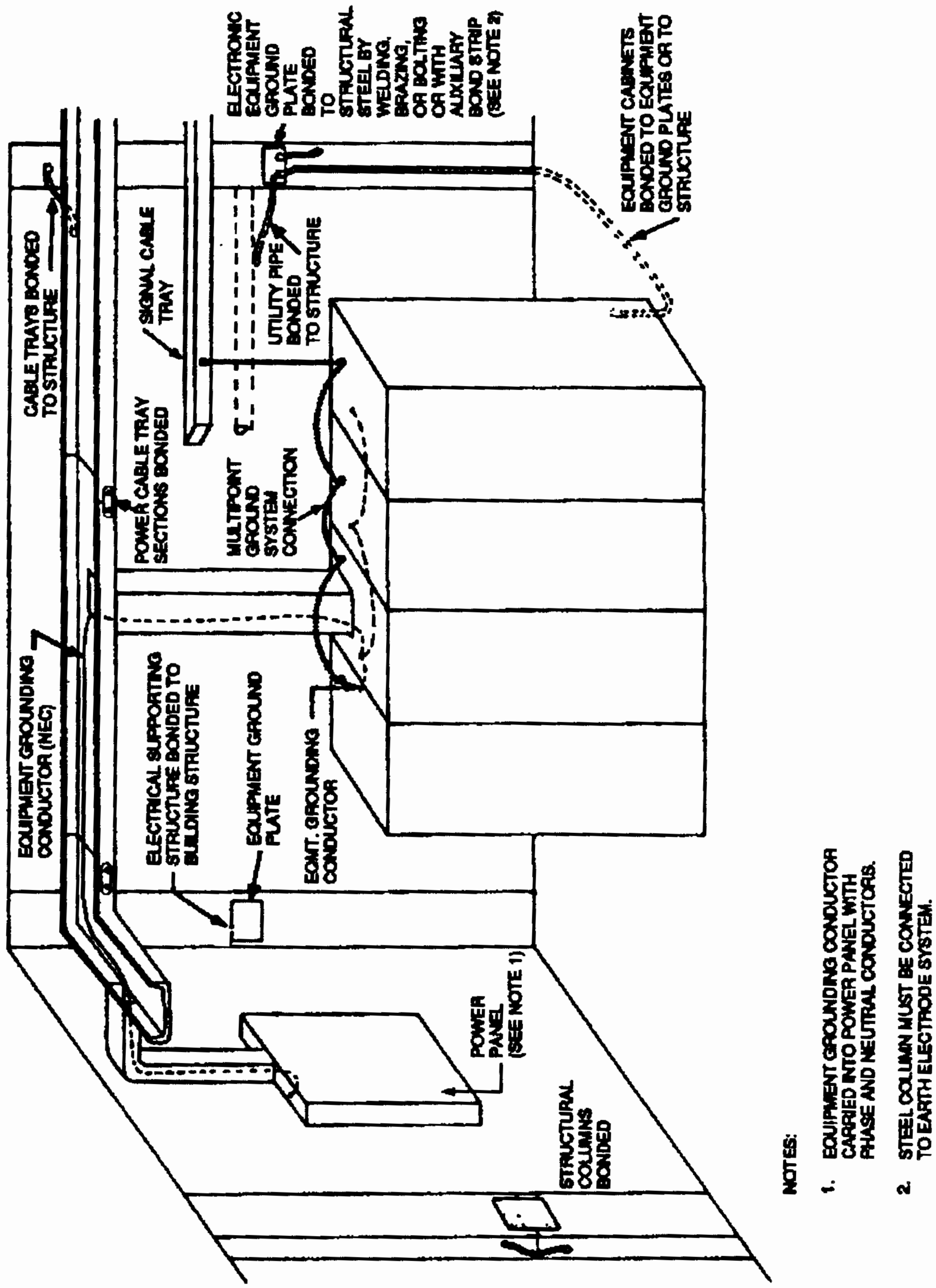


FIGURE 2-23. ELEMENTS OF THE MULTIPOINT GROUND SYSTEM

interconnections are shown on Figure 2-23. These interconnections SHALL NOT be used in lieu of, or replace, the power system equipment grounding conductors required by the National Electrical Code.

(2) Multipoint System Ground Plates. To provide points for conveniently grounding electronic equipment cabinets and electrical supporting structures to the multipoint ground system, install electronic equipment ground plates in readily accessible locations where required throughout the facility. The plates shall be made of high conductivity copper and shall be at (6.4 mm) thick. Where required, larger plates may be installed least 6 inches (152 mm) long, 4 inches (102 mm) wide and 1/4 inch to conveniently terminate the required number of electronic equipment multipoint ground cables. Ground buses may be used when distributed grounding is desired with a long row of electronic equipment cabinets. The width and thickness of the ground bus shall be selected from Table 2-2 according to the length required. These plates are not to be confused with the main ground plate, branch ground plates, and feeder ground plates, which are part of the single point ground system. The electronic equipment multipoint ground cables are not to be confused with, or to be used in lieu of the power system equipment grounding conductors, required by the National Electrical Code.

(a) Clearly mark the plates and bus with permanently attached plastic or metal labels that are predominantly green with distinguishing bright orange slashes. The label shall bear the caption "MAIN GROUND PLATE" in black, 3/8 inch (10 mm) high characters.

(b) Locate these plates throughout the facility so that they are convenient to all electronic equipment locations as shown in Figure 2-23.

(c) In properly grounded steel frame buildings, these plates are to be mounted on and bonded to the steel structural members wherever feasible. Where circumstances prevent the plates from being attached directly to the structure, use bonding cables conforming to the 2000 cmil per running foot criteria (but in no case less than No. 6 AWG) to assure electrical continuity with the structure.

(d) A supplementary ground plate shall be provided on the opposite side of the building from the main ground plate. This supplemental ground plate shall be connected to the earth electrode system providing a second path to the earth electrode system for the multipoint ground system. The cable from the supplementary ground plate to the earth electrode system shall not exceed 50 feet in length and shall be a 500 MCM or equivalent copper conductor. The cable shall be exothermically welded to the earth electrode system and shall be bolted to the supplementary ground plate with an UL approved connector. Connections shall be made between the supplementary ground plate and the multipoint electronic equipment, the multipoint electronic equipment ground plates and the structural steel of the building so that there is a minimum of two paths to ground throughout the multipoint grounding system.

(e) Following installation, verify that the DC resistance of any connections to any ground plates or to the earth electrode system does not exceed 1 milliohm.

(f) The cables of the electronic multipoint ground system shall be color coded green with a bright orange tracer. Where cables are concealed and not color coded, any exposed portion of the cable and each end of the cable for a minimum of 2 feet (0.6 m) shall be color coded by green tape

TABLE 2-2. SIZE OF MULTIPOINT GROUND SYSTEM CABLES

Cable Size (AWG)	**Maximum Path Length (FT)**	**(M)**
750 MCM	375	115
600 MCM	300	90
500 MCM	250	76
350 MCM	175	50
300 MCM	150	45
250 MCM	125	38
4/0 AWG	105	32
3/0 AWG	84	26
2/0 AWG	66	20
1/0 AWG	53	16
1 AWG	41	12
2 AWG	33	10
4 AWG	21	6
6 AWG	13	4
8 AWG	8	2.5

TABLE 2-2. SIZE OF MULTIPOINT GROUND SYSTEM CABLES (continued)

Busbar (IN)	Busbar (MM)	Maximum Path Length (FT)	Maximum Path Length (M)
4 x 1/4	100 x 6	636	149
4 x 1/8	100 x 3	318	97
3 x 1/4	76 x 6	476	145
3 x 1/8	76 x 3	238	72
2 x 1/4	51 x 6	318	97
2 x 1/8	51 x 3	159	49
2 x 1/16	51 x 2	79	24
1 x 1/4	25 x 6	159	48
1 x 1/8	25 x 3	79	24
1 x 1/16	25 x 2	39	12

overlaid with bright orange tape to form the tracer. Where routed through raceways or wireways or under raised floors, the color coding shall be such that by removing or opening any cover, the color coding shall be visible. Where conductors are routed through cable trays, color coding for a minimum length of 4 inches (10 cm) shall be accomplished at intervals not exceeding three feet (1 m) between the codings.

(3) Electrical/Electronic Supporting Structures (Raceways). Electrical/electronic supporting structures, such as conduits, cable trays, wiring system enclosures, and metallic power cable sheaths, shall be electrically continuous and are to be bonded to the electronic multipoint grounding system.

(a) Conduits.

1 All conduits shall be grounded, regardless of whether it is used for enclosing power systems cables or for enclosing electronic signal and control cables.

2 All joints between sections of conduit and between conduits, fittings and boxes shall be made electrically continuous when they are installed.

3 All pipe and locknut threads should be treated with a conductive lubricant before they are engaged and tightened firmly.

4 Gouging locknuts must positively penetrate all paint or other nonconductive finishes.

5 Any joints not inherently continuous shall be bonded with jumpers of No. 12 AWG or larger copper wire. These jumpers shall be welded in place or attached with approved clamps, split bolts, grounding bushings or screws and lock washers.

6 Protect the bonds against weather, corrosion, and mechanical damage.

7 Firmly tighten the screws on the cover plates of pull boxes, outlet boxes, junction boxes, conduit fittings, etc.

8 All conduit brackets and hangers shall be securely bonded to both the conduit and to the structural steel members to which they are attached. Bond conduit runs, to include the individual sections of conduit, couplings, line fittings, pull boxes, junction boxes, outlet boxes, etc. to the electronic multipoint ground system at intervals not exceeding 50 feet (15 m). The resistance to each connection should not exceed 5.0 milliohms.

(b) Cable Trays. Make all cable tray systems electrically continuous by bonding together each individual section as described in Section 4. Bond each support bracket or hanger to the cable trays which they support. Connect the cable tray assemblies to the electronic multipoint ground system with copper cables conforming to the 2000 cmil per running foot criterion (No. 6 AWG minimum). Make the connections within two feet (0.6 m) of each end of the tray and at intervals not exceeding 50 feet (15 m) along run of the cable tray. Where metal covers are used on the cable tray installation, they should be securely bolted in place. The resistance of each of these connections shall not exceed 5 milliohms.

(c) Enclosures. Ground all enclosures of electrical and electronic wiring and distribution equipment in accordance with the requirements of the National Electrical Code.

(4) Equipotential Planes. Equipotential planes shall be utilized as the multipoint grounding system where the frequencies are such that the impedance of the multipoint grounding conductors and the multipoint grounding system connections to the earth electrode system become too great for proper operation of the electronic equipment.

The use of a properly installed equipotential plane will reduce the impedance of the grounding system and will also help to reduce any noise problems in the electronic grounding installation. Conducting media that can be utilized for the equipotential plane are: (a) a subfloor of aluminum, copper, or sheet steel laid underneath the floor tile; (b) a ceiling grid above the electronic equipment; (c) a raised metal floor used in conjunction with a copper mesh laid on the subfloor below the raised floor and tied to alternate risers of the raised floor; or (d) a Signal Reference Grid (SRG). The SRG as noted hereafter, although referring to Computer Areas, may be beneficial for other electronic equipments utilizing higher frequencies and having harmonic distortion problems. The requirements of the SRG, such as the single point (window) of entry, Uninterruptible Power Supply (UPS), or isolation transformers would benefit any type of equipotential planes, however, costs could make this impractical. The requirements listed below for each type of equipotential plane are basically the minimum. Enhancements to any of the types of equipotential planes should be carefully analyzed for cost considerations, operational needs and benefits, etc.

(a) <u>Equipotential Plane Under Floor Tile or Carpet</u>. An equipotential plane can be realized by installing a solid metal sheet or roll of either aluminum or copper under the floor tile or carpet of the electronic equipment rooms. The plane shall be welded to the main structural steel members of the building at multiple locations. The structural steel shall in turn be bonded to the earth electrode system with No. 4/0 AWG copper conductors with the ends of each grounding conductor welded to the structural steel and to the earth electrode system. A more economical method would be to form a grid made up of copper strips, two to three inches wide and brazed at all crossovers, forming squares not more than two feet in size. The resultant grid shall be welded to the structural steel at the ends of each strip. Where steel frame and concrete construction are not used, a supplemental network consisting of large copper cables conforming to Table 2-2 shall be installed. This method is not considered as acceptable as the other techniques listed previously and should only be used after the other techniques have been considered to be unacceptable.

(b) <u>Overhead Equipotential Plane</u>. An overhead grid system consisting of wall members sized No. 1/0 AWG around the inner perimeter of the electronic equipment room and cross members sized No. 2 AWG above the electronic equipment rows can also be employed as an equipotential plane. The conductors shall be color coded green with bright orange tracers. The equipotential plane shall be connected to the earth electrode system with No. 2/0 AWG copper conductors from the lower ends of the wall members where there is no building steel. Minimum size No. 6 AWG copper conductor shall be used to connect the electronic equipment to the cross member to be used.

(c) Raised Flooring. Raised floors are used to structurally support equipment cabinets and provide a space between the original floor of the facility and raised floor plates for power and electronic cabling, air plenum or air conditioning ducting, piping, drains, etc. Raised floors provide an aesthetic room appearance and although normally used for computer systems, may be used for other electronic systems where installing an equipotential plane as described above is found to be difficult or impractical. The elements of the raised floor by itself shall not constitute an equipotential plane. Although three general types of floor systems are manufactured, only the bolted grid (stringer) or rigid grid system is acceptable as part of an equipotential plane. To be an effective equipotential plane, a copper mesh, similar to that described in Para. (d) below, must be utilized. The other types, the drop-in grid or removable grid type and the free standing, stringerless or pedestal type are not acceptable for use in developing an equipotential plane for use in the grounding of the electronic equipment. The raised floor utilizing the bolted grid (stringer) or rigid grid system will also be used as described below as part of a Signal Reference Grid.

c. Signal Reference Grid. The Signal Reference Grid (SRG) is a Signal Reference Structure (SRS) that is utilized as a high frequency (HF) ground reference. It is a low impedance network which establishes an equipotential plane. The SRG is recommended for larger sensitive electronic equipment installations such as Computer Rooms due to the operating frequencies of the computers.

(1) The SRG shall consist of a raised floor as described in paragraph (c) above and prefabricated copper strips, two inches wide by 26 gauge (0.0159 inches) thick on two (2) foot centers. The strips shall be welded at each crossover. The pedestals of the bolted grid or rigid grid of the raised floor shall be solidly bonded to the SRG at every second pedestal. This bond shall consist of 3/4 inch wide by 1/16 inch thick flexible braided copper securely connected to the pedestal and the SRG with exothermic welds. The length of these bonding conductors shall be as short as practical with no sharp bends or kinks. Each piece of electronic equipment shall be bonded to the SRG with a copper strap. These straps shall be kept as short as practical and shall not be folded or coiled, and shall have a bending radius of not less than eight (8) inches. Even where the electronic equipment is lined up and bolted together, each enclosure shall be bonded to the SRG with its own strap. The same broad strap used in the SRG may be used for the electronic equipment bonding straps. All paint shall be removed from the equipment where the bonding connection is made to the equipment. Where necessary to further reduce the inductive reactance, two bonding conductors, separated as far as practical, shall be connected from the electronic equipment to the SRG. All bonds to

the SRG shall be made with exothermic welds. Connections of the electronic equipment to the SRG shall **NOT** be made on the outermost grid conductor. Electronic equipment should be located and bonded to the SRG at a distance of more than six feet away from the building steel or other potential lightning paths. Heating, ventilating and air conditioning and electrical panelboards can be connected to the outermost grid connector.

(2) <u>The SRG shall not replace</u> the equipment grounding conductors of the power system for the equipment above the raised floor. The equipment grounding conductors shall be run in the same conduit as the power feeder to each item of equipment. The SRG must be connected to the ground source of the power system feeding the computer area, i.e., a grounding conductor shall be connected to the SRG from the power source neutral, as noted in paragraph (3) below. This grounding conductor shall be of a size appropriate to ampacity of the largest conductor brought into the computer room. The SRG shall also be bonded to the case of each sub-panel feeding the equipment of the system. The grounding conductors from the SRG to the power centers and sub-panels shall be kept as short as practical and shall be equal in size to the equipment grounding conductor, but in no case smaller than No. 4 AWG.

(3) <u>The power source to the computer area</u> shall be grounded to meet all requirements of the National Electrical Code (NEC). For the SRG to be most effective, and to keep the grounding conductor as short as practical, isolating transformers or UPS should be located conveniently close to the loads being served. The secondary of these items shall be grounded as a separately derived system, in accordance with the NEC, and to the SRG. This will basically isolate the AC voltage output to the area from outside sources of disturbance. Also, the AC voltage will be closely connected to the SRG and to the loads by conductors too short to cause any resonance problems or disturbances due to induction. The neutral of the separately derived source shall be connected to the nearest electrically continuous building steel column with an insulated copper grounding electrode conductor. This conductor shall be run in rigid steel conduit, and sized in accordance with the NEC, but in no case smaller than No. 6 AWG. (NOTE. It shall be verified that the steel columns are electrically continuous to the earth electrode system.) The neutral of the separately derived system shall also be connected to the SRG with a No. 4 AWG copper conductor. All bonds to the steel building columns and to the SRG shall be made with exothermic welds.

(4) <u>Point of entry</u> of power, communications, and life safety systems should be in one place rather than scattered around or on opposite sides of the room. This will permit the use of short interconnections to equalize ground voltage

differences without passing the resulting currents through the computer room. All conduits, water pipes, etc., entering the computer room must be bonded to the SRG, at each side of the room if they are horizontal.

(5) The SRG must be bonded to an earth return at as many points as possible. The SRG shall be bonded to all available building steel. These connections shall be made with as short as practical No. 4 AWG stranded copper conductors and bonded at each end with exothermic welds.

(6) Cables run under raised floors. All power cables shall be run in rigid galvanized steel conduit. The conduit shall be bonded at each end to the SRG with as short as practical No. 6 AWG copper conductors and exothermically welded. All data and other electronic lines run under the raised floor shall be laid directly on the SRG. This will aid in minimizing the noise in the cables.

(7) Transient Suppression Plates. Where the reinforcing in the concrete subfloor may be energized with high frequency electrical noise voltages or currents, the data and power cables lying on the subfloor may be subject to coupling by magnetic and capacitive means. A transient suppression trap may be installed to control and limit the appearance of noise voltage differences between the computer room ground and the reinforcing within the concrete. The Transient Suppression Plate provides a controlled bypass between the electrical ground connections and the reinforcing steel. This Transient Suppression Plate should be located at or near the point of power entry into the computer room. The Transient Suppressor Plate (or plates) shall be copper, four (4) feet by four (4) feet, and shall be bonded to the System Reference Grid with a short low impedance path. It shall also be bonded to the ground bus of the main breaker of the transformer output, and to the ground bus in each of the branch circuit panels. The Transient Suppression Plate may be bonded to the SRG and to the subfloor with a thin mastic.

(8) Summary of SRG installation requirements.

(a) All applicable codes and standards for safe grounding must be followed.

(b) The SRG must be bonded to all accessible building steel and to every metallic path crossing the plane or within six (6) feet of the SRG.

(c) Each piece of sensitive equipment must be bonded to the SRG.

(d) Bonding conductors to the SRG must be as short as practical with no sharp bends or folds.

(e) Do not connect any sensitive equipment to the outer edges of the SRG. Critical electronic equipment must be located not less than six (6) feet away from the building steel or lightning paths.

(f) All separately derived systems serving equipment located on the SRG must have their neutrals connected to the building steels and to the SRG.

(g) All metallic objects within the protected area shall be bonded to the SRG. This includes HVAC equipment and associated piping and ducts, metal wall studs, all electrical gear and their associated conduits, and all similar types of equipment.

(h) There shall be no separate earth grounding or separate ground paths.

(i) All power cables shall be run in rigid galvanized steel conduit which shall be bonded to the SRG. All electronic cables, when not in rigid steel conduit, shall lay directly on the SRG.

52. POWER DISTRIBUTION SYSTEM GROUNDING.

a. The facility electrical grounding shall comply with or exceed the grounding requirements of the National Electrical Code (NEC). The electronic grounding systems shall not replace or be used in lieu of the electrical distribution system equipment grounding conductor required by the NEC.

b. The grounded (neutral) conductor of an AC power distribution system is to be grounded only to the earth electrode system at the transformer serving the facility, and at the service disconnecting means of the facility, except for separately derived systems in the building. Where two or more facilities are separately supplied by a common distribution system, the grounded (neutral) conductor shall be connected to the earth electrode system at each facility on the line (supply) side of the service disconnecting means. At separate facilities having a common earth electrode system, each service disconnecting means shall be grounded to the closest ground rod in the earth electrode system.

c. Where one facility receives its electrical power from another facility, the equipment grounding conductor shall be carried in the same conduit or raceway with the phase and neutral conductors feeding the facility. The grounded (neutral) conductor shall not be grounded in the receiving facility.

d. The distribution system neutrals are to be isolated from equipment housings, frames, etc. and structural elements except at the service disconnecting means and at the secondary neutral of a separately derived system.

e. A copper grounding electrode conductor sized to meet the requirements of the NEC, except that in no case shall it be smaller than No. 4 AWG, shall connect the grounded conductor of the power distribution system to the earth electrode system. The grounding electrode conductor shall be continuous and unspliced from the neutral bus of the service disconnecting means to the nearest ground rod in the earth electrode system except where splices and taps are permitted by the NEC (bus bars and services consisting of more than one service disconnecting means). When routed through a metallic conduit or raceway the conductor shall be bonded to the conduit or raceway at each end of the conduit or raceway in accordance with the NEC.

f. A separately derived system is a premise wiring system whose power is derived from generator, transformer, or converter windings and has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system. The separately derived systems shall be grounded to meet the requirements as noted hereinafter.

(1) A copper grounding electrode conductor sized in accordance with the requirements of the NEC, except that it shall not be smaller than No. 6 AWG, shall be used to connect the grounded conductor (neutral) of the derived system to the grounding electrode. This connection shall be made at any point on the separately derived system, from the source to the first system disconnecting means or overcurrent device, or it shall be made at the source of a separately derived system which has no disconnect means or overcurrent devices. However, unless the first disconnect means or overcurrent device is adjacent to the source, the grounding electrode conductor shall be connected to the source of the separately derived system. The grounding electrode conductor, bonding jumper, grounded conductor (neutral), source housing, and the equipment grounding conductor are all connected together at the source housing.

(2) The grounding electrode conductor for the separately derived system shall be connected to the earth electrode system if feasible. Where this is not feasible, the grounding electrode conductor may be connected to the nearest effectively grounded structural steel member.

g. An engine-generator building located adjacent, but separate from a facility equipment building and sharing a common earth electrode system, shall not be considered as separate buildings where the service to the facility equipment building is fed through the engine-generator building. The service disconnecting means of the engine-generator shelter shall serve as the service disconnecting means for the entire facility. The service to the facility equipment building from the engine-generator building shall include an equipment grounding conductor run in the same conduit as the service conductors. This conduit shall be a rigid steel conduit, carefully bonded at each end. The grounded (neutral) conductor shall not be grounded at the facility equipment building.

h. A separate equipment grounding conductor, run in the same conduit, raceway or cord as its related phase and neutral conductors, shall be used to ground the electrical system. This separate equipment grounding conductor shall be color coded green and shall be sized in accordance with the NEC.

(1) The equipment grounding conductor shall terminate on the grounding terminal of the outlet box. Connect the grounding terminal of the convenience outlet to the grounding terminal of the outlet box with an equipment bonding jumper in accordance with the requirements of the NEC. Do not use wire mold or plug mold distribution strips which depend on serrated or toothed fingers for grounding. Effectively ground the ground terminals on such strips with equipment grounding conductors sized in accordance with the requirements of the NEC.

(2) Where required for the possible reduction of reported electrical noise (electromagnetic interference) on the grounding circuit, a receptacle in which the grounding terminal of the receptacle is purposely insulated from the receptacle mounting means is permitted. This grounding terminal shall be grounded by a separate equipment grounding conductor run in the same raceway as the related phase and neutral conductors. This separate equipment grounding conductor shall be permitted to pass through one or more panelboards without connection to the panelboard grounding terminals and shall terminate on the ground bus of the service disconnect means or at the ground bus of a separately derived system. This equipment grounding conductor shall be insulated and color coded green with yellow and red bands at each end and in each box through which it passes. A second equipment grounding conductor, color coded green and run with the related phase and neutral conductor, shall be installed from the ground bus of the panelboard housing the protective means for the receptacle to the ground terminal of the receptacle outlet box.

i. The frames and housings of standby engine-generators, not connected as a separately derived system, shall be grounded from the E/G control panel by an equipment grounding conductor. The neutral shall be connected to the facility neutral in the transfer switch and shall be isolated from ground in the engine-generator frame and housing, and in all engine-generator related controls and equipment. If the engine-generator is connected as a separately derived system, see paragraph 52f.

j. The frames of motors and other types of rotating machinery and all controllers thereof, shall be connected by the equipment grounding conductor. This shall be accomplished in accordance with the NEC and shall utilize a separate equipment grounding conductor.

53. COMBINED FACILITY GROUNDING. Figure 2-24 illustrates the recommended grounding practices for a typical electronic facility. Representative lightning protection system grounds, power distribution system grounds, and electronic system grounds, (both single point and multipoint ground systems), are shown. This figure should be interpreted only as illustrating how the various ground systems interface. Every ground situation is not shown.

a. The neutral of the wye-connected secondary of the distribution transformer is grounded to the transformer case and to a ground rod adjacent to the transformer or a grid surrounding the transformer. This transformer ground connection may be made at the facility earth electrode system when in close proximity to the transformer. The ground rod or grid of the transformer shall be interconnected to the facility earth electrode system wherever feasible with a copper conductor sized the same as the counterpoise wire of the facility earth electrode system. This interconnection is shown as a dashed line in Figure 2-24. If the transformer is the property of the local power company, the ground resistance and compatibility of the power company ground with the facility ground shall be verified. The power company should be requested to measure the resistance of the transformer ground and improvements made to their ground if necessary.

b. The neutral of the service conductors is connected to the facility earth electrode system as required by the NEC. The neutral shall be grounded on the input side of the service disconnecting means and at no other point in the facility except at separately derived systems in the facility. The neutral of the separately derived system shall be connected to the earth electrode system as noted in Paragraph 52f.

c. A separate equipment grounding conductor, run in the same raceway, conduit or cable as its related phase and neutral conductors, shall be utilized to ground all equipment cases,

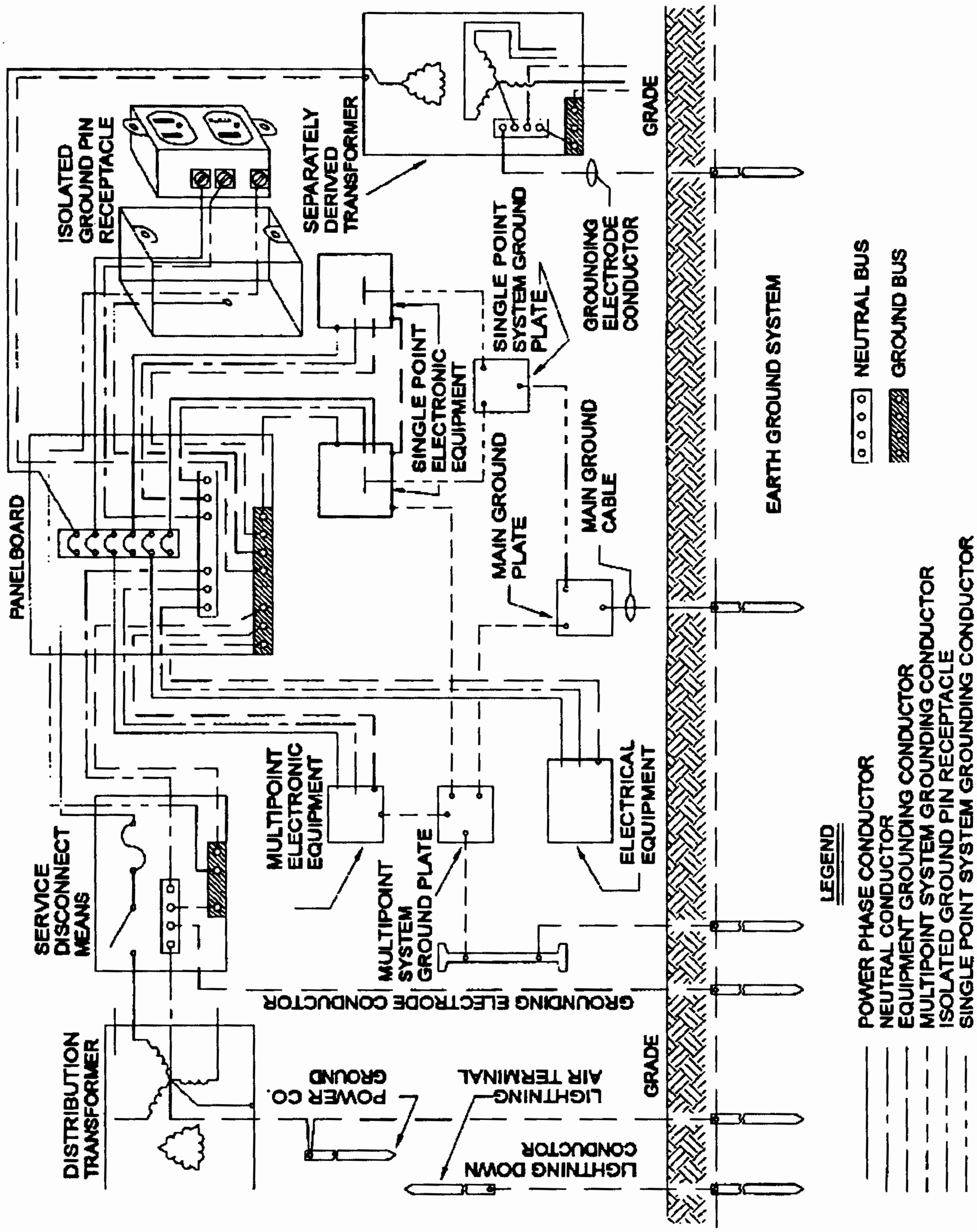


FIGURE 2-24. OVERALL FACILITY GROUNDING DIAGRAM

power and electronic, fed by AC power circuits. All exterior parts of electrical and electronic equipment exposed to human contact are also grounded in this manner. Where isolated ground pin receptacles are used, a second equipment grounding conductor shall be installed as noted in Paragraph 52h(2).

d. Electronic systems grounding as defined earlier shall be provided. An isolated single point signal reference network may be provided for low frequency electronic equipment or as required by the manufacturer of the equipment. A multipoint grounding network for high frequency electronic equipment utilizes the structural steel of the facility or a cable network to create numerous paths to ground. Supplemental electronic equipment grounding is provided by the equipment grounding cables of the multipoint ground system interconnected through electronic equipment ground plates. Structural elements are grounded to the earth electrode system as described in Paragraph 51b(1)(b). The main ground plate as described in single point ground systems, serves as a central tie point between the single point ground system, the multipoint ground system, and the earth electrode system. The counterpoise cable of the earth electrode system provides the interconnection between power ground system and the main ground plate. At no time shall the grounding electrode conductor of the power distribution grounding system be run to the earth electrode system through the main ground plate of the electronics ground system.

e. The lightning protection system is grounded to electrodes in the facility earth electrode system as described in Section 2. Care should be taken to obtain maximum practicable spacings between the lightning protection system down conductors and any electric cables and/or equipments in and structural elements of the building that could be effected by induced currents or flashover from lightning strikes. Where required secondary bonding, as described in NFPA 780, Lightning Protection Code, shall be provided.

54. MOBILE FACILITIES. A typical mobile facility is illustrated in Figure 2-25. The grounding requirements for an installation of this type are limited, particularly if the installation is temporary. The figure illustrates a facility with its own power supply provided by an engine generator unit. The basic requirement for personnel protection is that the neutral of the AC power line be grounded to exposed metal portions of the equipment, the shelter, and the engine generator unit. A grounding bus conforming to the NEC requirement should interconnect the engine generator frame and the metal shelter. The interconnected combination shall be grounded to earth with at least one ground rod. Note that since the earth is not part of an AC fault return path, the ground rod is not essential for personnel protection. Caution: This is true only with an

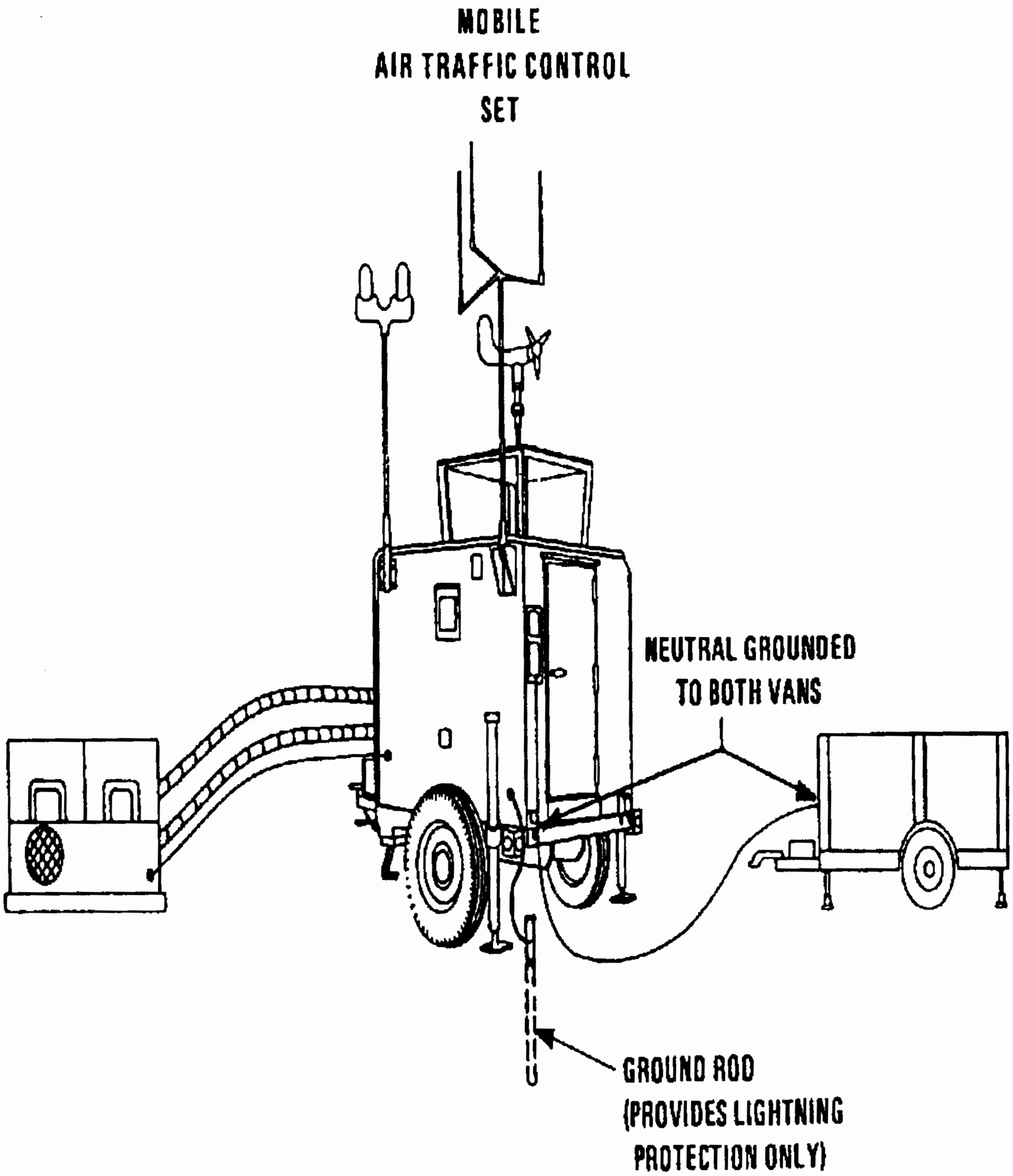


FIGURE 2-25. GROUNDING PRACTICES FOR MOBILE FACILITIES WITH INTEGRAL POWER SUPPLY

integral power supply. If commercial AC power is used, or if the power is from a remote engine generator unit, effective earth grounding shall be necessary for personnel protection.

a. The primary function of the ground rod with the integral power supply installation is to establish contact with the earth for lightning protection.

b. A permanent installation, even though mobile type facilities are used, when supplied by AC power shall be provided with an earth electrode system designed as installed in accordance with the recommendations of Section 1.

55. - 59. RESERVED.

SECTION 4. BONDING PRACTICES

60. GENERAL. High quality bonds between conducting elements throughout the facility are essential ingredients to the effective functioning of all grounding and shielding networks. It is of paramount importance that thorough consideration be given to bonds and bonding throughout the design and construction of a facility.

61. APPLICATION GUIDELINES.

a. Resistance. Unless otherwise specified in this order, all bonds shall exhibit a resistance of 1 milliohm or less when measured between the bonded members with a 4-terminal milliohmmeter.

b. Methods. Internal welded or brazed bonds shall be used whenever possible. Bolted or clamp-type connections shall be used only where permitted in other sections of this order. Exothermic welds may be used for any type of bond connection specified herein except where the bonds are required to be disconnected for maintenance purposes or can not be used between certain metals or due to the shape of the items to be bonded. Exothermic welds are preferred for all underground connections between the earth electrodes and the counterpoise cable and for other connections to the earth electrode system, and must be used for all underground connections in the Lightning Protection System.

c. Welds. Utilize welds whenever possible for permanently joined bonds. The welds must be adequate to support the mechanical load demands on the bonded members and the following minimum requirements must also be met:

(1) On members whose maximum dimension is 2 inches (50.8 mm) or less, the weld must extend completely across the side or surface of the largest dimension.

(2) On members whose largest dimension is greater than 2 inches (50.8 mm) but less than 12 inches (305 mm), one weld of at least 2 inches long shall be provided.

(3) On members whose largest dimension is greater than 12 inches(305 mm), two or more welds, each not less than 2 inches (50.8 mm) in length shall be provided at uniform spacings across the surface of the largest dimension. The maximum spacings between welds shall not exceed 12 inches.

(4) At butt joints use complete penetration welds on all members whose thickness is 1/4 inch (6.4 mm) or less. Where

the thickness of the members is greater than 1/4 inch, the depth of the weld shall be more than 1/4 inch.

(5) Fillet welds shall have an effective size equal to the thickness of the metals.

(6) At lap joints whose thickness is less than 1/4 inch (6.4 mm), double fillet welds shall be provided.

d. Brazing. The use of oxyacetylene results in hardening and brittleness of copper cables. Brazing shall only be used in the electronic multipoint ground system as follows:

(1) Brazing or silver soldering may be used for the permanent bonding of copper conductors or copper alloy materials.

TABLE 2-3. MINIMUM TORQUE REQUIREMENTS FOR BOLTED BONDS

Bolt Size	Threads/Inch	Min. Torque (in. lbs)	Tension (lbs)	Bond Area (in.)
#8	32 36	18 20	625 685	0.416 0.456
#10	24 32	23 32	705 940	0.470 0.626
1/4"	20 28	80 100	1840 2200	1.225 1.470
5/16"	18 20	140 150	2540 2620	1.690 1.750
3/8"	16 24	250 275	3740 3950	2.430 2.640
7/16"	14 20	400 425	5110 5120	3.400 3.420
1/2"	13 20	550 575	6110 6140	4.070 4.090
5/8"	11	920	7350	4.900
3/4"	10	1400	9300	6.200
7/8"	9	1950	11100	7.40
1"	8	2580	12900	8.600

(2) Either brazing or exothermic welding shall be used for the permanent bonding of copper conductors to steel or other ferrous structural members.

(3) All residual fluxes shall be removed and/or neutralized to prevent corrosion.

(4) Brazing shall not be used for buried connections in the facility ground system.

e. Soldered connections. Soldered connections shall not be used for any connection in either the power distribution system grounding networks, or the lightning protection system. Soldered connections shall only be used to improve conductivity in load bearing joints in electronic grounding systems and shall not be used to provide mechanical restraint.

f. Bolted connections. All bolted connections shall conform to the torque requirements in Table 2-3, Minimum Torque Requirements for Bolted Bonds.

The order of assembly for bolted bonds is illustrated in Figure 2-26. Position load distribution washers directly

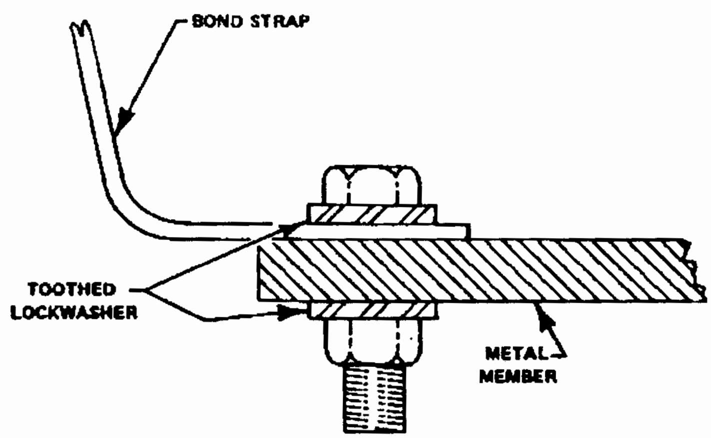


FIGURE 2-26. ORDER OF ASSEMBLY FOR BOLTED CONNECTION

underneath the bolt head or under the nut next to the primary member. Lockwashers may be placed between the nut and any load bearing washers. Toothed lockwashers may be used as long as the following conditions are met:

(1) Use only in interior locations that are not exposed to moisture.

(2) Do not depend on such washers to clean the faying surfaces.

(3) Use only electrochemical compatible metals for the washer and the bond members.

g. Hydraulically crimped. Hydraulically crimped mechanical connections, when made at the manufacturers recommended pressure to develop a minimum force of 6 tons, are acceptable as a FAA-approved pressure connection in access wells only. They are not acceptable for use in the lightning protection system, termination of the grounding electrode conductor, closure of the earth electrode system counterpoise loop, or bonding the earth electrode system counterpoise conductor to the ground rods.

h. Mating surfaces. Once the mating surfaces have been cleaned of all nonconductive material, join the bonding surfaces together as soon as possible. If delays beyond two hours are necessary in corrosive environments, the cleaned surfaces must be protected with an appropriate coating. The protective coating must be removed before completing the bond.

i. Clips and Clamps. Alligator clips and other spring-loaded clamps are to be employed only as temporary bonds. They are to be used primarily to insure that personnel are not inadvertently exposed to hazardous voltages when performing repair work on equipment or on facility wiring.

62. SURFACE PREPARATION.

a. Welding generally requires only the removal of foreign material which might prevent a homogeneous weld from being established.

b. Before exothermic welding, dirt and other debris must be wiped or burned away from the weld area. Any water present must be removed from the weld area. The area should then be wiped with a clean dry rag to remove any impurities. The weld mold must be thoroughly dried.

c. Surfaces to be brazed or soldered shall be cleaned of all foreign matter and metallic films that would prevent adhesion of the filler metal to the primary members, and appropriate fluxes are to be applied. Excess flux shall be removed and/or neutralized after the bond is completed to prevent future corrosion.

d. The mating surfaces of bolted or other compression type bonds require careful cleaning and preparation. Simple scraping is not acceptable. Surface should be sanded or ground down to the bare metal. The basic requirements are:

(1) All nonconductive material must be removed. Such materials include paint and other organic finishes; anodize films; oxide and sulfide films; and oil, grease, and other petroleum products.

(2) All corrosive agents must be removed. Such agents include water, acids, strong alkalies, and any other materials which provide conductive electrolytic paths.

(3) All solid matter which would interfere with the establishment of a low-resistance path across the bond interface or which forms a wedge or barrier that keeps the bond area open to the entrance of corrosive materials or agents must be removed. Such solid materials include dust, dirt, sand, metal filings, and corrosion by-products.

63. BOND PROTECTION CODE.

a. Corrosion. For bonds of high reliability, corrosion must be prevented by avoiding the pairing of dissimilar metals, and preventing the entrance of moisture or other electrolytes into the bonding area.

b. Compatible Metals. Metals to be in direct contact should fall as close together in the galvanic series as possible. Compatible groupings of the common metals are given in Table 2-4. The corrosive action between metals of different groups will be the greatest when the metallic union is openly exposed to salt spray, rain, or other liquids. The less exposed the bond, the less the rate of corrosion. The relative degree of exposure may be defined as follows:

(1) Exposed. Open, unprotected exposure to weather.

(2) Sheltered. Limited protection from direct action of weather. Locations in louvered housings, sheds, and vehicles offer sheltered exposure.

(3) Housed. Located in weatherproof buildings.

TABLE 2-4. COMPATIBLE GROUPS OF COMMON METALS

Group	Metals
I	Magnesium
II	Aluminum, aluminum alloys, zinc, cadmium
III	Carbon steel, iron, lead, tin, lead-tin solder
IV	Nickel, chromium, stainless steel
V	Copper, silver, gold, platinum, titanium

TABLE 2-5. BOND PROTECTION REQUIREMENTS

Condition of Exposure	Anode I	II	III	IV	Cathode
Exposed	A	A			II
Sheltered	A	A			
Housed	A	A			
Exposed	C	A	B		III
Sheltered	A	B	B		
Housed	A	B	B		
Exposed	C	A	B	B	IV
Sheltered	A	A	A	B	
Housed					
Exposed	C	C	C	A	V
Sheltered	A	A	A	B	
Housed	A	A	B	B	

c. Bond Protection. When bonds under these different exposure conditions must be made between different groups, they should be protected as indicated in Table 2-5. Condition A means that the couple must have a protective finish applied after metal-to-metal contact has been established so that no liquid film can bridge the two elements of the couple. Condition B means that the two metals may be joined with bare metal exposed at junction surfaces. The remainder of the bond must be given an appropriate protective finish. Condition C indicates that the combination cannot be used except under very unusual circumstances where short life expectancy can be tolerated.

Interior bonds not exposed to moisture or high humidity or when the equipment is normally stored and exposed for only short intervals do not require sealing. Consult Table 2-6 for assistance in choosing a method to protect the bond members against corrosion.

d. Bonding of straps and jumpers. Bonding straps and jumpers shall conform to the following:

(1) Bonding straps shall be attached to the basic members.

(2) Bonding straps shall be installed to be unaffected electrically by motion or vibration.

(3) Braided bonding straps shall not be used for bonding transmitters or other sources of RF fields.

(4) Bonding straps shall be installed whenever possible in areas accessible for maintenance.

(5) Bonding straps shall be installed so that they will not restrict movement of the members being bonded or other members nearby which must be able to move as part of the normal functional operation.

(6) Two or more bonding straps shall not be connected in series to provide a single bonding path.

(7) The method of installation and point of attachment of bonding straps shall not weaken the members to which they are attached.

(8) Bonding straps shall not be compression-fastened through non-metallic material.

e. Fasteners. Acceptable fastener materials for bonding aluminum and copper jumpers to structures are indicated in

TABLE 2-6. PROTECTIVE FINISHES FOR BOND MEMBERS

Type Bond	Finishing Requirements
1. Between Similar Metals	
A. Clad and corrosion resistant aluminum (6061)	Clean and deoxidize
B. Noncorrosion resistant aluminum	Chemically treat per MIL-C-5541 using colored inspectable coating in both members of joint (Alodine 600, Iridite 14).
C. Steel (alloy and carbon)	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.
D. Corrosion resistant steel (18-8 stainless steel)	Clean per TT-C-490 Method I (abrasive) or Method VI (phosphoric acid etch) for machined surfaces.
E. Copper and copper alloys	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.
2. Dissimilar Metals	
A. Corrosion resistant aluminum mated with the following metals:	Clean and deoxide.
(1) Noncorrosin resistant aluminum	Chemically treat per Mil-c-5541, colored inspectable coating (Alodine 600, Iridite 14).
(2) Steel (alloy and carbon)	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.
(3) Copper and copper alloys	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.

TABLE 2-6. PROTECTIVE FINISHES FOR BOND MEMBERS (CONTINUED)

(4) Corrosion-resistant	Clean per TT-C-490, Method I (abrasive) or Method VI (phosphoric acid etch).
B. Noncorrosion resistant aluminum mated with the following metals:	Chemically treat per MIL-C-5541, colored inspectable coating (Alodine 600, Iridite 14).
(1) Steel (alloy and carbon)	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush method.
(2) Copper and copper alloys	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.
C. Steel alloy and carbon) mated with the following metals:	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.
(1) Copper and copper alloys	If entire part is finished, plate with tin, MIL-T-10727, Type I or II. If only faying surface is finished, plate with tin using brush plating method.
(2) Corrosion resistant steel	Clean per TT-C-490, Method I (abrasive) or Method IV (phosphoric acid etch).

TABLE 2-7. METAL CONNECTIONS FOR ALUMINUM AND COPPER JUMPERS

Metal Structure (Outer Finish Metal)	**Connection for Aluminum Jumper**	**Screw Type**	**Connection for Tinned Copper Jumper**	**Screw Type**
Magnesium and Magnesium alloys	Direct or Magnesium washer	I	Aluminum or Magnesium washer	I
Zinc, Cadmium, Aluminum and Aluminum alloys	Direct	I	Aluminum washer	I
Steel (except stainless steel)	Direct	I	Direct	I
Tin, Lead, and Tin-lead solders	Direct	I	Direct	I or II
Copper and copper alloys	Tinned or Cadmium plated washer	I or II	Direct	I or II
Nickel and Nickel alloys	Tinned or Cadmium plated washer	I or II	Direct	I or II
Stainless Steel	Tinned or Cadmium plated washer	I or II	Direct	I or II
Silver, Gold and precious metals	Tinned or Cadmium plated washer	I or II	Direct	I or II

Table 2-7. The arrangement of the metals is in the order of decreasing galvanic activity. The screws, nuts and washers to be used in making the connections as indicated are:

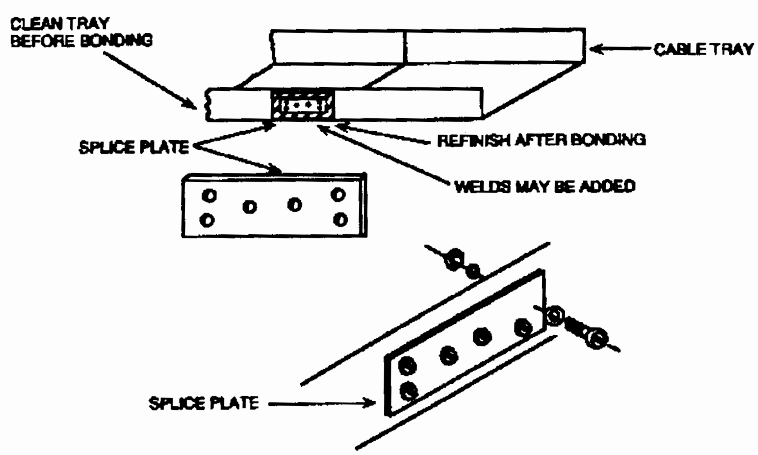
(1) Type I - Cadmium or zinc-plated steel, or aluminum
(2) Type II - Passivated stainless steel.

NOTE: When either type of securing hardware is indicated, Type II is preferred from a corrosion standpoint.

64. <u>TYPICAL TYPES OF STRUCTURAL BONDS</u>.

a. <u>Cable Trays</u>. Utilize cable trays as part of the overall system bonding scheme. Bond each section of each cable tray in the manner shown in Figure 2-27 to the following section to provide a continuous path. The trays should also be connected to equipment housings by wide, flexible, solid bond straps as illustrated in Figure 2-28.

b. <u>Tubing and Conduit</u>. Long spans of conduit should be properly bonded to the structure at both ends of the conduit and at several intermediate points. Ordinary clamps cannot be used to bond flexible conduit since the required pressure on a comparatively small surface area may be sufficiently high to compress or collapse the conduit. Instead of ordinary clamps,



<u>FIGURE 2-27. BONDING BETWEEN SECTIONS OF CABLE TRAYS</u>

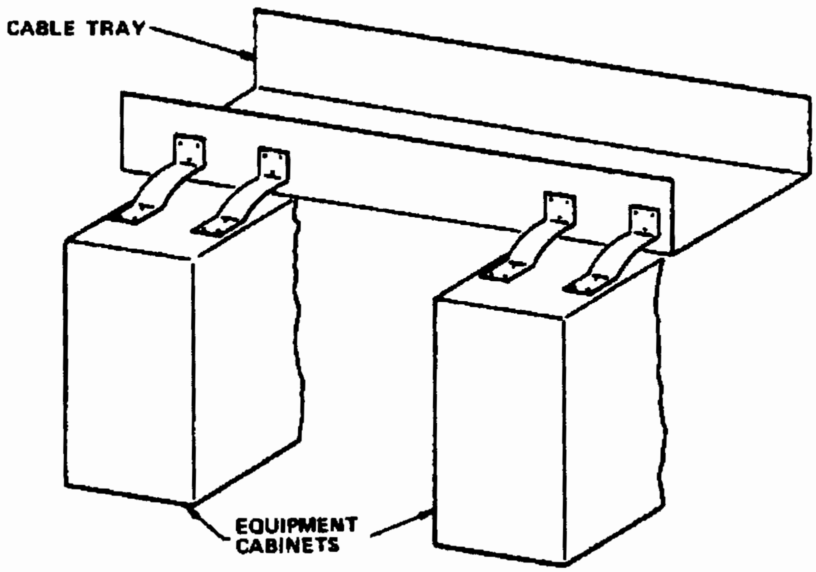


FIGURE 2-28. BONDING OF EQUIPMENT CABINETS TO CABLE TRAY

use a flared, split sleeve (Figure 2-29) 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 2-30 illustrates a method for bonding to rigid conduit. With either type of clamp, the conduit or tubing shall be cleansed of paint and foreign material over

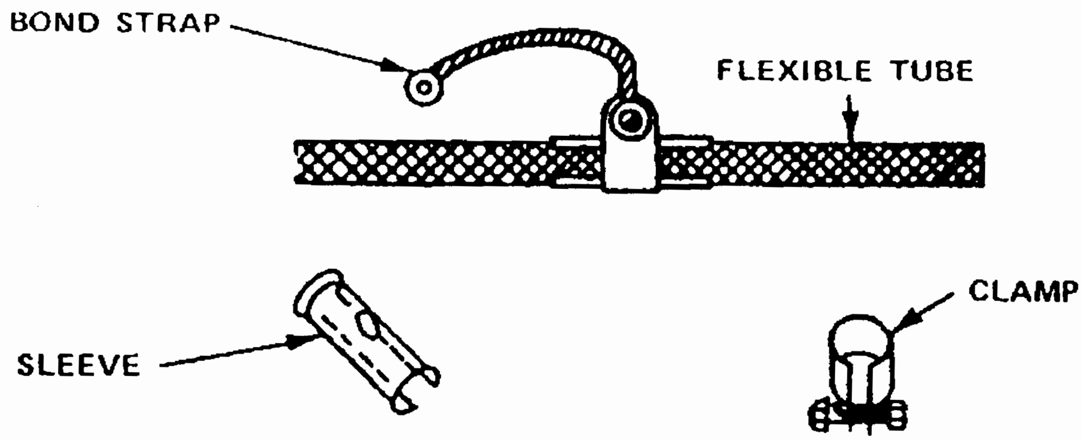


FIGURE 2-29. BONDING TO FLEXIBLE CABLE AND CONDUIT

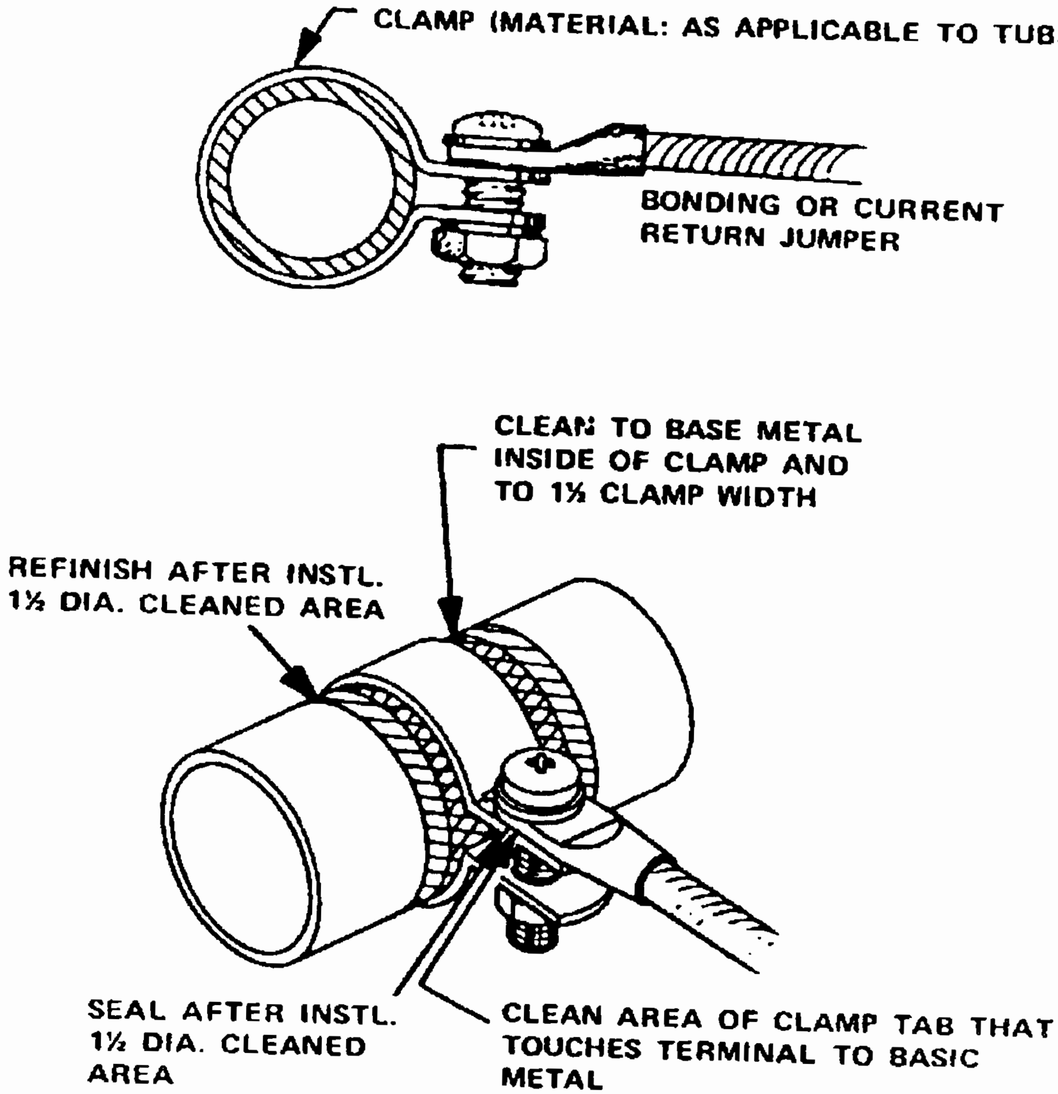


FIGURE 2-30. BONDING TO RIGID CONDUIT

the entire surface covered by the clamps. All insulating finishes shall be removed from the contact area before assembly, and anodized screws, nuts, and washers should not be used to attach contacting parts.

c. Other Examples. Figures 2-31 through 2-36 illustrate recommended methods appropriate for most facilities.

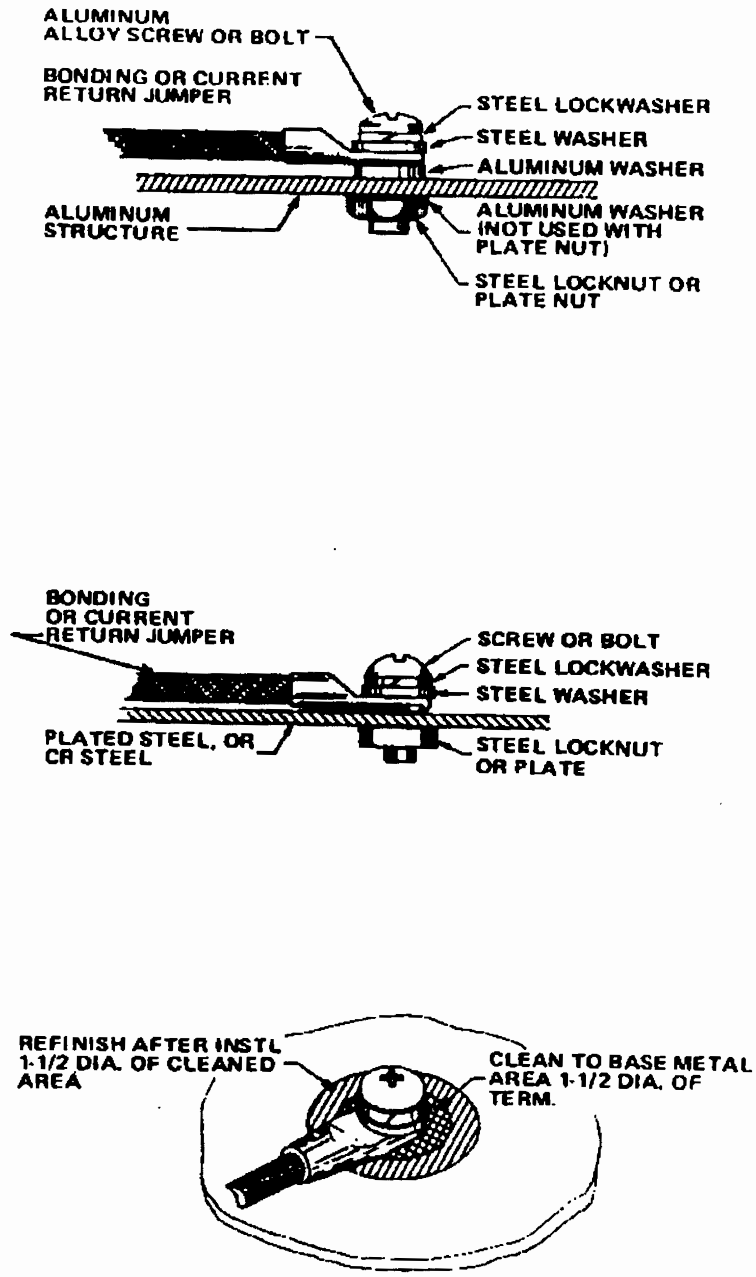


FIGURE 2-31. CONNECTION OF BONDING JUMPERS TO FLAT SURFACE

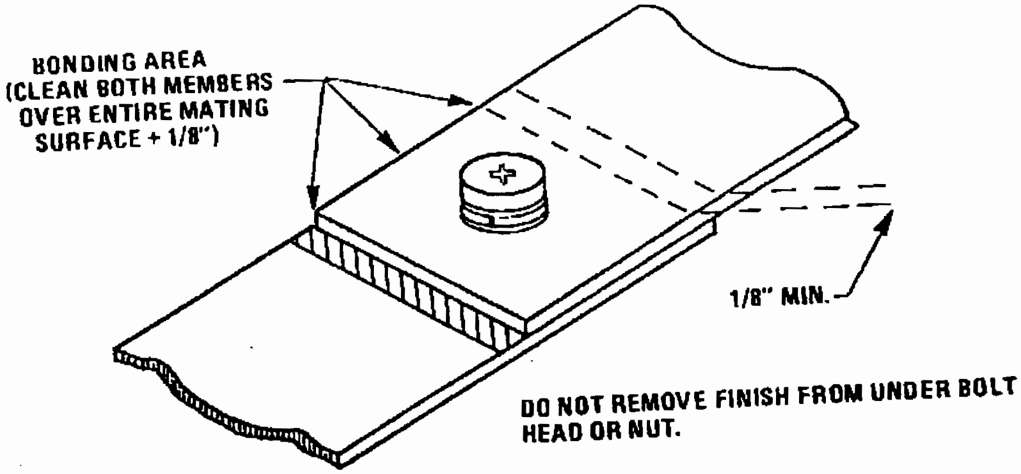


FIGURE 2-32. BOLTED BOND FLAT BASE

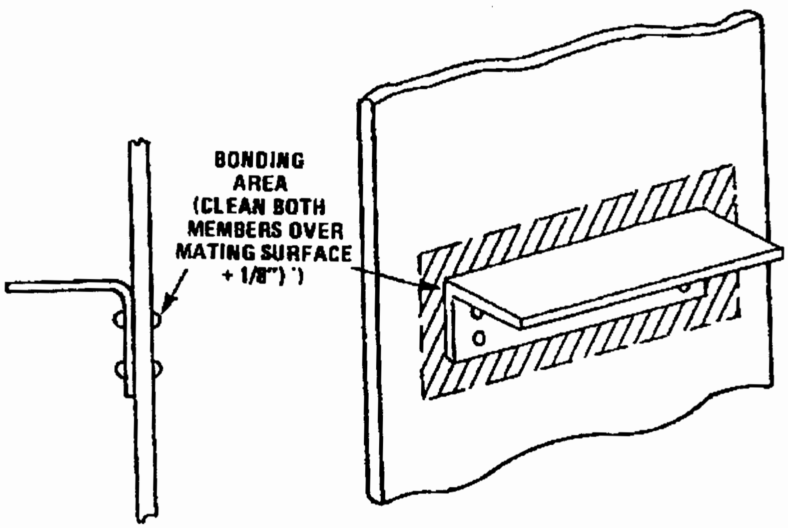


FIGURE 2-33. BRACKET INSTALLATION (RIVET OR WELD)

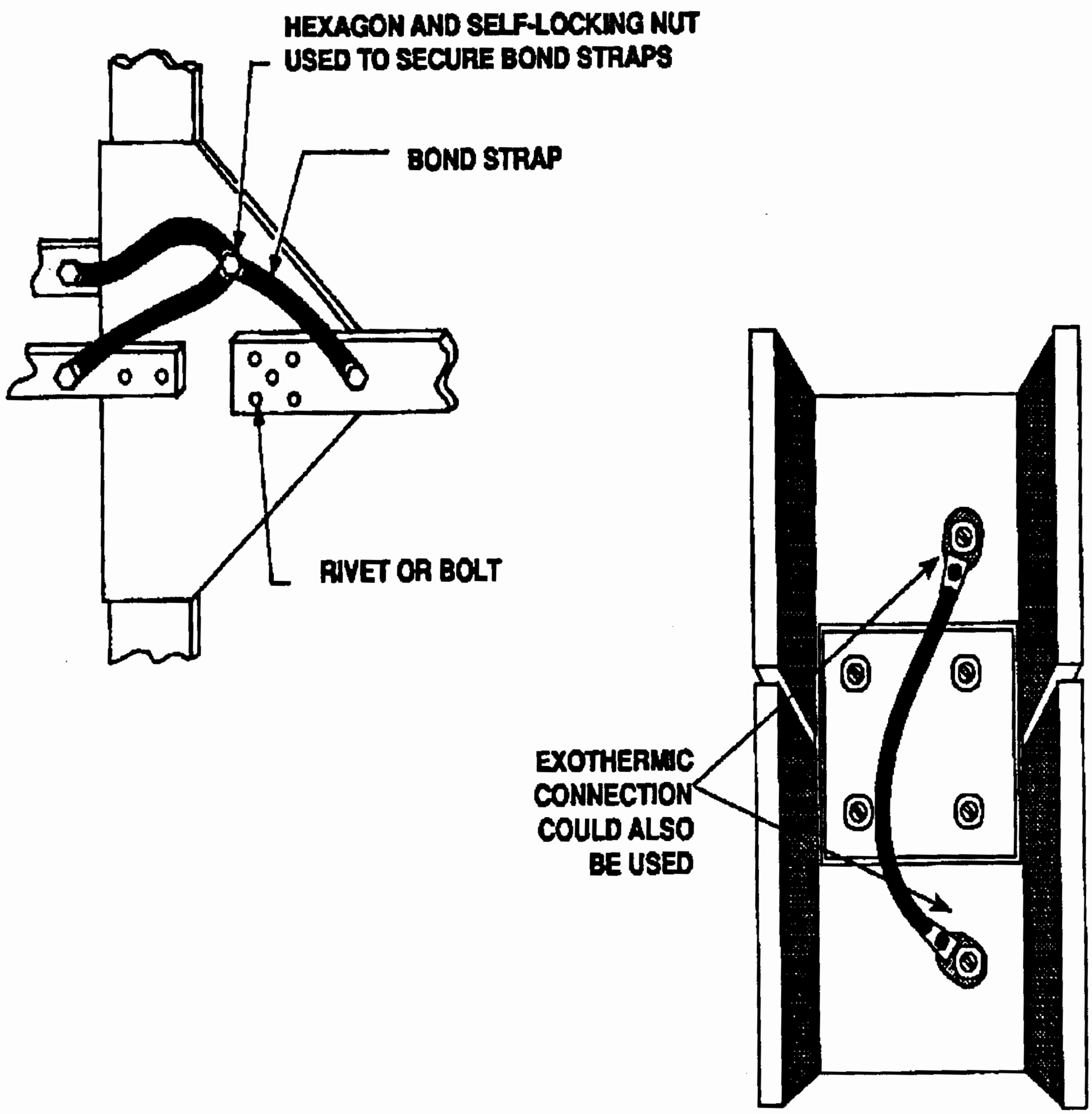


FIGURE 2-34. USE OF BONDING STRAPS FOR STRUCTURAL STEEL INTERCONNECTIONS

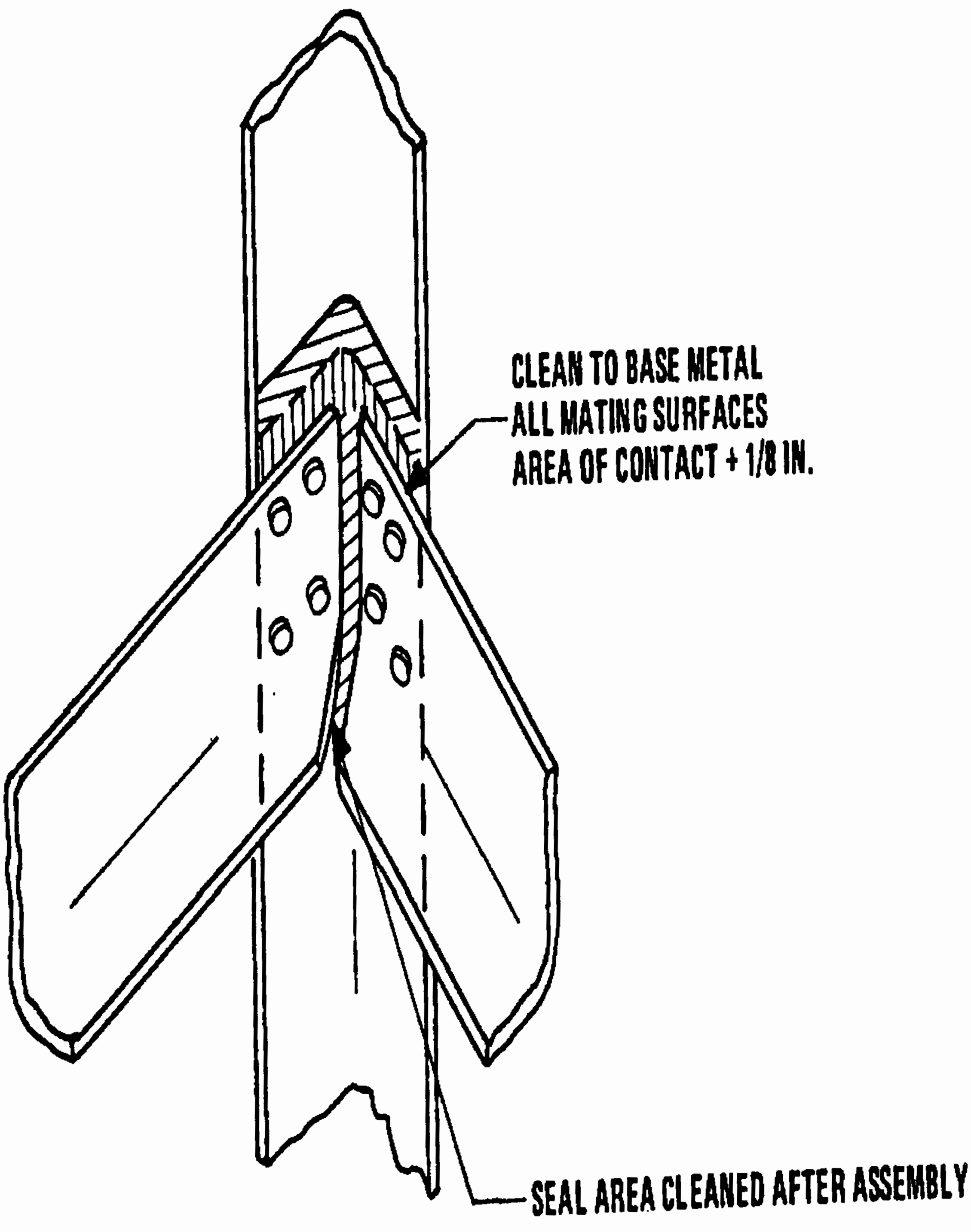


FIGURE 2-35. DIRECT BONDING OF STRUCTURAL ELEMENTS

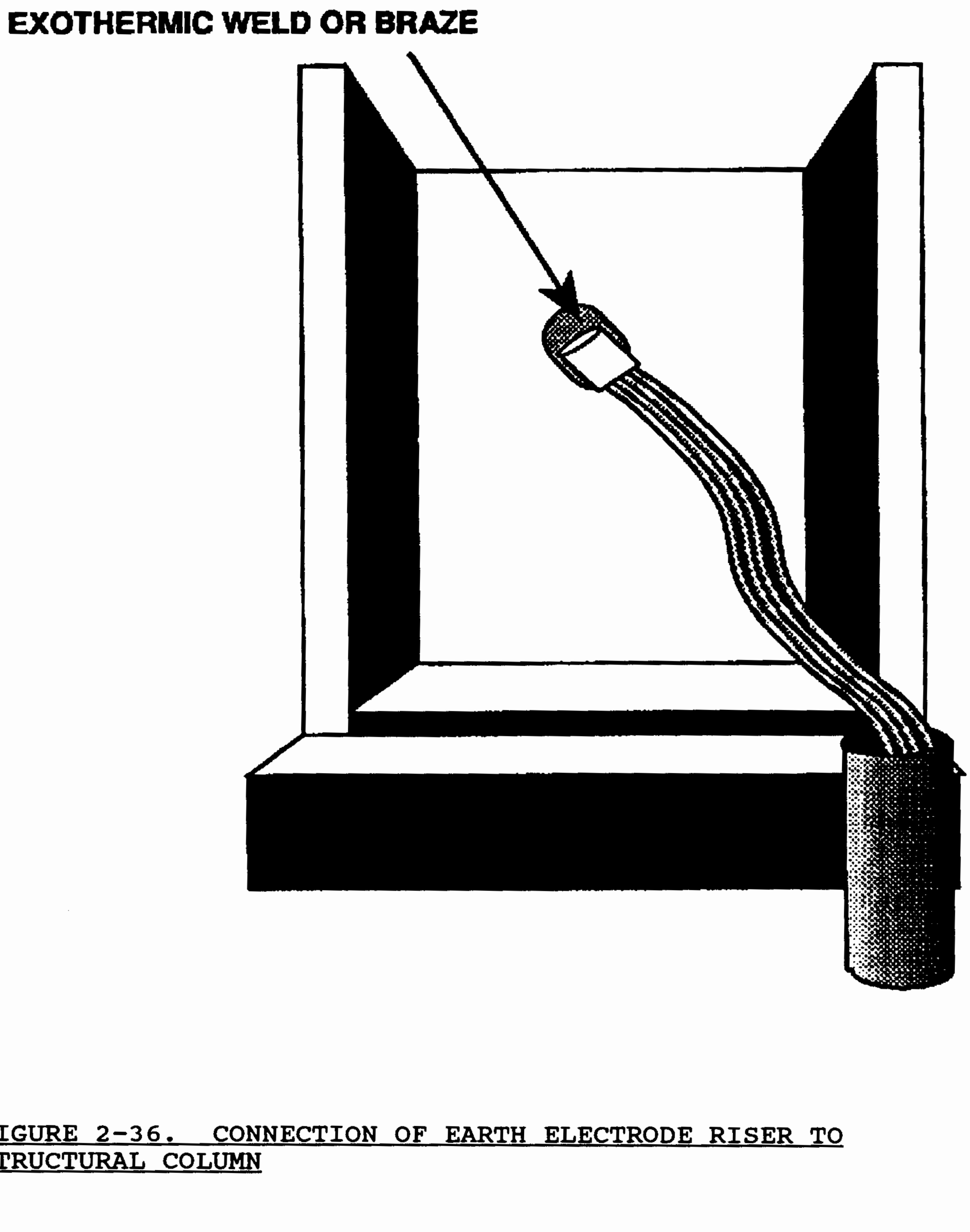


FIGURE 2-36. CONNECTION OF EARTH ELECTRODE RISER TO STRUCTURAL COLUMN

65. - 69. RESERVED.

SECTION 5. SHIELDING DESIGN AND IMPLEMENTATION

70. GENERAL. The shielding provided in a given facility should be adequate to provide the needed equipment and personnel protection. However, it need not go beyond what is required for that particular facility. To determine the shielding required at a facility, the electromagnetic environment at the planned location should first be surveyed. Threat to the environment should be compared with the response properties of the equipment to be located in that environment. If a need for shielding is indicated, then it should be provided either as a part of the facility or the equipment shielding should be upgraded. The final decision will be based on a tradeoff between the known (or estimated) shielding requirements and the relative cost to provide this shielding. Shielding of equipment conductors is described in Chapter 4 of this Order.

71. ESTABLISHMENT OF REQUIREMENTS.

a. Tailor the facility shielding according to the needs of the equipment, or systems, which can be determined by:

(1) Conducting an electromagnetic survey at the facility location (See Order 6950.20). The performance of these surveys requires specialized instrumentation, careful equipment calibration procedures, and calibrated antennas. Have this survey performed by an experienced team.

(2) Examining the history of performance of similar equipment at other facilities with comparable electromagnetic environments.

(3) Considering the measured EMI characteristics of the equipment.

b. If measured susceptibility data (the incident field levels which cause equipment interference) are available, determine the amount of additional shielding necessary by subtracting the equipment susceptibility level (in dB above a microvolt per meter, dB/uV/m) from the field strength (as measured in dB/uV/m) of the incident signals. If the measured signal strength is greater than the susceptibility level, arrange to provide the extra shielding necessary as part of the structure or building, or require that equipment shielding be upgraded (See Chapter 4). If susceptibility data is not available, make a best estimate of the amount of required shielding from the historical performance of the equipment (or similar types) at other sites.

c. Before deciding what type or how much supplemental shielding material is necessary, estimate the amount of shielding inherently provided by conventional building materials and techniques. For example:

(1) Use Figures 2-37 and 2-38. to estimate the shielding provided by normal construction techniques (steel skeleton with brick or concrete block exterior with standard wood, gypsum board, or concrete block interior walls).

(2) Reinforced concrete offers additional shielding because of the presence of the rebar. Estimate the shielding effectiveness of single course rebar to low-frequency magnetic fields from the curve shown in Figure 2-39. Use Table 2-8 to obtain attenuation correction factors to apply to Figure 2-39 for other size rebar and other spacings.

(3) Use Figure 2-40 to determine the relative attenuation of rebar (and other wire mesh or grid) to higher frequency electric fields and

TABLE 2-8. ATTENUATION CORRECTION FACTORS FOR REINFORCING STEEL

Bar Diameter in.	mm	Bar Spacing in.	mm	No. of Courses	Correction Factor dB
2.257	57	12	300	Single	+5
1.692	43	14	360	Single	0
1.000	25	18	460	Single	-6
2.257	57	20	510	Double	+8.5
1.692	43	14	360	Double	+13
1.000	25	16	400	Double	+5

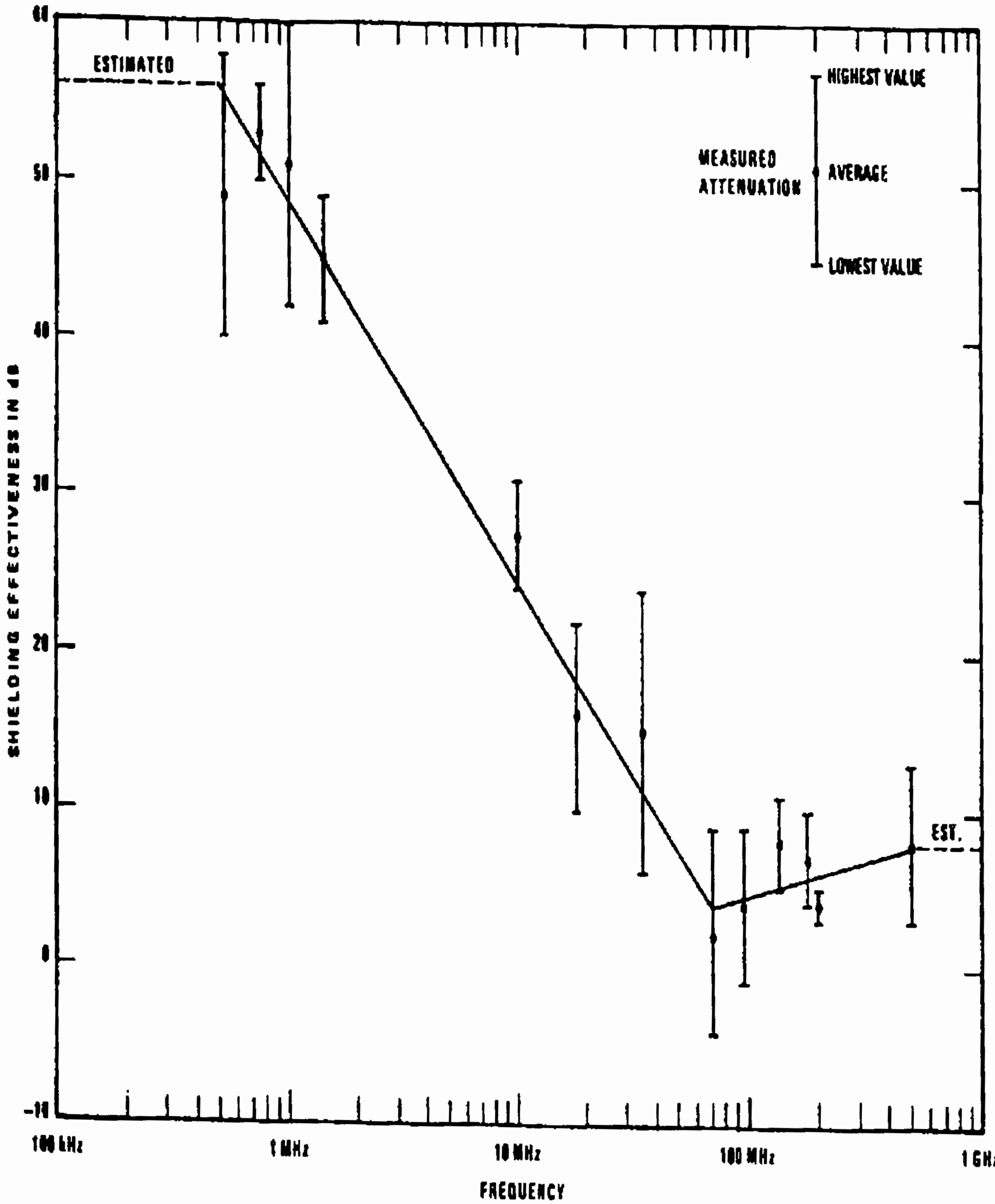


FIGURE 2-37. MEASURED ELECTROMAGNETIC SHIELDING EFFECTIVENESS OF A TYPICAL BUILDING AT 6 FEET INSIDE OUTER WALL

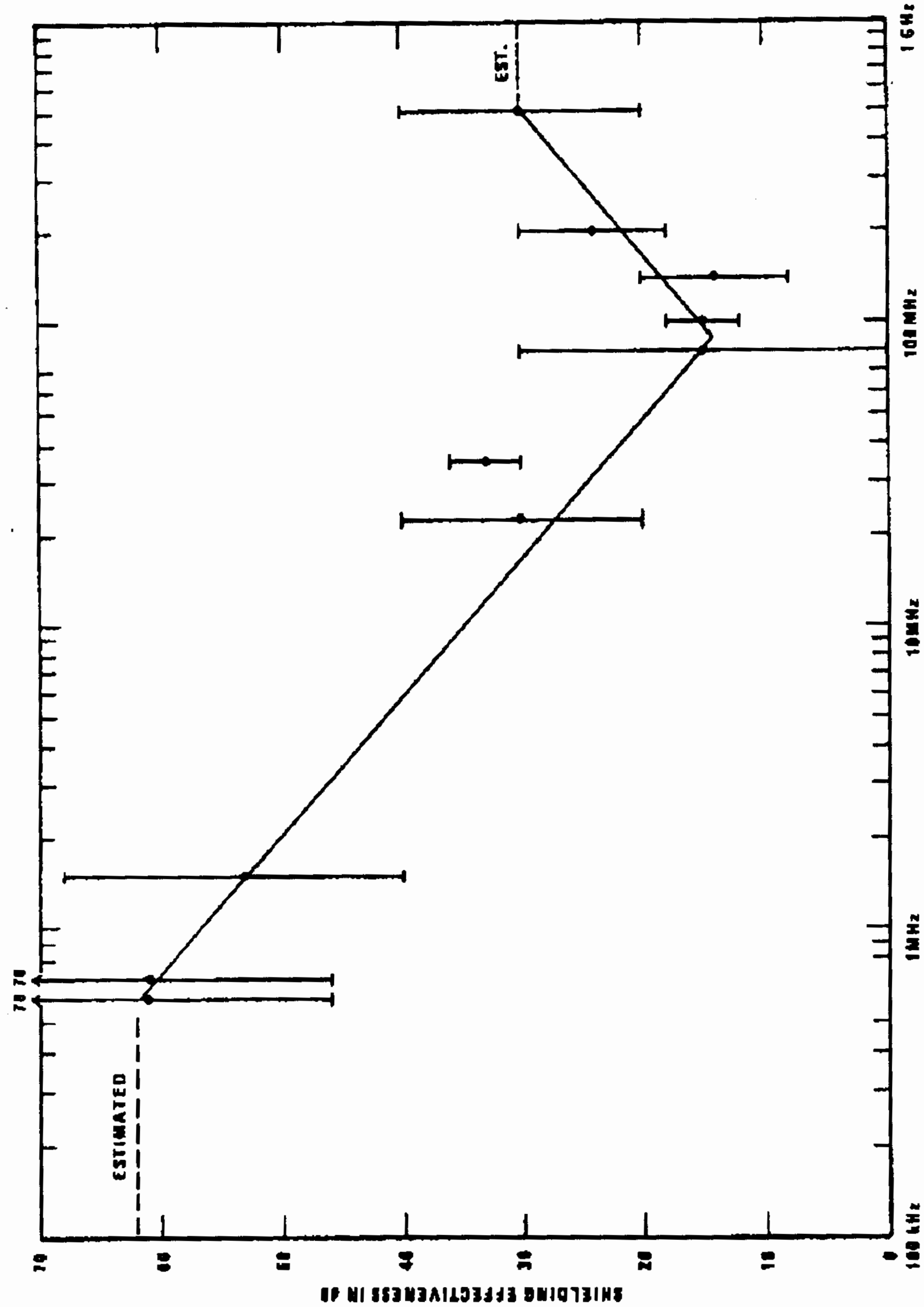


FIGURE 2-38. MEASURED ELECTROMAGNETIC SHIELDING EFFECTIVENESS OF A TYPICAL BUILDING AT 45 FEET INSIDE OUTER WALL

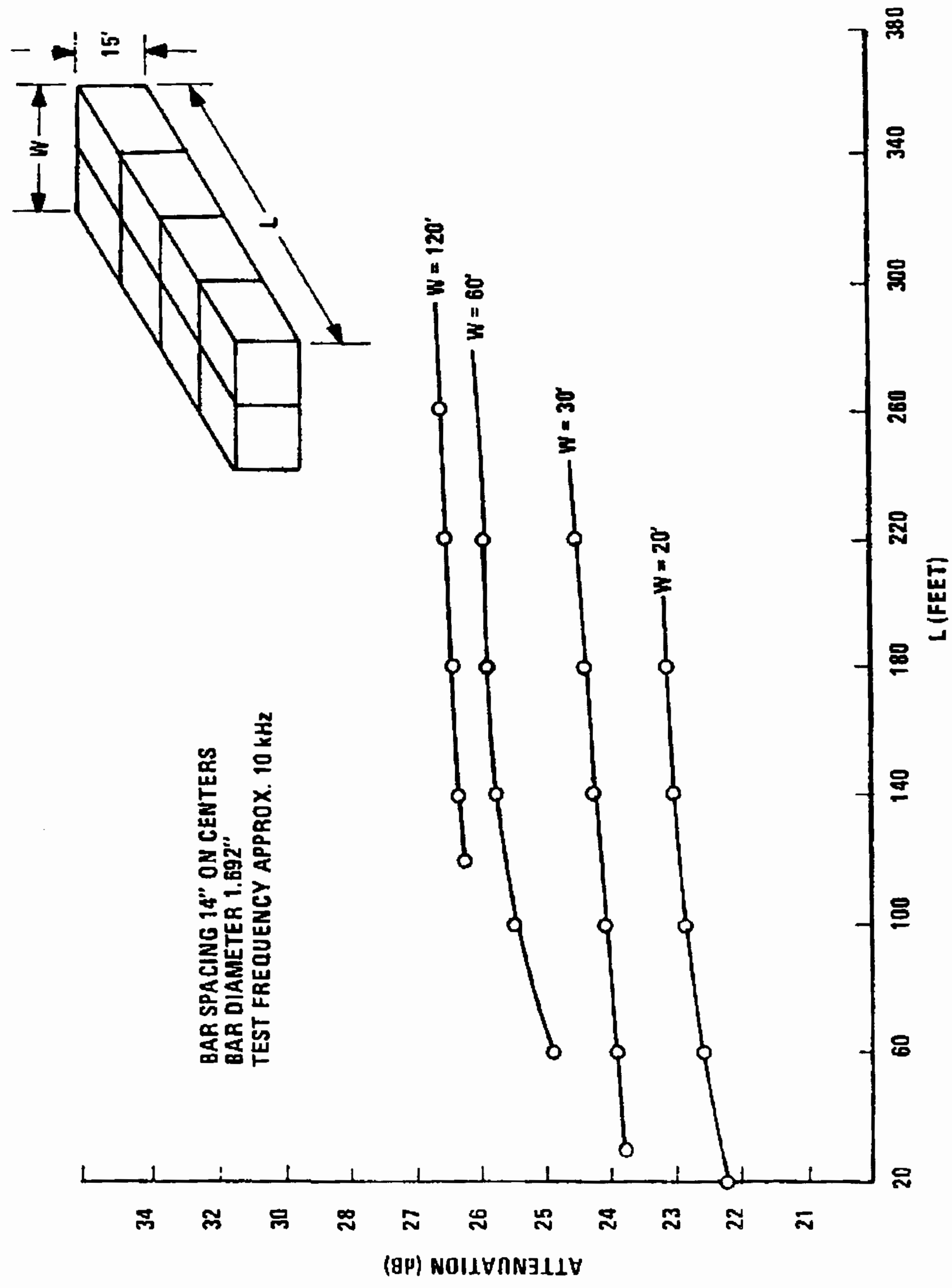


FIGURE 2-39. SHIELDING EFFECTIVENESS OF REBARS

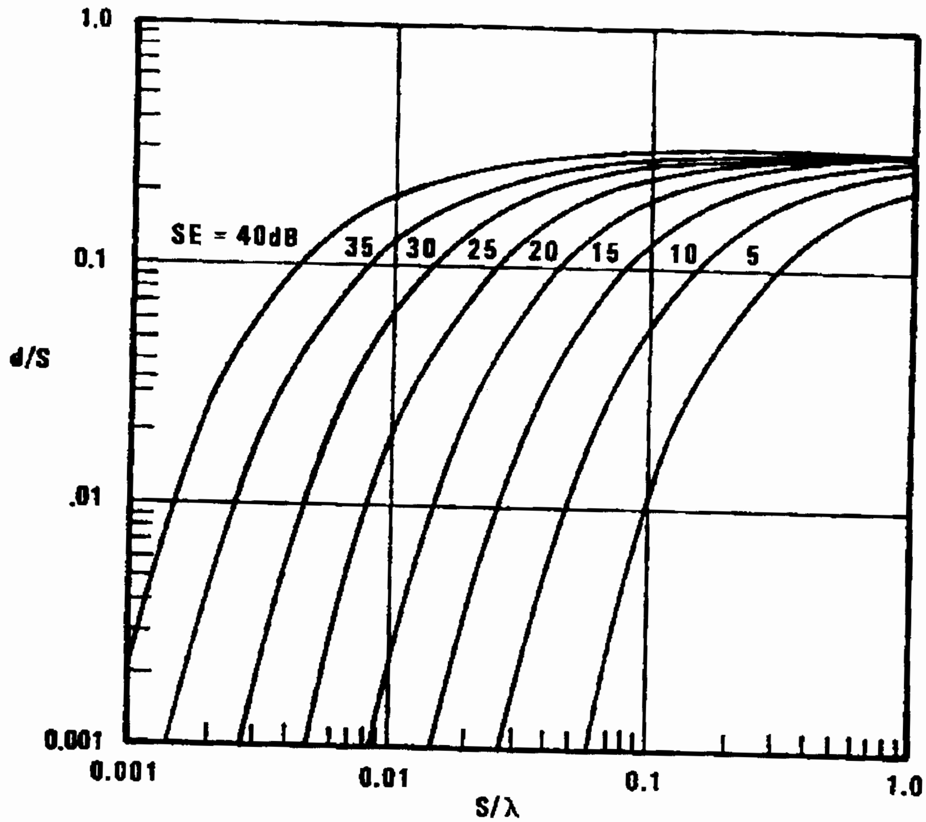


FIGURE 2-40. SHIELDING EFFECTIVENESS OF A GRID AS A FUNCTION OF WIRE DIAMETER, WIRE SPACING AND WAVELENGTH

plane waves. To use Figure 2-40, first calculate the ratio of the wire (or bar) diameter, d, to the wire spacing, S. Then determine the ratio of S to the wavelength, lambda, at the frequency, f, of interest (λ in meters = 3×10^8 divided by f in Hertz). For example, determine the shielding effectiveness at 100 MHz of a 1" x 2" (25.4 mm x 51 mm) grid made of No. 10 AWG (0.1" (2.5 mm) diameter) wire.

(4) Calculation Steps

(a) $\lambda = 3 \times 10^8 / 1 \times 10^8 = 3$ m = 118 inches.

(b) (S/λ) where S=1 = 1/118 = 0.0085 or,

(c) (S/λ) where S=2 = 2/118 = 0.017

depending upon the polarization of the incident wave.

(d) (d/S) where S=1 = 0.1/1 = 0.1

(d/S) where S=2 = 0.1/2 = 0.05

(e) The shielding effectiveness (SE), depending upon the polarization of the field, from Figure 2-40 is either

SE (where S=1) = 35 dB or

SE (where S=2) = 25 dB.

(f) Use the lowest SE (25 dB) for design purposes.

d. If these calculations or estimates indicate a need for additional shielding, incorporate the shielding into the design of the structure and schedule its installation at a time in the construction phase when it can be done most economically.

72. DESIGN GUIDELINES.

a. Design the shielding to conform to the needs of the system. Consider the relative ease of shielding an individual equipment rather than shielding a room or the entire structure.

b. Assure that the shielding provided is sufficient to meet system needs, both known and predicted, but do not excessively over design.

c. Use the inherent shielding properties of the structure to maximum advantage. Employ the small amount of shielding (typically 10-20 dB) offered by reinforced concrete. However, do not expect common building materials such as brick, concrete, wood, fiberglass, or plastic to provide any significant shielding to electromagnetic signals.

d. Locate most sensitive and most critical equipments as close to the core of the structure as operational requirements will permit.

e. To minimize the attenuation requirements on shields, predetermine the location of likely sources of interference such as power substations, engine generators, and RF transmitters; maximize the separation between such sources and potentially susceptible equipment or systems.

f. Where a choice exists as to exterior skin materials for the shelter or structure (e.g., fiberglass versus sheet steel or aluminum) choose metals to take advantage of their better shielding properties. In order to utilize metal sidings as effective shields, the seams must be electrically continuous.

g. Where the signal of greatest threat arrives from predominantly one direction, consider the use of partial shielding, (e.g., cover only one wall, the ceiling, or the floor).

h. Insure that shield continuity is maintained at entry points for signal cables, power conductors, and utility lines.

i. Make certain that windows, doors, and ventilation ports are shielded along with the walls. Use well-bonded screen wire for windows, use metal doors, and apply honeycomb ducts or appropriate screening over ventilation ports.

j. Equip all powerlines supplying shielded areas with powerline filters.

k. Use steel conduits in preference to aluminum conduits to take advantage of the improved magnetic shielding properties of steel.

l. Use enclosed metal wiring ducts or raceways in preference to open mesh or unenclosed types.

m. If the only purpose of the shield is to establish a personnel barrier to prevent inadvertent contact with DC and power frequency hazardous voltages, consider the use of nonconductive shields which may be less expensive. If metal shields are used to provide shock protection, they must be properly grounded to the power distribution grounding system with a properly installed and connected equipment grounding conductor meeting the requirements of the NEC.

73. SELECTION OF MATERIALS. The selection of a shielding material can be done either by choosing a possible metal of a given thickness and the determining if the shielding effectiveness is equal to or greater than the field attenuation desired, or starting with the desired attenuation and determining what thickness of metal sheet or what type of screen is required. Either approach is acceptable.

a. Type of Field. As the first step in the selection of a shield type and material, ascertain the nature of the field by determining whether it is an electric field, a magnetic field, or a plane wave. The distance between the source and the shield relative to signal wavelength gives an indication of the impedance characteristics of the incident field. Note the source may be either the actual signal generator such as a transmitter or it may be the current-carrying conductor such as a powerline or signal cable.

(1) First compute the wave length, λ or the incident signal or signals from

$$\lambda = 3 \times 10^8 / f$$

For f in Hertz, λ will be in meters

(2) If source location is known, measure or estimate r. Then calculate

$$2\pi r/\lambda$$

(3) If $2\pi r/\lambda$ is less than unity, the incident field will either be a high-impedance electric field or it will be a low-impedance magnetic field. To determine which one, try to establish what type of source produced the field. An electric field source is characterized by a high source impedance and relatively low currents. Examples are high-voltage DC power supplies; static discharges; short monopole antennas; etc. A magnetic field source is generally characterized as a low-impedance, high-current source. Typical magnetic sources are loop antennas and powerlines.

(4) If $2\pi r/\lambda$ is unity or greater, assume the incident field is a plane wave.

b. Absorption Loss. Use Figure 2-41 to obtain the absorption loss of the material selected. To use this nomograph, draw a straight line between a point on the right-hand vertical scale that corresponds to the particular metal involved and the correct point on the thickness scale (center scale on the nomograph). Mark where the straight line crosses the unlabeled pivot line. Next, place a straightedge between the marked point on the pivot line and the frequency of interest (left most vertical scale). Read the absorption loss off the compressed scale just to the left of the thickness scale. The determination of the absorption loss of a 15 mil sheet of stainless steel at 1 kHz is illustrated on Figure 2-41. First, line 1 is drawn between stainless steel on the right-hand scale and 15 mils on the thickness scale. The line 2 is drawn between 1 kHz on the left-hand scale and the crossover point. The indicates absorption loss is 3 db. If the specific metal of interest is not indicated on the righthand scale, obtain both the relative conductivity, gr, and the relative permeability, ur from Table 2-9. Multiply gr times ur; use the product as the

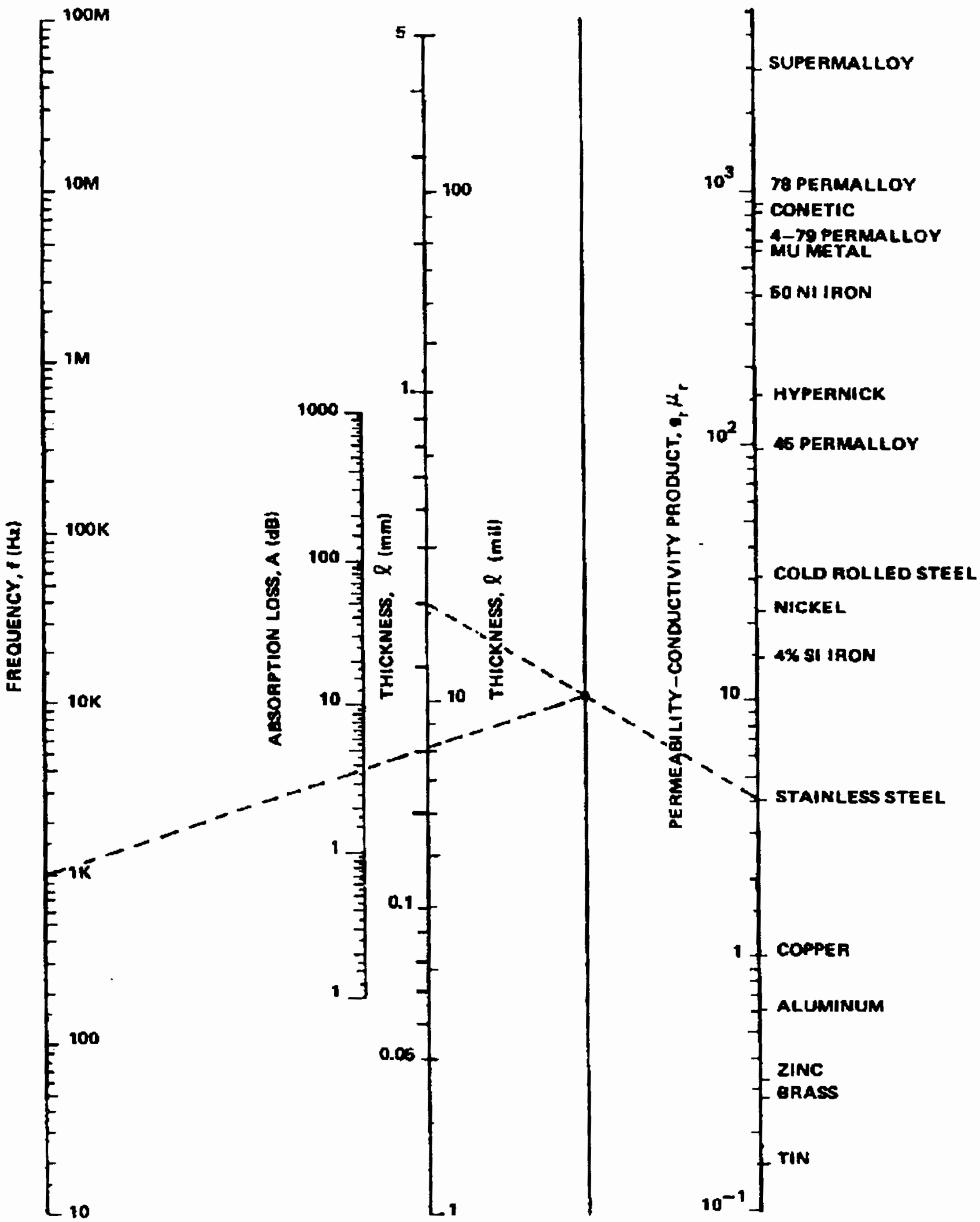


FIGURE 2-41. SHIELD ABSORPTION LOSS NOMOGRAPH

TABLE 2-9. RELATIVE CONDUCTIVITY AND RELATIVE PERMEABILITY OF COMMON METALS

Metal	Relative Conductivity (gr)	Relative Permeability (μr) Initial	Relative Permeability (μr) Maximum	Comments
Alfenol	.011	3,450	116,000	
Beryllium	.377	1		
Brass	.442	1		66% Cu, 34% Zn
Cadmium	.230	1		
Chromax	.017	------	-------	15% Cr, 35% Ni, 50% Fe
Chromium	.663	1		
Cobalt	.177	70	250	
Constantan	.039	------	-------	55% Cu, 45% Ni
Copper	1.000	1		Commercial annealed
Gold	.707	1		
HyMu80	.030	20,000	100,000	80% Ni, 20% Fe
Iron, pure	.178	25,000	350,000	Annealed
Iron, Swedish	.172	250	5,500	
Iron, cast	.057	100	600	
Kovar A	.006	------	-------	29% Ni, 17% Co, 0.3% Mn, 53.7% Fe
Lead	.079	1		
Magnesium	.387	1		
Manganin	.039	------	-------	84% Cu, 12% Mn, 4% Ni
Monel Metal	.041	------	-------	67% Ni, 30% Cu, 1.4% Fe, 1% Mn

TABLE 2-9. RELATIVE CONDUCTIVITY AND RELATIVE PERMEABILITY OF COMMON METALS (CONTINUED)

Metal	Relative Conductivity (gr)	Relative Permeability (μr) Initial	Maximum	Comments
Mumetal	.034 - .069	20,000	100,000	71-78% Ni, 4.3-6% Cu, 0-2% Cr, bal. Fe
Nickel	.250	110	600	
Nickel-silver	.062	-------	-------	64% Cu, 18% Zn, 18% Ni
Palladium	.160	1		
Permalloy	.038	2,500	25,000	45% Ni, 55% Fe
Permendure	.066	800	4,500	50% Co, 1-2% V, bal. Fe
Platinum	.164	1		
Rhodium	.338	1		
Rhometal	.019	1,000	5,000	36% Ni, 64% Fe
Sendust	.022 - .029	30,000	120,000	10% Si, 5% Al, 85% Fe (cast)
Silver	1.064	1		
Steel	.078 - .133	50	=100	0.4%-0.5% C, bal. Fe
Steel, manganese	.025	-------	-------	13% Mo, 1% C, 86% Fe
Steel, silicon	.034	500	7,000	4% Si, 96% Fe (hot rolled)
Steel, stainless	.019	-------	-------	0.1% C, 18% Cr, 8% Ni, 73.9% Fe
Supermalloy	.029	100,000	1,000,000	79% Ni, 5% Mo, 16% Fe
Tin	.051	1		
Titanium	.036	1		
Tungsten	.315	1		
Zinc	.287	1		

right-hand location for line 1 and complete the determination. Given the frequency and the desired absorption loss, this nomograph can be used to determine the thickness and/or type of metal needed.

c. Shielding Effectiveness. The total shielding effectiveness is the sum of the absorption and the reflection loss. Use Figure 2-42 to determine the reflection loss of various metals to magnetic fields; use the nomograph of Figure 2-43 to determine the reflection loss of electric fields. The procedures for using these nomographs are similar to that described previously for determining absorption lose. Note that the right-hand scale is based on the ratio of relative conductivity to relative permeability instead of the product of the two as used in the absorption loss nomograph.

(1) Determine the reflection loss for plane waves with the use of Figure 2-44. Simply lay a straightedge between the metal of interest (or the correct gr/ur ratio on the right-hand scale and the frequency of interest on the left-hand scale; read the reflection loss on the scale in between.

(2) Thin shields with low values of absorption loss can experience re-reflections which may cause the estimates of shielding effectiveness to be in error. If the absorption loss is less than 10 dB, see Order 6950.20 for ways to account for the effect of re-reflections.

d. Metal Foils. Consider the use of thin metal foils for shielding high frequency (broadcast frequencies and above) plane and electric fields. Use Figures 2-45 and 2-46 to estimate the amount of shielding that can be achieved with aluminum and copper.

74. CONSTRUCTION GUIDELINES.

a. Securely ground all metal shields.

b. All seams and joints must be well bonded. Welded seams are highly desirable in enclosures which must provide a high degree (80 dB) of RF shielding or are intended for Electromagnetic Pulse (EMP) protection. Where welding is impractical, solder or knitted gaskets should be used to supplement the mechanical fasteners. Figures 2-47 and 2-48 show two recommended techniques for constructing seams in shields.

c. Limit openings (windows, doors, ventilation ports) and penetrations (signal lines, powerlines, utilities) to the lowest possible number and restrict dimensions to a minimum.

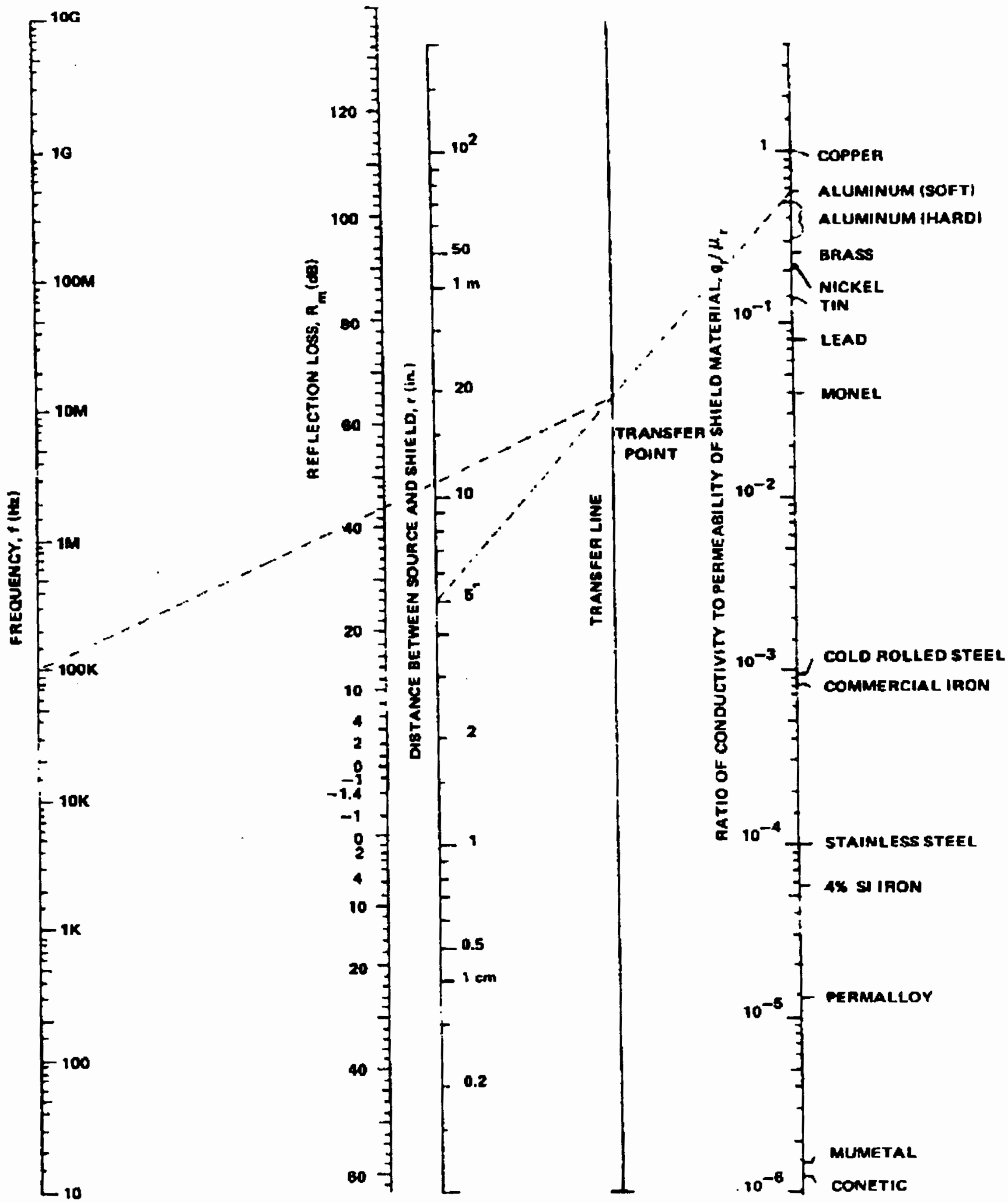


FIGURE 2-42. NOMOGRAPH FOR DETERMINING MAGNETIC FIELD REFLECTION LOSS

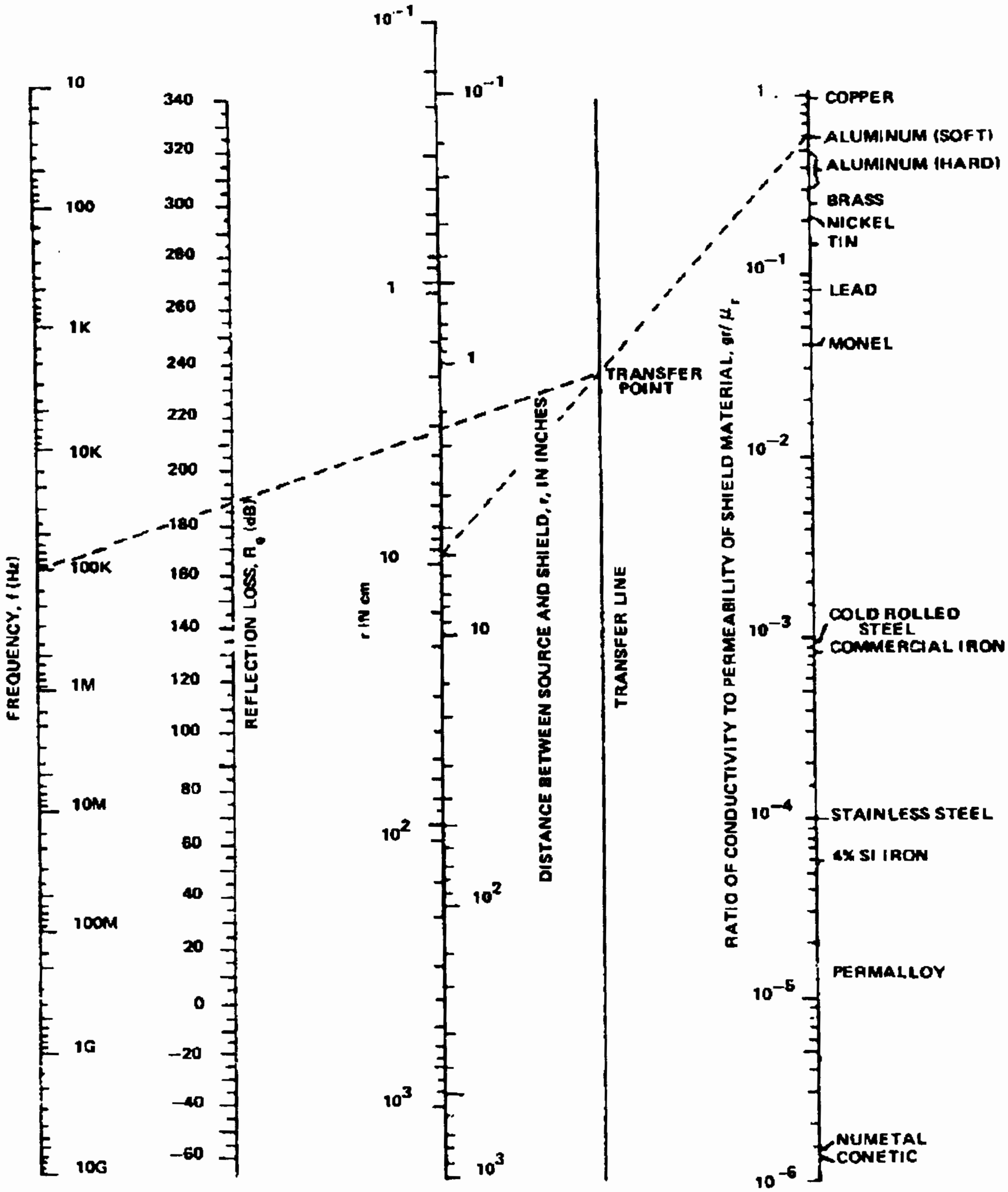


FIGURE 2-43. NOMOGRAPH FOR DETERMINING ELECTRIC FIELD REFLECTION LOSS

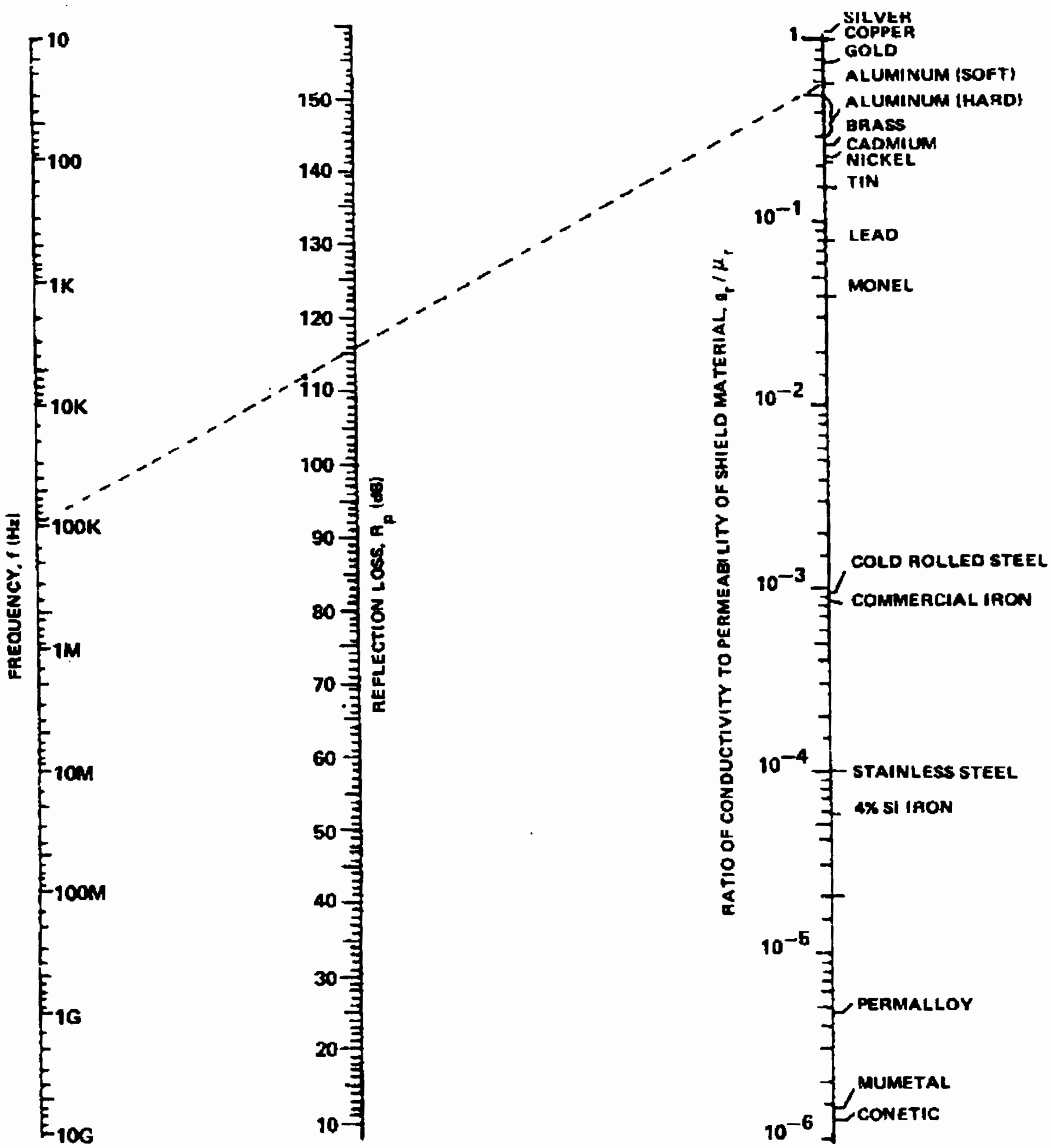


FIGURE 2-44. NOMOGRAPH FOR DETERMINING PLANE WAVE REFLECTION LOSS

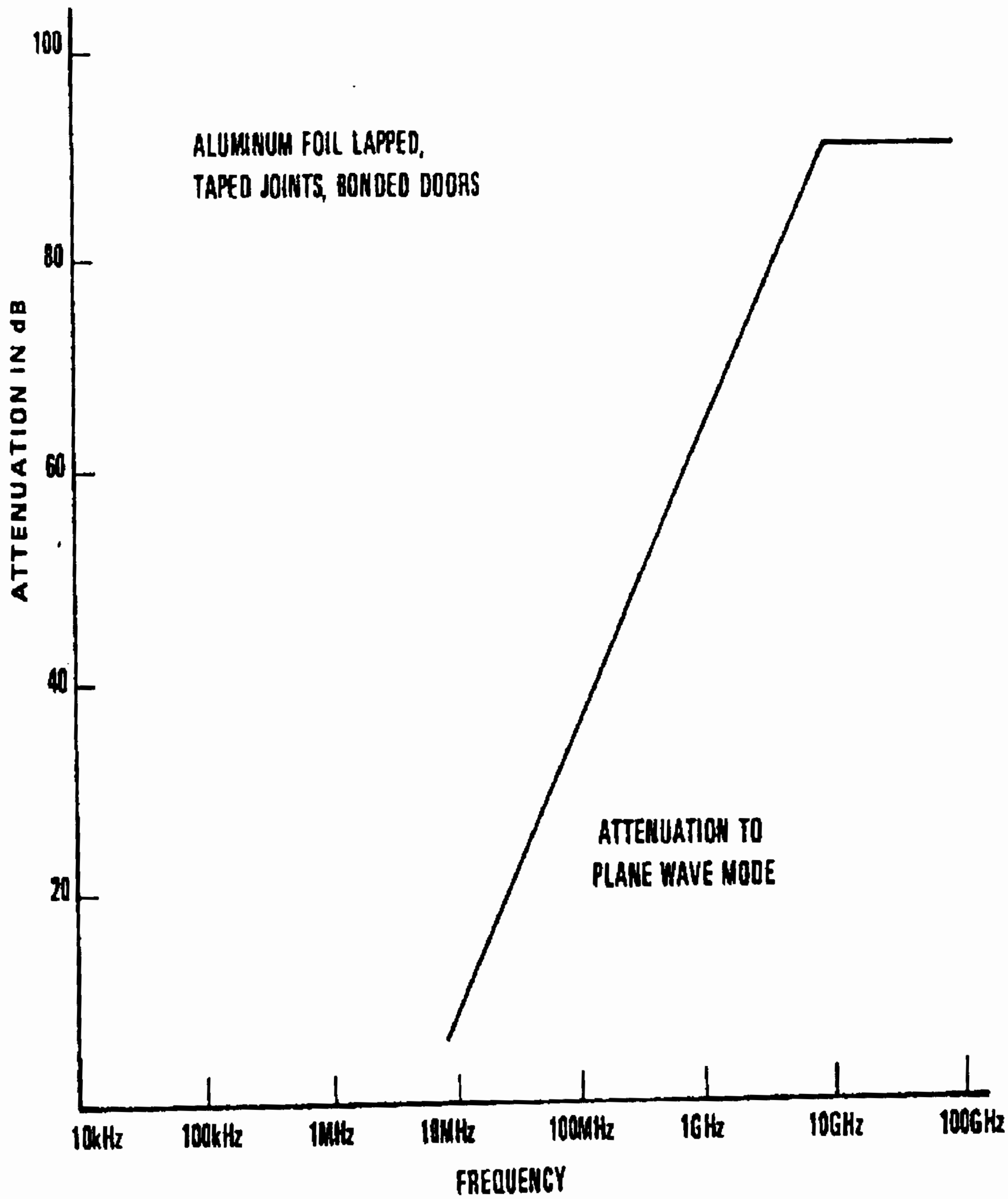
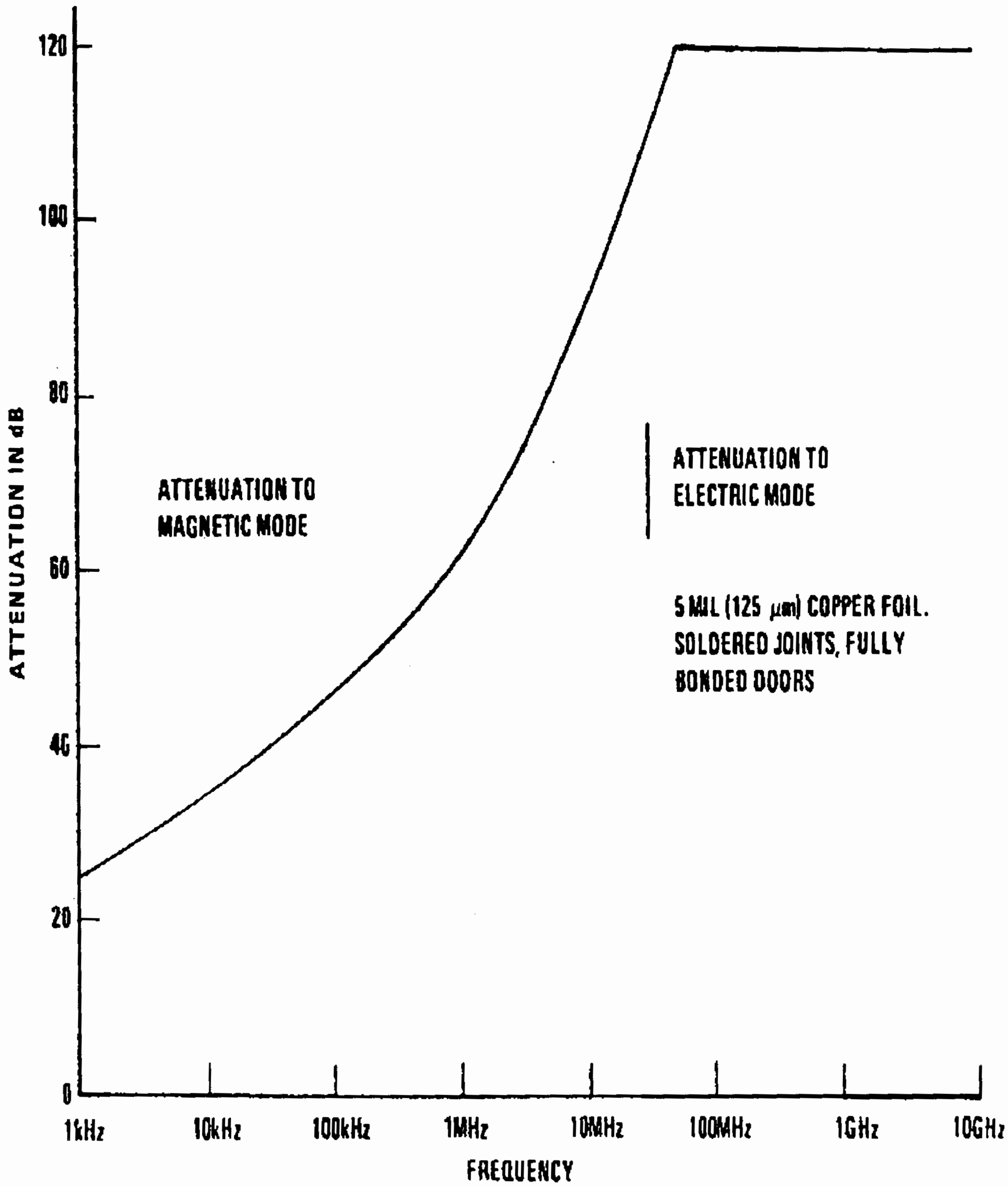


FIGURE 2-45. SHIELDING EFFECTIVENESS OF ALUMINUM FOIL SHIELDED ROOM



<u>FIGURE 2-46. SHIELDING EFFECTIVENESS OF COPPER FOIL SHIELDED ROOM</u>

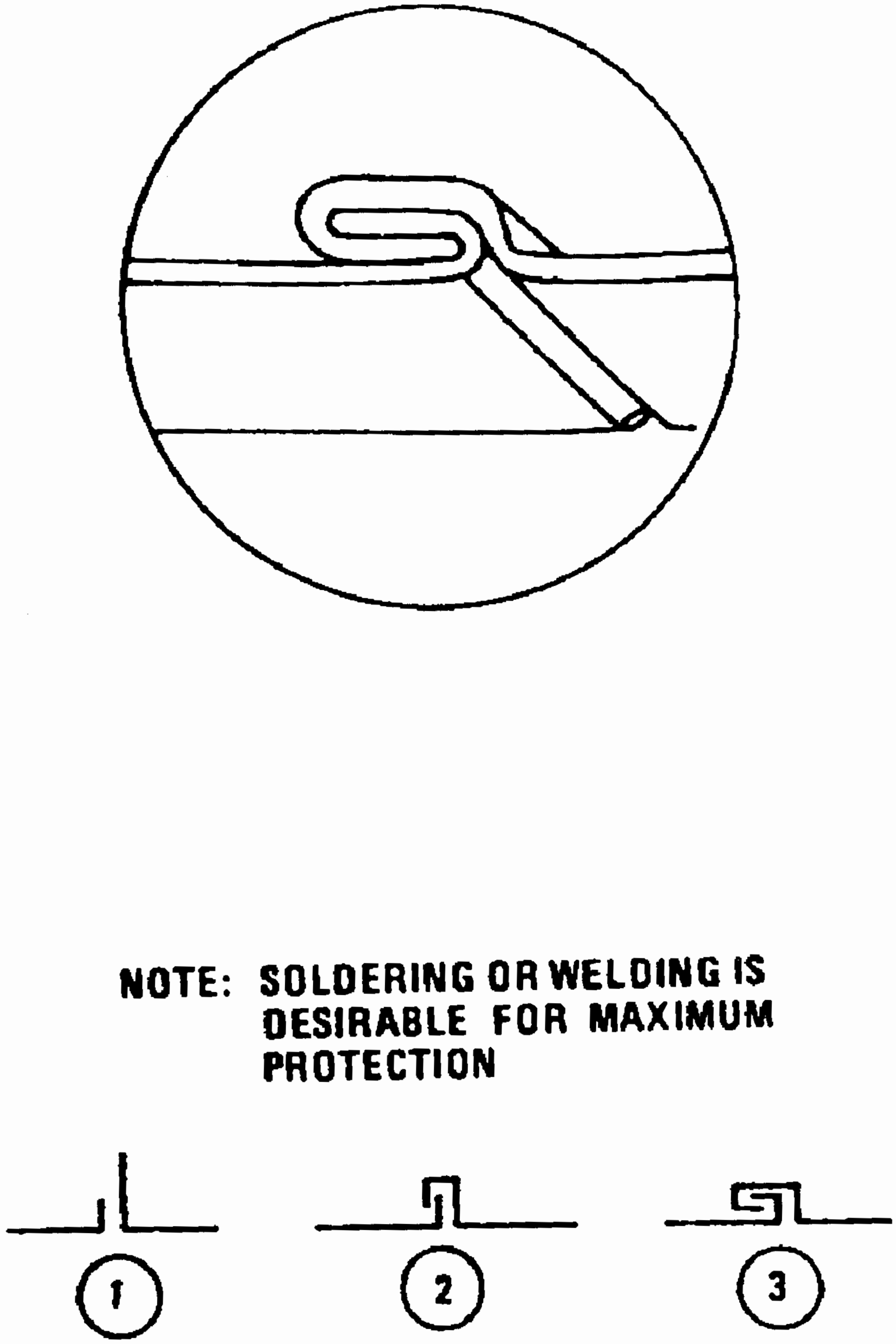


FIGURE 2-47. FORMATION OF PERMANENT OVERLEAF SEAM

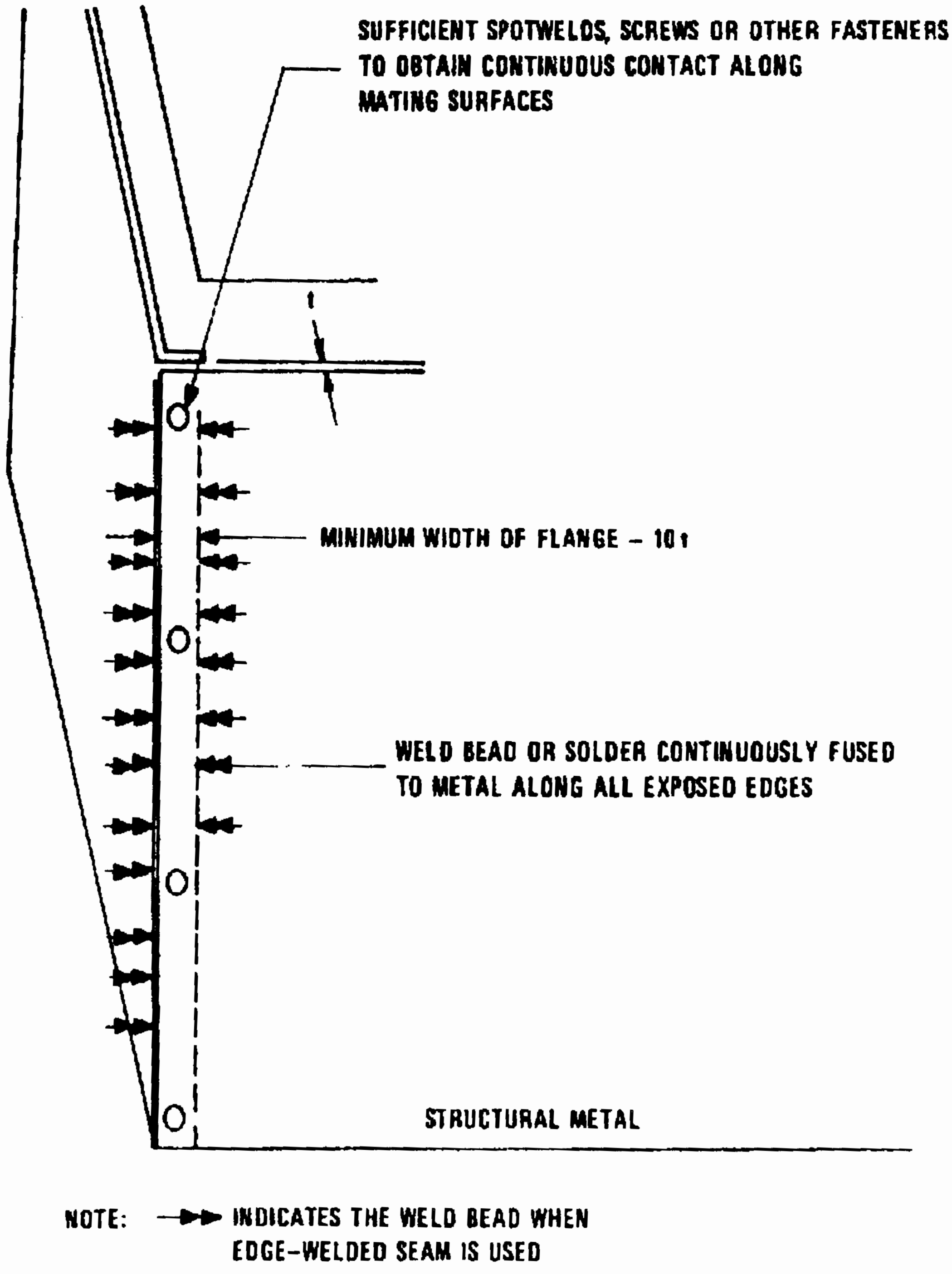


FIGURE 2-48. GOOD CORNER SEAM DESIGN

(1) If holes through the shield are necessary, see Order 6950.20 to determine the optimum size and spacing.

(2) Use honeycomb (see Order 6950.20) for the shielding of ventilation ports wherever possible. Where forced ventilation is used through ports shielded with either honeycomb or wire mesh, predict the pressure drop with the aid of Figure 2-49. A larger blower will generally be necessary to

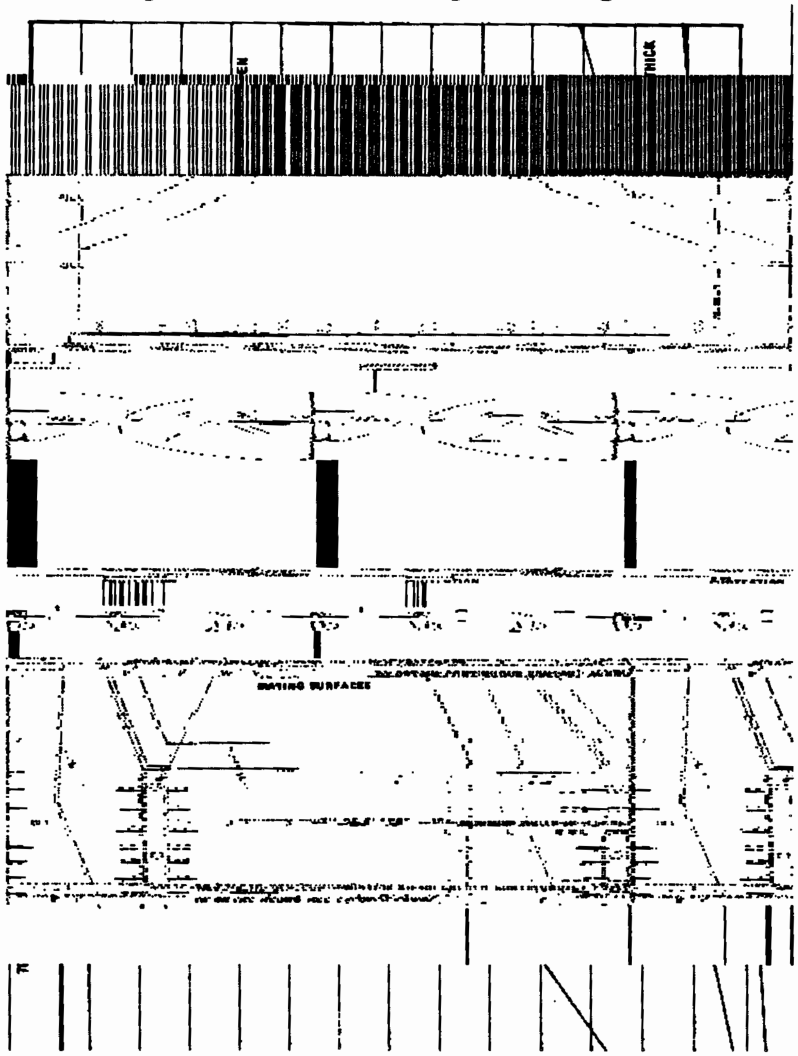


FIGURE 2-49. PRESSURE DROP THROUGH VARIOUS MATERIALS USED TO SHIELD VENTILATION OPENINGS

provide the same volume of air through a shielded port than would be required through an unshielded port.

d. Peripherally bond metallic utility lines to the shield at entrance point. Nonmetallic lines, entering through waveguide-below-cutoff ducts or tubes, may also be used for water, gas, and compressed air. See Order 6950.20.

e. Cover all openings required for visual access with wire screen or conductive glass (see Order 6950.20). Insure that the screen or glass is carefully bonded to the enclosure around the perimeter of the opening.

f. Doors should be metal with solid, uniform contact around the edges. Wire mesh gaskets or finger stock should be provided.

g. For large shielded enclosures where high traffic volume is expected, consider the use of waveguide-below-cutoff hallways.

h. Grounding of shields for equipment connections and cable connections in Chapter 4, Section 3 of this order.

75. - 79. RESERVED.

SECTION 6. LIGHTNING INDUCED SURGE AND TRANSIENT PROTECTION FOR ELECTRICAL AND ELECTRONIC SYSTEMS

80. GENERAL. Electrical and electronic equipments at various facilities have been severely damaged by lightning induced surges and transients. The surges and transients occur on externally exposed lines that directly interface equipment. Externally exposed lines are outside lines, buried, overhead, etc., that are exposed to the weather. These lines include AC service conductors, and electronic equipment signal, status, control and intrafacility AC and DC powerlines to electronic equipment. This section identifies surge and transient sources and damage, waveforms and amplitudes of projected surges and transients on different types of lines, frequency of surge and transient occurrence, and effective implementation methods to preclude electronic equipment damage and operational upset when surges and transients occur. Fiber optic conductors may be used where feasible for electronic landlines as this type of conductor is not effected by lightning as it is not susceptible to lightning induced transients.

NOTE: Surges and transients actually are the same and the terminology is interchangeable. For the purpose of clarity, the FAA uses the following terminology; surges on AC power service lines into the facility and transients on the landlines to electronic equipments.

81. SURGE AND TRANSIENT SOURCES AND EQUIPMENT DAMAGE.

a. Surge and Transient Sources. Electrical and electronic equipment comprising an operating system is susceptible to damage from lightning induced surges and transients via two primary sources as follows:

(1) Transient Surges coupled to equipment from incoming AC power service conductors. This will be noted as surges hereafter.

(2) Transient Surges coupled to electronic equipment by connected facility control, status, power, data and signal lines that originate or terminate at electronic equipment located external to the building or structure housing the electronic equipment of interest. This will be noted as transients hereafter.

b. Surge and Transient Damage. Damage resulting from lightning induced surges and transients occur in many forms. Entire electronic equipment chassis have been exploded and burned, and wall-mounted equipments blown off the wall by large magnitude surge energy. However, two forms of damage are most prevalent and are listed below:

(1) Sudden catastrophic electronic component failure at the time of surge or transient occurrence.

(2) Shortened operating lifetime of components resulting from overstress at time of surge or transient occurrence.

82. MINIMIZING DAMAGE.

a. Damage can be minimized, and in most cases eliminated, by properly using the generally field-proven protective methods detailed in this section. In order to be cost effective and to provide effective protection, allocation of protection must be divided into general categories which are:

(1) Surge and transient protection by means of metal conduit or guard wires for outside lines that interface electronic equipment to be protected.

(2) Installation of transient suppression devices on both ends of exterior landlines immediately after electronic equipment building penetration or at exterior electronic equipment termination.

(3) Installation of surge arresters on incoming AC service entrance conductors at the facility service disconnecting means.

(4) Transient suppression included as an integral part of protected electronic equipment at the exterior line-equipment interfaces.

(5) Installation of fiber optic cables for exterior electronic landlines.

b. If realistic surge and transient protection is to be designed, the frequency of occurrence, amplitude, and waveforms of surges and transients, and the withstand levels of protected electronic equipment must be defined. The withstand level is the short-duration voltage and current surge levels that electronic equipment can withstand without overstressing or destruction of components occurring, and without electronic equipment upset occurring. The information required for effective protection is provided in this section. The most susceptible components are identified together with typical withstand levels. Frequency of surge and transient occurrence is also provided. Because of the large physical size of incoming AC service conductors, less impedance (resistance and reactance) is presented to surge current flow. As a result, amplitude and waveforms of surges appearing at the AC service inputs are quite different from the transients appearing at the electronic control, status, data, signal landlines and the in-system powerline inputs. Therefore, protection for incoming AC service power service conductors is discussed separately from that for the externally exposed electronic landlines.

83. SUSCEPTIBLE COMPONENTS. Integrated circuits, discrete transistors and diodes, capacitors, and miniature relays, transformers, and switches used in the design of solid state equipment are very susceptible to damage from lightning induced surges and transients. Other components are not immune to damage, but are susceptible to a much lesser degree. Standards do not exist for specifying the withstand level against surges and transients for most electronic equipment and components. Therefore, accurate information must be obtained from manufacturers, laboratory testing performed or conservative engineering estimates made. Typical withstand level limits for some common types of electrical and electronic equipment and electronic components are:

a. Integrated circuits: 1.5 times normal rated junction and Vcc voltage.

b. Discrete transistors: 2 times normal rated junction voltage.

c. Diodes: 1.5 times peak inverse voltage (PIV).

d. Miniature relays, transformers, and switches: 3 times rated voltage.

e. Capacitors: 1.5 times DC working voltage unless transient dielectric punch-through voltage known.

f. DC power supplies with step-down transformer and diode bridge: 1.5 times diode PIV rating times the transformer secondary to primary voltage ratio.

g. Small motors, small transformers and light machinery: 10 times normal operating voltage.

h. Large motors, large transformers and heavy machinery: 20 times normal operating voltage.

84. FREQUENCY OF SURGE AND TRANSIENT OCCURRENCE. Precise calculation of the number of lightning induced surges and transients that will occur at a specific location in a specified time interval is not possible. However, enough observations have been made to permit statistical evaluation of the number of lightning flashes that are likely to occur in an area with a known average number of thunderstorm days per year. Some flashes may not produce any surges or transients while others will produce several surges and transients. The available data, after considerable averaging, and rounding, is provided in Table 2-10. The table lists a typical number of surges and transients that might be expected to occur from lightning strikes at facilities located in high and low-incidence lightning areas. When used in conjunction with Figure 2-50, the table will permit calculation of the number of lightning surges that will occur anywhere in the United States in a 10 year period. (NOTE: The figure in Table 2-10, under high incidence area, decreases by 10 percent for each decrease of 10 thunderstorm days per year.)

TABLE 2-10. FREQUENCY OF TRANSIENT OCCURRENCES

Number of Lightning Surges
In 10 Years at One Facility

High Incidence Area (100 Thunderstorm Days Per Year)	Low Incidence Area (10 Thunderstorm Days Per Year)
1750	175

85. SURGE DEFINITION, AC SERVICE CONDUCTORS. Prediction of the exact amplitude, waveforms, and number of surges and transients that will occur at a particular facility over a specific time interval is not possible. However, current amplitudes and waveforms induced by direct lightning strikes have been measured and recorded. Also, sufficient data has been recorded to permit statistical calculation of waveforms and amplitudes that are likely to occur. This data is provided in subsequent paragraphs. Frequency of occurrence is provided in Paragraph 84 and Table 2-10.

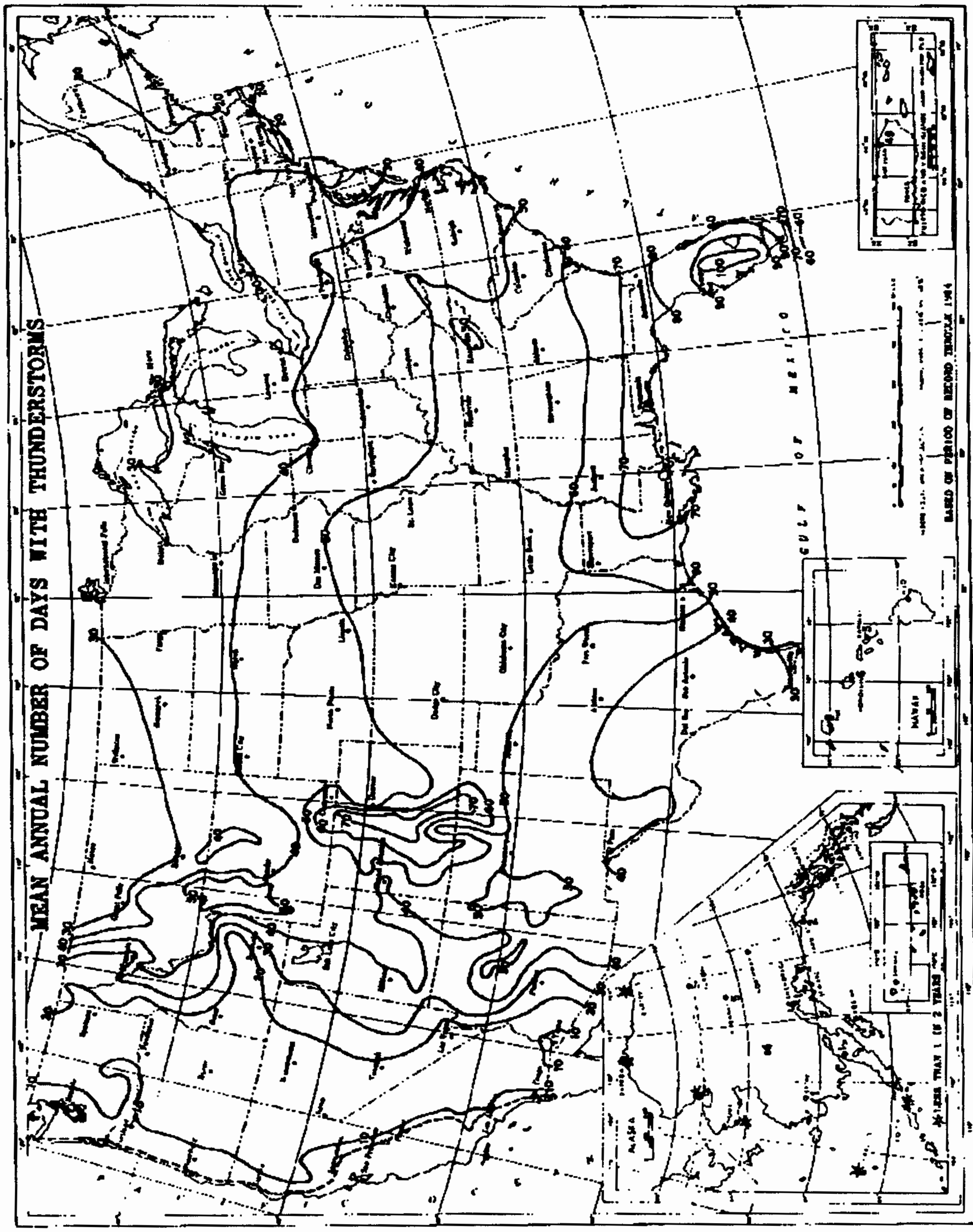


FIGURE 2-50. MEAN NUMBER OF THUNDERSTORM DAYS PER YEAR FOR THE UNITED STATES

a. Surge Amplitudes From Direct Strikes. Measured current amplitudes resulting from direct lightning strikes have varied from 1,000 amperes to 250,000 amperes. Results of several thousand measurements have been reduced and are provided in Table 2-11. As shown in Table 2-11, typical peak current is 10 to 20 kiloamperes. Table 2-12 tabulates the peak current amplitudes measured for 2721 flashes. The median peak value for the peak currents was approximately 15 kiloamperes. This is in agreement with the typical values provided in Table 2-11, and there is agreement among authoritative sources that the peak current for a large percentage of strikes is in the 10-to-30 kiloampere range. Note that in Table 2-12, 1818 of the 2721 current amplitudes, or 66.8%, were in the range of 1-to-20 kiloamperes. Also note that only 14% were greater than 40,000 amperes, and it follows directly that 86% of the peak amplitudes were 40 kiloamperes or less. Only 45 of the 2721 measured amplitudes, or 1.65%, were above the 100-kiloampere level. Also, it is emphasized that the peak current amplitudes noted in the foregoing resulted from direct strikes to metal towers for primary transmission lines.

b. Induced Surge Amplitude. After installation of the appropriate surge suppression, induced surges will still occur as a result of close proximity, high intensity strikes, and some lightning surge energy will be coupled through the service transformer onto the incoming AC service lines. The amplitude of those coupled and induced surges will be reduced a minimum of 50% of direct strike amplitudes due to earth resistance, attenuation of electromagnetic fields due to propagation through air, and coupling losses imposed by the service transformer windings. Therefore, 86% of the surge currents appearing at a facility service disconnect means will be 20,000 amperes or less, and the greater percentage of the surges, 68%, will be in the 500 ampere to 10,000 ampere range. Only 1% of the surges will be above 50 kiloamperes, and only 0.1% will be above 75 kiloamperes. Table 2-13 provides a tabulation of surge amplitudes and the percentage of surges on incoming AC lines that will as a maximum be of the amplitude listed.

c. Surge Waveforms, AC Service Lines. Waveshapes for surges will vary depending on the proximity of the strike, intensity of the strike, and length and inductance of the incoming AC service conductors. Table 2-11 lists the typical time to peak as 1.5 to 2 microseconds and 40 to 50 microseconds as the typical time from the start of the pulse until the current decays to 50% of peak value. Thus a typical waveform for current surges induced by a direct strike is 2-by-40 microseconds. Surges measured at the service disconnecting means (amplitude in excess of 3,000 volts) have had rise times of 1 to 2 microseconds and decay times of 20 to 40 microseconds. However, the inductance of some incoming AC service conductors will slow down the rise time slightly. Most manufacturers of secondary AC surge arresters use either 8-by-20 or 10-by-20 microsecond current waveforms for testing and specification purposes, primarily because the waveform is relatively easy to generate while a 2-by-40 microsecond waveform is quite difficult to generate. The 8-by-20 and 10-by-20 microsecond waveforms are considered suitable for testing. However, installed arresters should allow for the following conditions:

(1) Surges with rise times faster than 8 microseconds may appear across the arrester terminals resulting in higher sparkover or turnon voltage for the arrester than specified.

(2) Surges with decay times up to 40 microseconds may appear across the arrester terminals which will require the arrester to dissipate considerable more surge energy than would be required for a 20 microsecond decay time.

TABLE 2-11. PARAMETER FOR DIRECT LIGHTNING STRIKE CURRENT

Parameter	**Minimum**	**Typical**	**Maximum**	**Comments**
Number of return strokes per flash	1	2 to 4	26	
Time between strokes (ms)	3	40 to 60	100	Without continuing current
Peak current per return stroke (kA)	1	10 to 20	250	
Time to peak current (μs)	<0.5	1.5 to 2	30	
Rate of rise (kA/μ)	<1	20	210	
Time to half-value (μs)	10	40 to 50	250	
Duration of continuing current (ms)	50	150	500	
Peak continuing current (amperes)	30	150	1600	

TABLE 2-12. PEAK CURRENTS FROM DIRECT LIGHTNING STRIKES

Range of current, (amperes)	No. of Flashes with Peak Current in Range	No. at or above Level	Percentage at or above Level
1,000- 5,000	567	2,721	100
5,001- 10,000	611	2,154	79.2
10,001- 20,000	640	1,543	56.7
20,001- 30,000	296	903	33.2
30,001- 40,000	227	607	22.3
40,001- 50,000	140	380	14.0
50,001- 60,000	80	240	8.82
60,001- 70,000	61	160	5.88
70,001- 80,000	22	99	3.64
80,001- 90,000	21	77	2.83
90,001-100,000	11	56	2.06
100,001-110,000	11	45	1.65
110,001-120,000	9	34	1.25
120,001-130,000	9	25	0.918
130,001-140,000	7	16	0.588
140,001-150,000	2	9	0.331
150,001-160,000	3	7	0.257
160,001-170,000	0	4	0.137
170,001-180,000	1	4	0.147
180,001-190,000	0	3	0.110
190,001-200,000	1	3	0.110
200,001-210,000	0	2	0.073
212,000	1	2	0.073
218,000	1	1	0.037

TABLE 2-13. SURGE AMPLITUDES

Amplitude (Amperes)	**Percentage of as Listed Amplitude**
500 to 2,500	21%
2,501 to 5,000	23%
5,001 to 10,000	24%
10,001 to 20,000	19%
20,001 to 30,000	8%
30,001 to 40,000	3%
40,001 to 50,000	1%
50,001 to 75,000	0.9%
75,001 to 100,000	0.1%

86. METHODS FOR SURGE PROTECTION ON AC SERVICE CONDUCTORS.

Proper use of the following provide effective protection against lightning-induced surges on incoming AC powerlines.

a. Completely enclosing buried lines in ferrous metal, electrically continuous, watertight conduits.

b. Use of overhead guard wires to protect overhead lines.

c. Use of buried guard wires to protect direct buried cables.

d. Installation of a secondary AC surge arrester at the facility service disconnecting means.

e. Including transient suppressors (to protect against voltage and current levels that may exceed the withstand levels of the electronic equipment that may be passed through the AC surge arrester) as an integral part of electronic equipment at AC power inputs and rectifier outputs of low level (5 to 48 volt) power supplies, when a power supply operates from the facility AC power and supplies operating power for solid state equipment.

f. Installation of suitable lightning arresters on the primary and surge arresters on the secondary of the service transformer.

87. USE OF FERROUS METAL CONDUITS. Since surges and transients are induced on buried conductors by electromagnetic waves created by lightning current flow, all buried incoming AC service lines shall be completely enclosed in ferrous metal, watertight conduit. Rigid galvanized (heavy wall) steel shall be used. To be effective, the conduit must be electrically continuous and effectively bonded to earth ground at each end. No. 2 AWG bare copper stranded cable is suitable for the earth ground connection, and exothermic welds provide effective bonding in earth. FAA-approved pressure connectors are suitable for connection above ground. The conduits should extend from the service transformer housing to the facility service disconnecting means and shall be effectively bonded to both, which in turn are effectively bonded to the earth at the transformer and at the facility with copper conductors sized in accordance with the NEC for grounding electrode conductors. The use of rigid galvanized steel conduits will eliminate low-level induced surges and transients and will attenuate otherwise high-amplitude induced surges by 90%.

Although properly installed conduits provide effective protection against induced surges, they do not provide protection against surges that enter the service entrance conductors directly from the secondary of the transformer. They do however, attenuate the surge current thereby adding a degree of protection that would not be available if direct buried cables were installed.

88. USE OF GUARD WIRES. Overhead guard wires to protect overhead incoming AC service conductors and buried guard wires to protect buried cable runs not enclosed in rigid galvanized steel conduits have proven effective in protecting against lightning induced surges on the conductors.

a. Overhead Guard Wire. Since enclosing overhead incoming AC service conductors in metal conduit is not feasible, the use of overhead guard wires has been proven to provide an effective level of protection for overhead service conductors against direct strikes. The guard wire, when used, must be located above and parallel to the service conductors.

To be effective, the height of the guard wire must be that required to form a zone of protection (see Section 2, this Chapter) for the service conductors, and the guard wire must extend from the secondary of the service transformer for the facility to the facility service entrance fitting. Also, at each end the guard wire must extend to, and be bonded to, an effective earth ground. This is a ground rod at the base of the transformer pole and a ground rod in the earth electrode system at the facility. Either copper or aluminum guard wire is satisfactory.

In most cases, use of aluminum wire will be more cost effective. Size of the guard wire should be the same as the service conductors, but need not exceed 1/0 AWG. Since the NEC prohibits running aluminum wire into the ground, UL-approved bimetallic connectors must be used to connect the aluminum wire to a copper wire before extending the guard wire into earth.

Exothermic welding is the most effective method for bonding the guard wire to a ground rod. The guard wire is effective in providing protection against direct lightning strikes to protected service conductors and also provides a low level of protection against surges and transients induced on the lines by close-proximity strikes and cloud-to-cloud discharges.

b. Buried Guard Wire. The use of a buried guard wire embedded in the soil above and parallel to direct buried cables, including armored cables, or cables installed in non-metallic conduits, has provided effective attenuation of lightning induced surges. The AC service conductors shall be run in rigid galvanized steel (heavywall) conduit. However, in the rare instances where this is not practical, and for other AC conductors to exterior equipment where the use of rigid galvanized steel conduit is not feasible, the use of a guard wire is required. Bare No. 6 AWG solid copper conductor has provided effective protection during experimental use. To be effective the guard wire must be embedded in the soil a minimum of 10 inches (25 cm) above and parallel to the protected cable run or duct. The guard wire must be effectively bonded to the ground rod at the service transformer and to the earth electrode system of the facility housing the service disconnect means. Exothermic welds shall be used to provide the bonding. Lengths of guard wires exceeding 300 feet (90 m) shall have an additional connection to earth ground. For each 300 feet (90 m) or portion thereof in excess of 300 feet, an earth ground connection shall be made utilizing 3/4 inch by 10 foot ground rods located not less then six (6) feet from the guard wire. These connections to earth should be located at approximately equal spacings between the ground connections at each end of the guard wire installation.

c. Where conductors are installed as direct buried or in non-metallic conduits, rigid steel conduits should be used to enter the transformer housing and the facility structure, terminating on and securely bonded to the transformer housing and the service disconnecting means, respectively. The conduit from the transformer housing shall extend a minimum of 5 feet beyond the ground rod for the transformer installation. The conduit from the service disconnect means shall extend a minimum of

5 feet past the counterpoise wire of the facility's earth electrode system. The open end of each conduit shall be effectively bonded to its related earth ground system. Where armored cable is installed, the cable armor shall be bonded to the earth electrode system at the point of entry into the facility with a No. 2 bare copper conductor. Where this is not feasible, the armor shall be bonded to the ground bus of the service disconnecting means.

89. SECONDARY AC SURGE ARRESTER. Installation of a properly selected secondary AC surge arrester at the facility service disconnecting means provides the best method for ensuring that high energy surges are not coupled to electronic equipment by AC distribution lines within the facility. The surge arrester installed must have certain characteristics to ensure adequate protection.

a. Characteristics.

(1) Be capable of safely dissipating surges of amplitudes and wave forms expected at the facility for a predetermined period of time. Selection of an arrester that will provide protection for a period of ten (10) years is recommended.

(2) Have a turnon time fast enough to ensure that surge energy will not be reflected across protected electronic equipment for a period of time that will cause damage before the surge arrester turns on and clamps.

(3) Maintain a low enough discharge (clamp) voltage while dissipating the surge current to prevent damage to protected electronic equipment.

(4) Have a reverse standoff voltage high enough to ensure that the arrester will remain in the non-conducting state during normal operation.

b. Additional Requirements. In addition to the above, the surge arrester must be properly constructed to ensure optimum operation. The arrester shall be manufactured so as to meet all requirements of the NEC and Underwriters Laboratories for this type of equipment. The input to each phase element contained in the surge arrester should be internally fused to provide protection against overload of, or damage to, the AC supply in the event an arrester or element of the arrester should short. Also, indicator lights that go off when a fuse opens should be provided on the front of the surge arrester as a maintenance aid. Where a group of elements are combined to form the surge protection for a phase of the AC circuit and each element has a fuse wire, the indicator lights will grow dimmer as each of the fuse wires to the group of elements opens. Normally two lights per phase are used.

90. SURGE ARRESTER INSTALLATION. Proper installation of the surge arrester is of vital importance for optimum operation. A surge arrester with excellent operating characteristics cannot function properly if correct installation procedures are not used. The most important installation criteria is provided and applies to surge arrester phase input connections and the ground connections. All surge arresters should be installed in accordance with the manufacturer's recommendations.

a. Installation Criteria.

(1) Keep interconnecting lead lengths as short as feasible.

(2) Use interconnecting conductors of sufficient size to preclude adding resistance and inductance in the surge current path to earth ground through the surge arrester.

(3) Interconnecting conductors shall be routed as straight and direct as possible with no sharp bends or kinks and with the least number of bends possible.

(4) Do not install any loops in the wiring. Trim all conductors as necessary to meet the above installation requirements.

(5) The earth ground connection must be as short and direct as practicable with no loops, sharp bends or kinks, and shall be properly bonded to the earth electrode system.

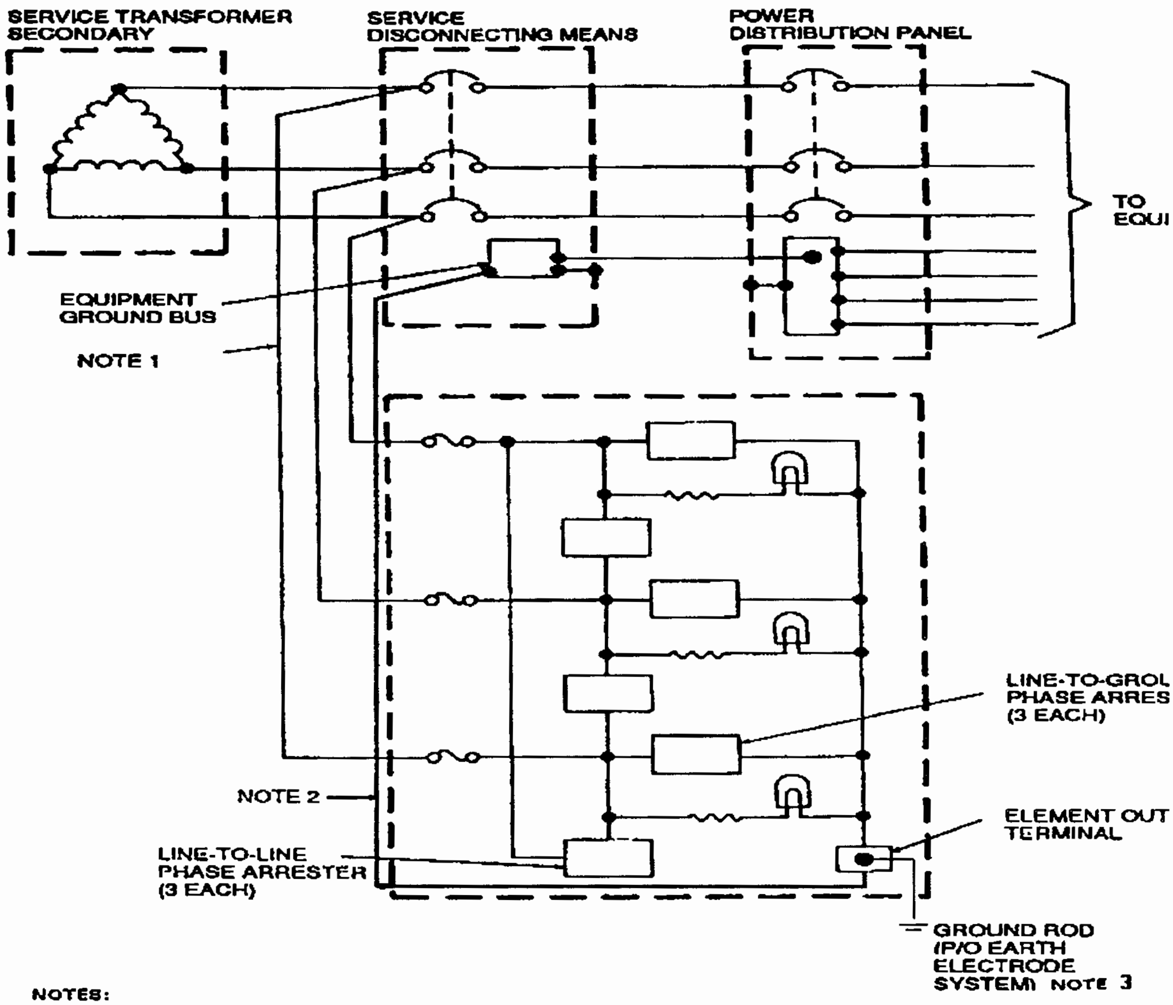
b. Surge Arrester Input Connections. Installation of surge arresters is shown for grounded service in Figure 2-51 and for ungrounded service in Figure 2-52. The phase inputs of the AC surge arrester shall be connected to the line (supply) side of the service disconnecting means. The installation of a surge arrester is also advisable on the primary side of isolation type Delta-Wye transformers. A secondary surge arrester, connected phase to phase, at this point significantly reduces the coupling of surges into the transformer secondary. In order to prevent introducing excessive inductance and resistance in the surge current path to the surge arrester, No. 4 AWG (minimum) insulated stranded copper wire of the minimum feasible length shall be used to make the interconnection(s). Larger conductors may be used if recommended by the manufacturer. Also, the interconnecting conductors shall not contain loops or sharp bends or kinks.

Otherwise, the response time of the surge arrester will be delayed and a higher clamp voltage than that of the surge arrester will be impressed across the protected electronic equipment, thus increasing the possibility of damage and, in the event a very fast surge should occur, it is quite likely that the surge arrester would never turn on, and all of the surge energy would be dissipated by the supposedly protected electronic equipment.

c. Surge Arrester Ground Connection. The response time of the surge arrester will be delayed, and a higher clamp voltage than that of the surge arrester will be impressed across protected equipment when the surge arrester is not properly grounded. The above can be expected to occur if the earth ground connection for the surge arrester contains loops, or sharp bends or kinks, or is not properly bonded to the earth electrode system as noted, hereinafter in this paragraph. No. 4 AWG. (minimum) stranded, insulated copper conductor must be used to make the ground connection.

Figure 2-51 shows a surge arrester installed on a grounded service (neutral grounded), which has the element output terminal of the arrester connected to the grounded neutral bus in the service disconnecting means. Figure 2-52 shows the connections for a surge arrester installed at the service disconnecting means, where there is an ungrounded system (no neutral ground). In this case, the element output terminal of the surge arrester is shown connected directly to the ground bus of the service disconnect means, which is connected directly to a ground rod in the earth electrode system. In both cases, the element output terminal of the surge arrester is insulated from the housing of the arrester, and the arrester housing connected to the ground bus in the service disconnecting means with a green insulated No. 6 AWG equipment grounding conductor. Connections above ground may be by UL approved pressure connectors.

Where it is necessary to install a surge arrester at a location other than where the grounded neutral is bonded to the grounding electrode conductor, the surge arrester shall provide both differential (normal) and common mode protection.



NOTES:

1. NO. 4 AWG MINIMUM, STRANDED COPPER, INSULATED, COLOR-CODED, SHORT DIRECT CONNECTIONS, NO SHARP BENDS, LOOPS OR KINKS.

2. NO. 4 AWG MINIMUM, STRANDED COPPER, INSULATED, WHITE OR COLOR-CODED WHITE, SHORT, DIRECT CONNECTIONS, NO SHARP BENDS, LOOPS OR KINKS.

3. NO. 6 AWG MINIMUM, COPPER

FIGURE 2-52. SECONDARY AC ARRESTER INSTALLATION, UNGROUNDED SERVICE

TABLE 2-14. SURGE OCCURRENCE, HIGH-INCIDENT LIGHTNING AREAS

Transient Amplitude (Amperes)	No. of Transients in 10-year Period
500 to 2,500	368
2,501 to 5,000	402
5,001 to 10,000	420
10,001 to 20,000	333
20,001 to 30,000	140
30,001 to 40,000	52
40,001 to 50,000	17
50,001 to 75,000	16
75,001 to 100,000	2

91. OPERATING CHARACTERISTICS OF SURGE ARRESTERS. Operating characteristics of different types of surge arresters are discussed in the following subparagraphs. Guidelines for selection of an adequate surge arrester are also provided.

a. Surge Dissipation Capability. Selection of a surge arrester that will provide adequate protection against worst case surges and transients is recommended. Waveforms are defined in Paragraph 85. The worst case waveform is 2-by-40 microseconds. The number and amplitude of surges that can be expected to occur can be determined by referring to Tables 2-10 and 2-13.

(1) In a high-lightning incident area (average of 100 thunderstorm days per year), 1750 surges are expected to occur in a ten year period. Referring to Tables 2-13 and 2-14, surge amplitudes and occurrences can be determined.

(2) In a low-lightning incident area, (average of 10 thunderstorm days per year) only 175 surges are expected to occur in a 10-year period. Surge occurrence and amplitudes may be as listed in Table 2-15.

b. Turnon Time. Turnon time (response time) is the time required for an arrester to turn on and clamp a surge after turnon voltage is impressed across the device terminals. All basic suppressor devices used in the manufacture of surge arresters are voltage dependent for ionization, breakdown, and other phenomena associated with breakdown. Therefore, a low turnon voltage enhances a faster turnon time. Turnon time requirements for a surge arrester must be directly related to the withstand level for electronic equipment and components being protected. For instance, if only heavy duty electrical equipment, such as motors, contactors, and switches are being protected, relatively slow turnon of 1 to 5 microseconds can be tolerated. However, if solid-state electronic equipment is being protected, turnon time becomes much more critical. In general, the most rapid response time available is desirable. However, cost and current dissipation capability normally place constraints on such selection criteria. Four types of arresters are currently manufactured as noted below. Additional data for each type is provided in Paragraph 92.

(1) Gas-filled spark gap with series-connected nonlinear resistance.

(2) Zinc oxide nonlinear resistor (ZNR) or metal oxide varistor (MOV).

(3) Solid-state.

(4) Hybrid of above components.

TABLE 2-15. SURGE OCCURRENCES, LOW-INCIDENT LIGHTNING AREAS

Transient Amplitude (Amperes)	No. of Transients in 10-year Period
500 to 2,500	37
2,501 to 5,000	40
5,001 to 10,000	42
10,001 to 20,000	33
20,001 to 30,000	14
30,001 to 40,000	5
40,001 to 50,000	1.75
50,001 to 75,000	1.5
75,001 to 100,000	0.175

c. Important Turnon Time Characteristics. Generalized characteristics for the three basic types of surge arresters are listed in Table 2-16. Turnon time of 50 nanoseconds is sufficiently fast to protect all except very critical components that would directly receive surge energy prior to turnon and clamp of the surge arrester. Solid-state units may be used for protection of very critical electronic equipment components, and the gas-filled spark gap type will provide adequate protection for heavy duty electrical equipment such as motors, contactors and switches. However, arresters with slow turnon time and high turnon voltage should not be used to protect electronic equipment that has low-voltage, fast-turnon transient suppression devices or circuits included as an integral part of the electronic equipment. Otherwise, the transient suppression devices in the electronic equipment will turn on and attempt to dissipate transient energy before the surge arrester installed at the service disconnecting means turns on. In most cases, this will rapidly destroy electronic equipment-level transient suppression.

The impedance and inductance of power distribution panels and power distribution wiring within the facility will tend to slow down the surge rise time and also dissipate some of the surge energy before and after the surge arrester turns on. The resistance and inductance works in conjunction with the surge arrester at the service disconnecting means to provide additional protection. However, the true degree of protection thus provided varies widely due to varying surge waveforms, and size and length of distribution wiring within the facility. In summary, most important characteristics for turnon time are:

(1) Turnon time must be rapid enough to preclude damage to electronic equipment resulting from overvoltage reflected across the protected electronic equipment from the time of surge occurrence until the surge arrester turns on and clamps the incoming surge.

(2) Turnon voltage and time for the surge arrester must be compatible with the characteristics of transient suppressor circuits included as an integral part of the protected electronic equipment. Otherwise electronic equipment-level transient suppressors/circuits will attempt to dissipate the surge before the surge arrester turns on. When this occurs, the electronic equipment level transient suppression will likely be destroyed resulting in damage or operational upset of protected electronic equipment.

d. Discharge (Clamp) Voltage. The clamp voltage, sometimes referred to as the discharge voltage, for a surge arrester is the voltage that appears across the arrester input terminals and ground terminal while conducting a surge current to ground. The clamp voltage waveform occurring across the surge arrester installed at the service disconnecting means is reflected across the protected electronic equipment after losses imposed by inductance and resistance of power distribution conductors and panels.

(1) In general, a surge arrester with the lowest clamp voltage possible is desirable. An all solid-state arrester provides the lowest clamping voltage available (Table 2-16).

However, as with turnon time, other factors such as current dissipation capability and cost normally place constraint on simply installing a surge arrester at the service disconnecting means with the lowest clamping voltage available.

TABLE 2-16. GENERALIZED CHARACTERISTICS FOR SURGE ARRESTERS BY TYPE

Type	**Turnon Time**	**Current Capacity**	**Clamp Voltage**	**Cost**
Gas-filled Spark gap	150-250 nano-seconds for 10 kV/S rise time	Extreme duty to 150,000 amperes Lifetime: 2500 surges at 10,000 Amperes	High-750 to 5500 volts	Moderate $25 to $750
MOV or ZNR	50 nanoseconds or less, any rise time	Varies-can be equivalent to spark gap type	Moderate-300 to 3000 volts	Moderate $50 to $1,000
Solid State	10 nanoseconds or less, any rise time	Varies-Generally 50 to 100 amperes except for costly units	Low-275 to 750 volts	Moderate $100 to $25,000

(2) In new facilities, with surge suppression as an integral part of electronic equipment at AC inputs, higher clamping voltages can be tolerated at the service disconnecting means. When good engineering design practices are used, electronic equipment level suppressors will have a slightly lower turnon voltage threshold and a slightly faster turnon time than

the surge arrester at the service disconnecting means. This permits the electronic equipment-level suppressors to maintain a lower clamping level to provide maximum electronic equipment protection. Therefore, when a surge occurs, the electronic equipment-level suppressor(s) will turn on first.

(3) This circuit operation generates the requirement for a properly sized (2 microhenries minimum) inductor to be installed in series with applicable AC conductors. The inductor must be between the surge arrester and integral electronic equipment-level transient suppression, and may be a part of the surge arrester or electronic equipment-level transient suppression. This inductance may be supplied by the interconnecting cabling itself, depending upon routing and length.

(4) The electronic equipment-level suppressor will immediately start towards clamp voltage as surge current is conducted. Because of resistance and inductance of the power distribution conductors and panels, the surge arrester will turn on very soon (nanoseconds) after the electronic equipment-level suppressor(s) and dissipates most of the remaining surge energy. After the surge arrester turns on, the electronic equipment-level suppressor(s) are required to dissipate only the surge energy resulting from the clamp voltage of the surge arrester.

(5) Thus, the surge arrester dissipates most of the surge, and the electronic equipment-level suppressor(s) provide electronic equipment protection against fast rise time surges and reduce the surge arrester clamp voltage to levels that can be safely tolerated by protected electronic equipment. In summary, clamp voltage for the surge arrester must be low enough while dissipating a high-energy surge to provide adequate protection taking into consideration:

(a) Protection provided by transient protection that is an integral part of the facility electronic equipment.

(b) Impedance (resistance and inductance) of power distribution conductors and panels within the facility.

e. Reverse Standoff Voltage. Reverse standoff voltage is specified in various ways by surge arrester manufacturers such as maximum allowable voltage, voltage rating, and reverse standoff voltage. For usage herein, reverse standoff voltage is defined as the maximum voltage that can be applied across the surge arrester and the surge arrester remain in the off state (current leakage through arrester to ground 1 milliampere or less). Good engineering practice dictates that the surge arrester remain off during normal operations.

(1) Design of effective lightning surge protection requires that the surge arrester turn on very rapidly at the lowest voltage possible when a surge occurs. In addition, it is desirable that a low clamp voltage be maintained across the surge arrester while conducting surge current to ground. Turnon voltage and associated turnon time as well as clamp voltage are proportional to reverse standoff voltage. That is, an arrester with a low reverse standoff voltage has a lower turnon voltage (and thus a faster turnon time) and a lower clamp voltage than an arrester with a higher reverse standoff voltage. Therefore, it is important that the surge arrester have the lowest possible reverse standoff voltage.

(2) For effective protection, the reverse standoff voltage should be 125 percent plus or minus 5 percent of nominal voltage, line-to-ground for a surge arrester that is to be installed line-to-ground and line-to-line for a surge arrester that is to be installed line-to-line.

92. CHARACTERISTICS OF DIFFERENT TYPES OF SURGE ARRESTERS. Various types of surge arresters are presently available for purchase as off-the-shelf items from a magnitude of manufacturers. Most have desirable, as well as undesirable, characteristics. Some types have the capability of dissipating tremendous amounts of current, but turn on relatively slowly (150 to 200 nanoseconds) after turnon voltage appears across the device terminals. Another type turns on more rapidly (50 nanoseconds or less) but will not dissipate as much current as the slower devices, unless many devices are connected in parallel which is not totally desirable. Solid-state arresters are available which have very fast turnon times but most of them are limited in current dissipation capability except for expensive units. Hybrid units consist of a solid-state suppressor for dissipation of low-energy transients, and a separate suppressor section for dissipation of high-energy surges. The two sections are normally separated by a choke in series with the protected phase line.

The three most important characteristics of an AC surge arrester are the capability to dissipate the required levels of surge current, maintain a low discharge (clamp) voltage while dissipating the surge current, and a fast response time. The fast response time is important to preclude reflection of high level surge energy (overshoot voltage) across protected equipment for an intolerable length of time before the arrester turns on and clamps. Various types of suppressors are discussed below

together with typical operating characteristics.
Note: The FAA does not permit use of any devices whose components are sealed epoxy or other sealants and cannot be maintained without replacement of the entire sealed component.

a. Gas-Filled Spark Gap with Series-Connected Silicon Carbide Block. The gas-filled spark gap arrester is capable of conducting very high currents. Some units have an extreme duty discharge capacity of 150,000 amperes peak for one surge with a 10-by-20 microsecond waveform. Minimum life of such units is dissipation of 2,500 surges of 10,000 amperes peak surge current with a 10-by-20 microsecond waveform. Impulse sparkover (turnon) voltage is 1,400 volts peak for a surge with a 10 Kv/sec waveform for this type of arrester. Some typical discharge (clamp) voltages are listed in Table 2-17 for 10-by-20 microsecond waveforms of the surge amplitude listed.

TABLE 2-17. TYPICAL MAXIMUM CLAMP VOLTAGE FOR SPARK GAP ARRESTERS

Peak Surge Amplitude	Maximum Clamp Voltage
10,000 Amperes	2,000 Volts
40,000 Amperes	3,000 Volts
150,000 Amperes	5,500 Volts

(1) Follow Current. The typical discharge (arc) voltage across a spark gap is 20 to 30 volts while it is in full conduction. Because of the low arc voltage, the voltage and current available from the AC power supply would maintain the spark gap in an on state after a surge was dissipated until the first zero crossing of the power supply or until a supply line fuse opened, a line burned open, the spark gap burned open, or the service transformer burned open. For this reason, a silicon carbide block (nonlinear resistor) is connected in series with a spark gap to ground to ensure that the spark gap extinguishes on the first zero crossing of the connected line, and, more importantly, to limit follow current through the spark gap after a surge is dissipated until the first zero crossing of the powerline (8.3 milliseconds maximum). The silicon carbide block is a nonlinear resistance, and resistance decreases as applied voltage increases. Thus, the resistance is relatively high at powerline voltages to limit follow current, but decreases to a fraction of an ohm when high-level surge voltage is applied. However, the resistance remains high enough to generate a

relatively high clamp voltage when discharging high-amplitude surge currents.

(2) Sparkover (Turnon) Voltage. Sparkover time for the spark gap arrester is directly related to a surge risetime since a finite amount of time is required for the spark gap to ionize and transition from the off mode through the glow region and into the arc mode of operation. Also, ionization time is to some extent related to risetime of the surge. Transition time from the off to arc mode of operation is typically 150 to 200 nanoseconds after sparkover voltage appears across arrester terminals.

(3) Summary. In summary, the gas-filled spark gap is capable of discharging high-amplitude surges, but has a relatively slow response time and a relatively high discharge voltage. Follow current (10 to 80 amperes typical) occurs, but normally presents no significant problems. Figure 2-53 depicts typical operating curves for two series of gas-filled spark gap arresters with a series-connected silicon carbide resistor.

b. ZNR and MOV Type Arresters. The ZNR type arresters have several desirable characteristics. Other types of MOV arresters are currently under development that have voltage-current characteristics similar to the ZNR type. The ZNR type arresters have a relatively fast turnon time (50 nanoseconds or less), low turnon voltage, relatively low clamping voltage, and various levels of current dissipation capability since the ZNR are available in different energy level packages. Table 2-18 lists related characteristics for ZNR available in one type of energy level package and Table 2-19 lists related characteristics for a high-energy package.

TABLE 2-18. ZNR TYPE DEVICE (MOLDED CASE TYPE) TYPICAL CHARACTERISTICS

PARAMETER	RANGE OF AVAILABLE DEVICES 20 MM DISC	25 MM DISC	32 MM DISC
DC BREAKDOWN VOLTAGE AT 1 MILLIAMPERE	200-910 V	200-910 V	200-910 V
MAXIMUM CLAMPING VOLTAGE AT MAXIMUM SURGE CURRENT	525-2800 V	590-3200 V	640-3800 V
MAXIMUM SURGE CURRENT (8 X 20 MICROSECOND WAVEFORM)	2.5-5 kA	5-10 kA	10-20 kA
LIFE	DEPENDS ON SURGE CURRENT AND WAVEFORM.[1]		

1 MAXIMUM SURGE CURRENT (8x20 MICROSECONDS) CAN BE APPLIED TWICE WITHOUT INCURRING DAMAGE OR OVER STRESSING THE DEVICES.

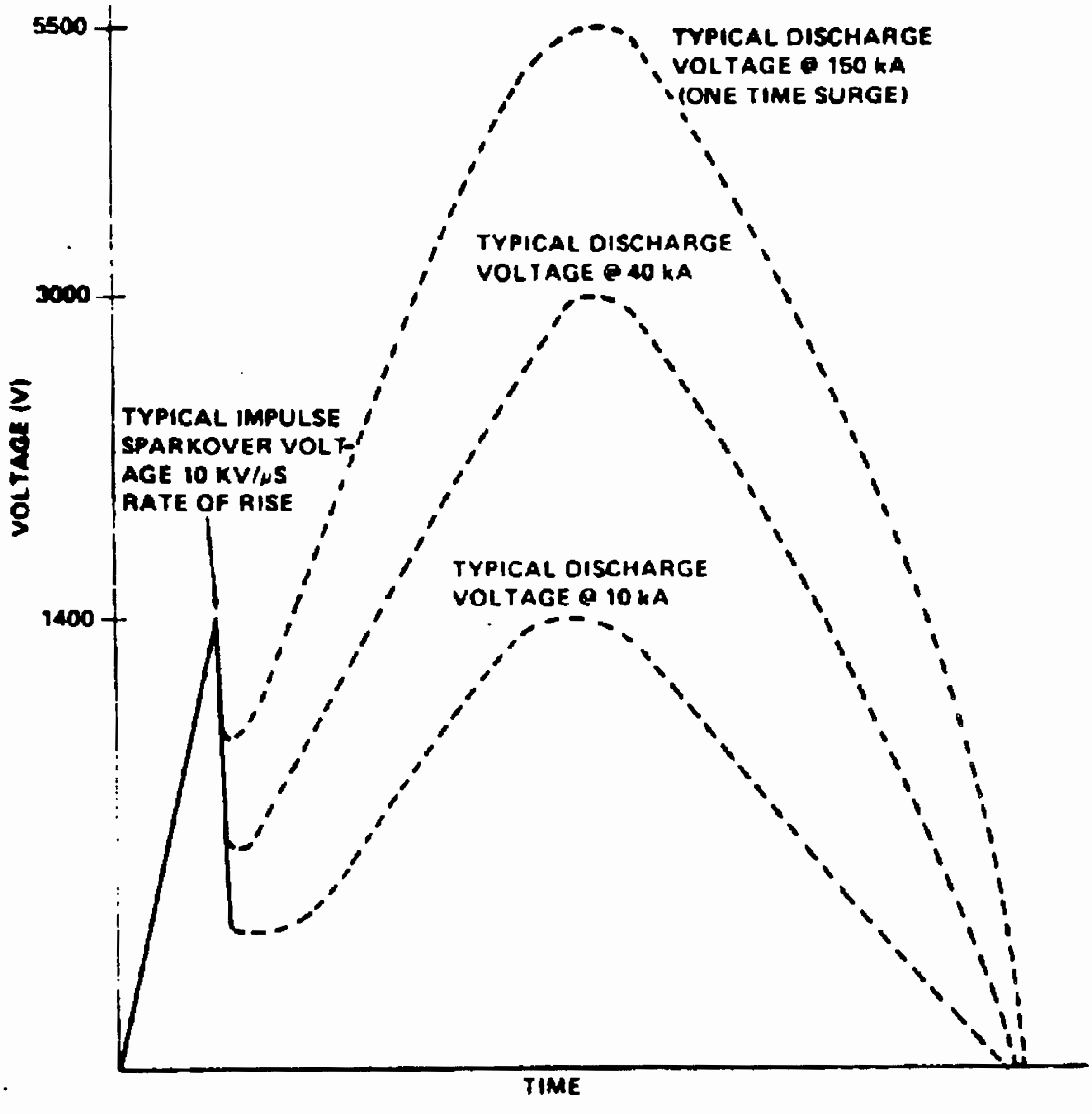


FIGURE 2-53. TYPICAL OPERATING CURVE FOR THE SERIES OF GAS-FILLED SPARK GAP ARRESTERS WITH NON-LINEAR SERIES RESISTOR

TABLE 2-19. HIGH ENERGY ZNR SURGE ARRESTER TYPICAL CHARACTERISTICS

SIZE:	**THREE 80 MM DISCS IN PARALLEL**
POWERLINE VOLTAGE:	250 V AC MAXIMUM
DC BREAKDOWN VOLTAGE AT 1 MILLIAMPERE:	550 VOLTS
MAXIMUM CLAMPING VOLTAGE (10 X 20 MICROSECONDS)	CURRENT / CLAMPING VOLTAGE 10 kA / 1300 VOLTS 40 kA / 1600 VOLTS 150 kA / 2450 VOLTS
LIFE	DEPENDS ON SURGE CURRENT AND WAVEFORM.[1]

[1] MAXIMUM SURGE CURRENT (8x20 MICROSECONDS) CAN BE APPLIED TWICE WITHOUT INCURRING DAMAGE OR OVER STRESSING THE DEVICES.

TABLE 2-20. TEST RESULTS FOR PARALLEL-CONNECTED ZNR

Number of Surges Applied	**Surges Amplitude**	**Clamp Voltage (Peak)**
2000	250A @ 1000V	300V
2500	400A @ 1600V	315V
225	20,000A @ 8.75kV	500V
25	40,000A @ 16.8kV	650V
8	50,000A @ 20kV	700V

(1) Current Dissipation. Testing has established that connection of the devices listed in Table 2-18 in parallel for line-to-ground or line-to-line protection is feasible. Use of the ZNR in parallel provides increased current dissipation capability and a lower maximum clamping voltage than a single high-energy ZNR can provide. Five of the devices were connected in parallel and surged as listed in Table 2-20. The clamp voltages listed in Table 2-20 occurred. Current division was very good. NOTE: When used in parallel, all of the ZNR devices must be balanced and be within 1% of the average turn on voltage for all devices in the parallel group.

(2) Turnon. Although the ZNR devices used in ZNR-type arresters are not solid-state junction-type devices, the arrester acts very much like junction-type devices. That is, when the breakdown voltage is reached, transition from off to on occurs very rapidly as shown in Figure 2-54 (part b), which is a typical operating curve for a ZNR. Since the devices used in ZNR-type surge arresters are essentially nonlinear resistors, resistance decreases rapidly as applied voltage across the device increases above breakdown voltage. Therefore, current flow through this type arrester increases rapidly after breakdown as shown in Figure 2-54 (part b). Primarily because of resistance and capacitance of the ZNR, the clamp voltage slightly lags the surge current waveform. The ZNR-type arrester automatically restores to the off state when applied voltage falls below turnon voltage. Therefore, no follow through current occurs during the turnoff phase.

c. Solid-State Type Arresters. So many different types of solid-state arresters are currently manufactured that it is difficult to generally evaluate them. In general, solid-state arresters, manufactured by connecting silicon avalanche diode suppressors (SAS) in series to attain the desired current handling capability, have truly fast response times of 1 to 10 nanoseconds. However, this type of arrester is generally limited to handling approximately 500 amperes surge current (waveform 8-by-20 to 8-by-40 microseconds). Figure 2-54a is a typical operating curve for a solid-state suppressor. This type of arrester also has a low clamp voltage (normally 160% of breakdown voltage, maximum) compared to other types of arresters. Other solid-state arresters are a combination of silicon avalanche diodes or rectifier diodes connected in a bridge network followed by a second stage consisting primarily of a silicon-controlled rectifier (SCR) with a varying-value current-limiting resistor in series with the SCR. This type arrester has a slow response time, sometimes approaching 1 microsecond, because of the slow turnon time for the SCR. Also, the clamping voltage can be high depending on the value of the SCR current-limiting resistor. Because of the proliferation of solid-state arresters available, it is strongly recommended that complete laboratory demonstration testing be required prior to implementation of the solid-state arresters.

d. Hybrid Type Arresters. Hybrid type arresters consist of a combination of gas filled spark gaps and ZNR or MOV arresters, and two-stage arresters consisting of a solid-state stage for dissipation of low energy fast transient overvoltage and a separate stage consisting of ZNR, MOV, or gas tube arresters for dissipation of high energy long time constant surges. The coordination between the two stages is accomplished utilizing a very low DC resistance choke insuring that the high energy stage fires prior to the destruction of the solid-state (low energy) stage. This is accomplished by developing a voltage drop across the inductor sufficient to fire the high energy stage at or below the maximum current rating of the solid-state stage. The operational theory is similar to that for the hybrid devices used to protect FAA landlines. NOTE: Devices which utilize components other than inductors (chokes) in line are not approved for use in FAA facilities. Devices for which schematics are unavailable or in which the components are encapsulated are not approved for use in FAA facilities.

e. <u>Other Arresters</u> Other arresters are being marketed by various manufacturers which may seem to offer increases in protection capabilities. Many of these devices have been investigated and found to not conform to FAA's requirements. There is a requirement that schematics be available for any type of FAA approved surge arrester. It is necessary to be very careful when investigating any new type of surge suppressor as some have been found to be improperly fused, creating a fire hazard. When confronted by manufacturers, or their representatives, it is important to refer them to the regional focal point position for Lightning Protection, Grounding, Bonding, and Shielding (LPGBS) who should be trained to make decisions of this nature.

93. <u>TRANSIENT PROTECTION FOR EXTERNALLY EXPOSED ELECTRONIC EQUIPMENT LINES</u>. In order to effectively protect electronic equipment against damage from lightning induced transients on externally exposed (outside) electronic equipment lines, the following must have some definition which is provided in subsequent paragraphs.

a. <u>Frequency</u> of transient occurrence.

b. <u>Amplitude</u> and waveform of occurring transients.

c. <u>Equipment</u> withstand levels.

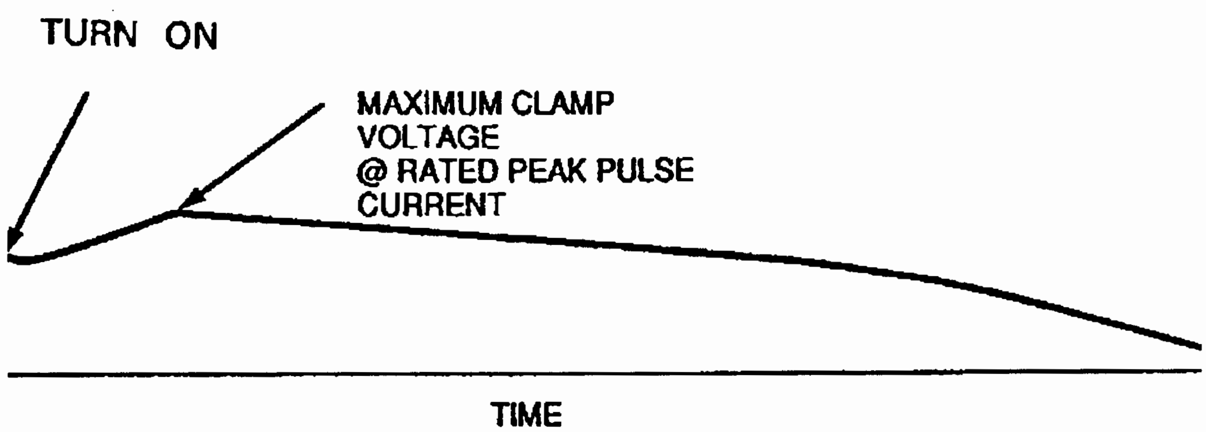
d. <u>Effective</u> protection methods.

94. <u>FREQUENCY OF TRANSIENT OCCURRENCE</u>. There is no existing method for precise calculation of the number of lightning-induced transients that will occur at a specific location in a given period of time. However, by using the best available data, (Paragraph 84), projections are that 1750 transients will occur in a 10-year period at a facility located in a high-lightning incident area with an average of 100 thunderstorm days a year, and only 175 transients will occur in a 10-year period at a facility in a low-incident lightning area with an average of

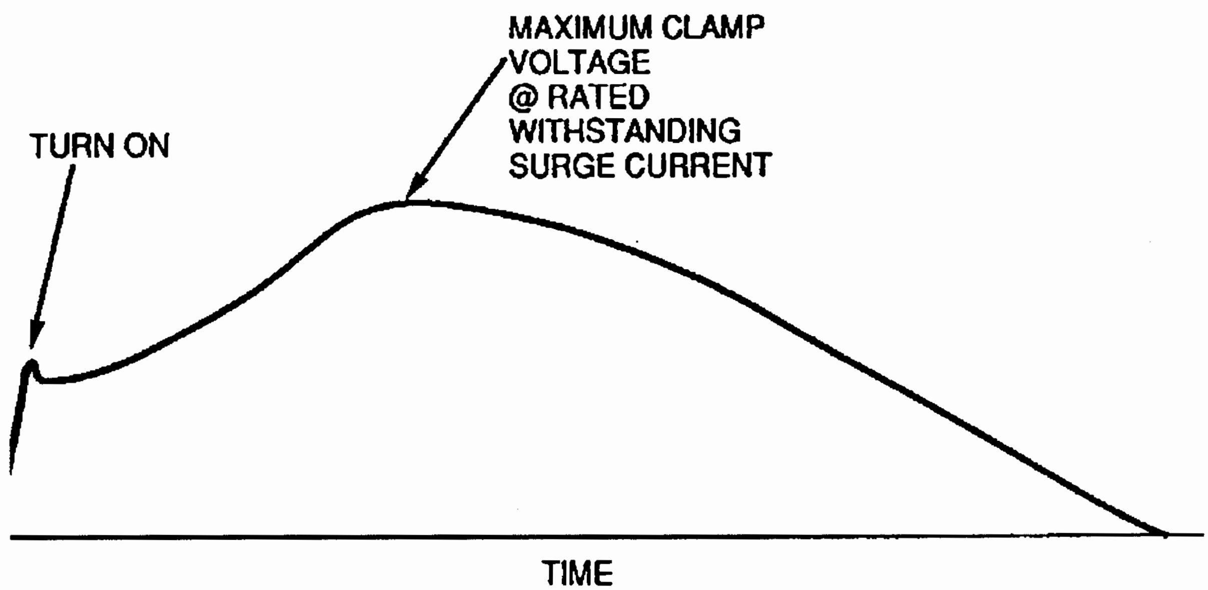
10 thunderstorm days per year. Note that the number of transients is decreased by one order of magnitude for the low-lightning incident area. Therefore, by using Figure 2-50 to determine the average number of thunderstorm days per year in a specific location, and decreasing 1750 by 10% for each decrease of 10 thunderstorm days per year, the number of transients projected to occur at any location in the United States can be determined.

95. AMPLITUDES AND WAVEFORMS OF OCCURRING TRANSIENTS. Transients occurring on landlines have been defined as 10-by-1000 microsecond, 1000-volt peak pulses where 10 microseconds is the time from the start of the transient to peak voltage, and 1000 microseconds is the time from the start of the transient until the amplitude exponentially decays to 50% of peak value. Source impedance cannot be precisely defined but for design purposes is assumed to be 1 ohm. Therefore, for design purposes, a typical lightning-induced transient can be defined as 10-by-1000 microseconds, 1000 volts peak with a peak surge current of 1,000 amperes. Using Table 2-13, the 1750 transient pulses defined in Paragraph 94 and the worst case transient pulse defined above, the number of transients of varying amplitude would be as listed in Table 2-21 over a 10-year period for an externally exposed line in a high-incident lightning area (average of 100 thunderstorm days per year).

96. EQUIPMENT WITHSTAND LEVELS. Equipment withstand levels were generally defined in Paragraph 83. A more specific definition, however, cannot be provided because manufacturers generally do not specify electronic equipment or component withstand levels against lightning-induced transient surges. It is, therefore, imperative that the withstand level be analyzed and determined for each item of equipment to be protected. The withstand level should be 10% below both the damage threshold level and operational upset level for the electronic equipment. The damage threshold level is defined as the level where immediate component destruction occurs or the repeated application energy level that decreases useful operational lifetime of electronic equipment components, whichever is lower. The operational upset level is defined as the transient voltage that causes an intolerable change in electronic equipment operation. It is imperative that an accurate withstand level be established. Otherwise, designed transient suppression may not be effective, or conversely, costly transient protection may be designed when not required.



A. TYPICAL OPERATING CURVE FOR SILICON AVAILANCHE SUPPRESSOR



B. TYPICAL OPERATING CURVE FOR ZNR SUPPRESSOR

FIGURE 2-54. TYPICAL ARRESTER OPERATING CURVES, SAS AND ZNR

TABLE 2-21. TRANSIENTS PROJECTED TO OCCUR ON EXTERNALLY EXPOSED LINE IN HIGH-LIGHTNING AREA OVER 10-YEAR PERIOD

No. of Transients	Percentage	Peak Voltage (Volts)	Peak Current (Amperes)
2	0.1	750 to 1,000	750 to 1,000
15	0.9	500 to 749	500 to 749
18	1	400 to 499	400 to 499
53	3	300 to 399	300 to 399
140	8	200 to 299	200 to 299
332	19	100 to 199	100 to 199
420	24	50 to 99	50 to 99
403	23	25 to 49	25 to 49
367	21	5 to 24	5 to 24

97. PROTECTION METHODS AGAINST TRANSIENTS. Methods listed below are effective, when properly implemented, in providing electronic equipment protection against lightning induced transients appearing on externally-exposed electronic equipment signal, status, control, and AC and DC intrafacility landlines. Subsequent paragraphs delineate proper implementation techniques for the listed methods.

a. Completely enclosed buried lines end-to-end in rigid galvanized steel, watertight conduits.

b. Installation of buried guard wire above buried cable runs not in rigid galvanized steel conduit. Buried cables should enter the facility structures at each end in rigid steel conduits as described in Paragraph 99.

c. Connecting transient suppressors line-to-ground on both ends of externally exposed electronic equipment lines as soon as feasible after building penetration or at a point of termination at exterior electronic equipment.

d. Including transient suppressors or transient suppression circuits as an integral part of protected electronic equipment at all external line-equipment interfaces.

e. Routing RF coaxial lines through grounded metal bulkhead connector plates immediately after building penetration.

f. The installation of fiber optic cables where feasible for electronic landlines.

98. ENCLOSING CABLE RUNS IN RIGID GALVANIZED STEEL. Transients are induced on external lines by electromagnetic waves created by lightning current flow, and by cloud-to-cloud lightning discharges. Therefore, completely enclosing buried external cable runs in rigid galvanized (heavywall) steel, watertight, electrically continuous conduit provides an effective protection level against lightning-induced transients. The metal conduit will effectively eliminate low-amplitude induced transients, and attenuate high-amplitude induced transients 90% minimum.

a. Cost Considerations. When a buried cable run is 300 feet (90 m) or less in length, it is economically feasible to enclose the cable run end-to-end in rigid galvanized (heavywall steel) conduit. When the cable run exceeds 300 feet (90 m) in length, it may be more economically feasible to provide transient suppression at building penetration and electronic equipment level than to install the conduit. However, use of rigid steel conduit provides the most effective protection against induced transients, regardless of the length of the cable run. The rigid steel conduit must extend from building penetration to building penetration, or building penetration to exterior electronic equipment termination and shall be terminated using conductive fittings to facility junction boxes, electronic equipment cabinet enclosures or other grounded metal structures.

b. Grounding of Conduits. To be effective, the conduits must be electrically continuous and effectively bonded to earth ground at each end. At each location where the conduits enclosing the electronic landline conductors terminate or first penetrate a shelter or building's exterior wall, short direct connections shall be made to the earth electrode system or to the electronic system multipoint ground system, with No. 2 AWG stranded copper conductor. Grounding connections shall be made by exothermic welds or FAA approved pressure connectors to provide effective bonding, above or below grade. Approved grounding collars shall be used for grounding connections within facility buildings or shelters. The structural steel of antenna towers may be used to effectively ground the conduit, provided the total bond resistance from the conduit to the earth electrode system is 5 milliohms or less. When the conduit runs exceed 300 feet (90 m), the conduit shall be grounded at each end and additional ground connections made every 300 feet (90 m) or fraction thereof. The ground connection to the conduit, other than at the ends, shall be by connection of a #2 AWG copper conductor to a ground rod driven 6 feet from the conduit.

c. Transient Suppression for Landlines in Rigid Galvanized Steel Conduits. Only one level of transient suppression is required for effective protection against induced transients conducted by landlines in rigid galvanized steel conduits. The one level of suppression may be located at building penetration or designed as an integral part of the applicable electronic equipment. This single level of suppression may consist of normal (line-to-line) mode or common (line-to-ground) mode suppression, or both. This protection should be grounded to the equipment chassis being protected, or alternatively to some other point in the multipoint ground system.

d. Amplitude of Transients on External Lines Enclosed in Rigid Galvanized Conduits. The number of lightning-induced transients occurring on external cables will not change as a result of enclosing cable runs in metal conduits. However, the voltage and current amplitudes will decrease a minimum of 90%. Therefore, Table 2-21 for the number and amplitude (voltage and current) of transients that are projected to occur on externally exposed landlines, in high-lightning incident areas, can be used to determine the voltage and current amplitudes for landlines enclosed in metal conduits.

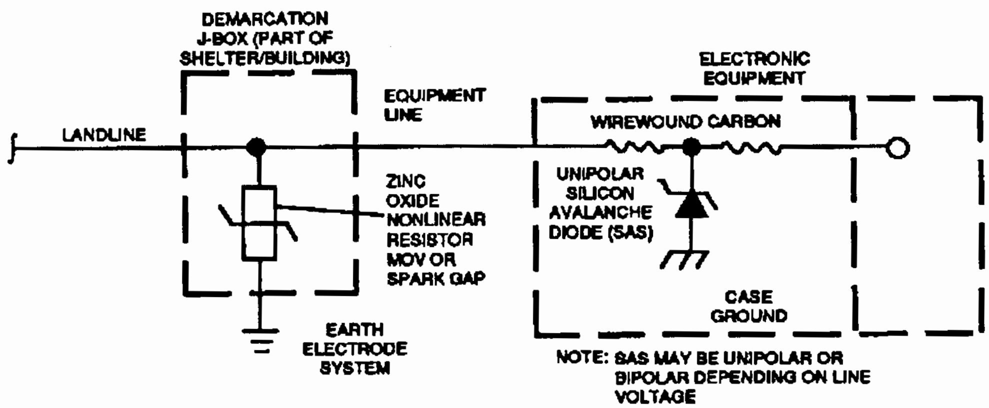
99. BURIED GUARD WIRES. Use of a buried #6 AWG solid copper guard wire (counterpoise) embedded in soil above and parallel to buried cable runs not enclosed in rigid galvanized steel conduits, including armored cable, has provided effective attenuation of lightning-induced transients. To be effective, the guard wire must be embedded in the soil a minimum of 10 inches (25 cm) above and parallel to the protected buried cable run or duct.

When the width of the cable run or duct bank does not exceed 3 feet (1 m), one guard wire, centered over the cable run or duct bank, provides adequate protection. When the cable run or duct bank is more than 3 feet (1 m) wide, two guard wires shall be installed. The guard wires should be at least 12 inches (30 cm) apart and be not less than 12 inches (30 cm) nor more than 18 inches (45 cm) inside the outermost wires or the edges of the duct bank. The guard wires must be bonded to the earth electrode system at each terminating facility. Exothermic welds or FAA approved pressure connectors provide effective bonding. Guard wires exceeding 300 feet (90 m) in length shall also be connected to a ground rod every 300 feet (90 m) or portion thereof in excess of 300 feet (90 m).

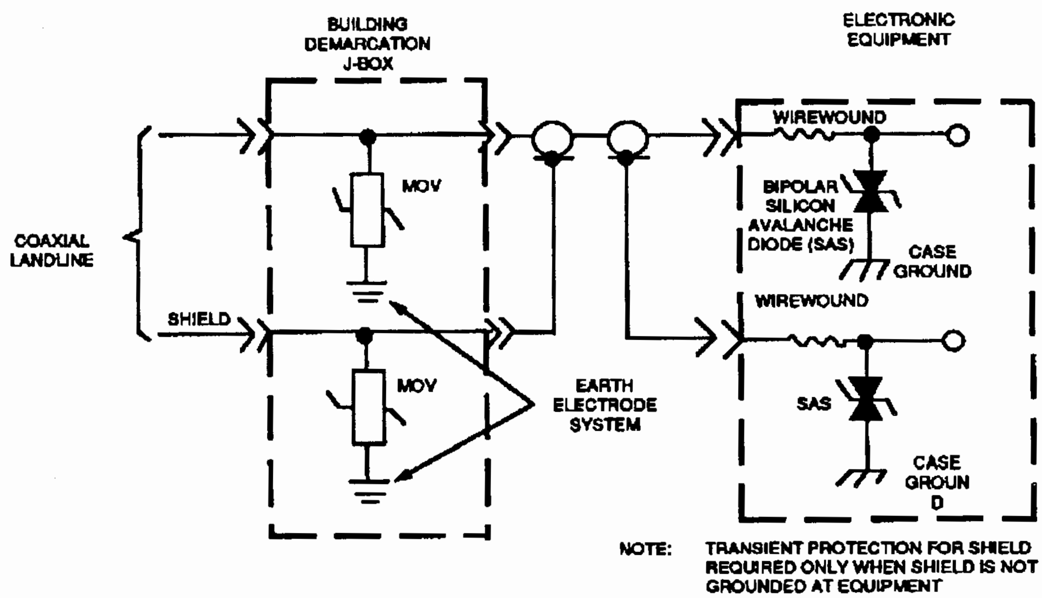
Direct buried cables or cables run in non-metallic ducts shall enter the facility in rigid galvanized steel conduits. These conduits shall extend a minimum of 5 feet past the earth electrode system and shall be bonded to the earth electrode system with exothermic welds or FAA approved pressure connectors. This connection to the metal conduits shall be made at the end of the conduits. The interior ends of the conduits shall be bonded to their respective entrance housings. Where armored cables are installed, the cable armor shall be bonded to the earth electrode system at the point of entry into the facility with a No. 2 AWG bare copper conductor. Where this is not feasible, the cable armor shall be bonded to the main ground plate. If none of the above are available, the armor shall be grounded, by bonding it to the ground bus in the service disconnecting means. If the armor is continued on to the electronic equipment, it shall be bonded to the multipoint ground system of the electronic equipment, unless the equipment is required to be isolated.

100. TRANSIENT SUPPRESSION. In order to provide effective electronic equipment protection against lightning-induced transients, externally exposed landlines must have transient suppression installed on each end where the landline directly interfaces with electrical or electronic equipment. This requirement applies to all cases when the withstand level of the interfaced equipment is below the transient levels projected to occur at the landline equipment interface. As previously noted, transient amplitudes projected to occur on lines enclosed end-to-end in electrically continuous, ferrous metal conduits are only 10% of the transient amplitudes projected to occur on lines not enclosed in metal conduits (Table 2-21).

Figure 2-55 depicts typical transient suppression at the facility and electronic equipment level for both coaxial cables and single wires or pairs. Suppressors installed at building penetration should be located in the junction box that first terminates the externally exposed lines after building penetration. Where it is not practical to install the high-energy level transient suppressor at the building entrance and the low-energy transient suppressor as an integral part of the equipment (such as with existing equipments), both transient devices should be packaged in one housing located where the landline enters the facility and connected as described hereinafter. It is important to note that control and data lines in tall ATCT shafts may experience electromagnetic coupling of large scale transients during lightning strikes. These transients may necessitate the installation of low energy transient protection on the interior lines. Additional protection requirements applicable to audio,



a. TYPICAL TRANSIENT PROTECTION CONFIGURATION



b. TRANSIENT PROTECTION FOR EXTERNALLY-EXPOSED
COAXIAL CABLES

FIGURE 2-55. TYPICAL TRANSIENT SUPPRESSOR INSTALLATION, FACILITY AND EQUIPMENT LEVEL radio frequency (RF) and other signals transmitted by axial-type cables are described in subsequent paragraphs.

a. Grounding for Transient Suppression. In order for the transient suppressor to operate properly and provide optimum electronic equipment protection, the ground sides of the high-energy and low-energy transient suppressors, contained in the suppression package, must be connected as directly as possible to an effective earth ground via separate paths.

(1) Installation of the high-energy level suppressor must be such that its ground is isolated from other equipment grounds and connected directly to the earth electrode system both to enable the optimum functioning of the transient suppressors and to preclude electronic equipment damage resulting from high-voltage, short-duration spikes on the electronic equipment ground. The high-energy transient suppressors shall be installed in an enclosed junction box immediately following building or shelter entrance. The junction box shall be adequately sized for the purpose and shall be UL approved. A ground bus bar, electrically isolated from the junction box by a minimum of 1 megohm DC resistance, shall be provided to serve as the earth ground point for all of the high-energy suppressors installed in the enclosure. The ground bus bar shall be solid copper suitable for the connections of the ground leads from the suppressors. The ground bus shall be directly connected to the facility earth electrode system with an insulated 600 volt, No. 4 AWG stranded copper conductor of minimum length, color coded green with a bright red tracer, and installed with no loops, sharp bends or kinks. The connections from the transient suppressors to the ground bus in the enclosure shall be as short and direct as possible with no loops, sharp bends or kinks. The earth electrode system shall be with exothermic welds or FAA approved pressure connectors.

(2) Installation of the low-energy level suppressor shall be in a separate shielded metal enclosure or as an integral part of the electronic equipment.

(a) Low level suppressors mounted in separate enclosures shall be grounded via path from a copper bus within the enclosure to the enclosure and then to the earth electrode system via the electronic multipoint ground system. One enclosure should be utilized for each rack of equipment to be protected and the enclosure bonded to the electronic multipoint ground bus in the rack (rack ground). When a single point grounding system is used the possible difference in potential between the electronic single point ground system and the electronic multipoint ground system may necessitate the connection of the low energy suppressor to the electronic single point system.

NOTE: It is extremely important that the ground for the low energy level suppressor be through the same path as that for the equipment being protected.

(b) Integrally mounted low level suppressors are grounded via the internal ground of the equipment. If the equipment is configured as part of a electronic multipoint ground system, a large internal bus, bonded to the equipment chassis, is most effective. If the equipment is configured as part of an electronic single point ground system, the most effective means of providing this protection, is with surface mount devices connected to large ground planes on the cards requiring protection.

(3) Installation at externally mounted electronic equipment shall have the suppression specified above for facility and electronic equipment entrances installed at the electronic landlines entrance to the equipment. Two copper bus bars shall be installed for connecting the high-energy and low-energy level suppression components to the earth electrode system of the electronic equipment and the electronic equipment case ground, respectively.

The ground bus for the high-energy level components is noted as the "A" bus. It shall be electrically isolated from the electronic equipment and shall be directly connected to the earth electrode system with an insulated 600 volt No 4 AWG or larger stranded copper conductor without loops, sharp bends or kinks, and shall be color coded green with a bright red tracer. The connection to the earth electrode system shall be made with exothermic welds or FAA approved pressure connectors.

The low energy level suppressor shall be connected to the second copper bus, noted as the "B" bus, which shall be connected to the electronic equipment ground system with a minimum insulated (green with a bright orange tracer) No. 6 AWG 600 volt stranded copper conductor. Alternatively, the low-energy suppression component may be mounted directly to the circuit board receiving the landline signal and be grounded to the ground plane on that board. The connections from the grounds of the transient suppressor components to the ground buses shall be as direct as possible without loops, sharp bends or kinks.

The above components, the high- and low-energy transient suppressor circuits, and the ground buses shall be housed in an enclosed junction box sized to suit the installation and allowing ample room for maintenance. Access shall be provided for visual inspection of the suppressors as well as for replacement of components.

(4) Suppressors can be installed between applicable terminal boards and the ground bus bar with short direct connections having no loops, sharp bends or kinks. This is important to prevent inductance from being introduced into the device that would delay turnon and response to the transient suppressor.

(a) Government furnished transient suppressor kits have been installed at many of the existing FAA electronic installations. Where it is not feasible to install high-energy level suppression at the entrance to the facility and low-energy level suppression at the electronic equipment entrance, installations similar to the Government furnished kits, as described below, may be installed.

The transient suppression devices are designed for installation where the landlines enter the facility and consist of a properly sized, enclosed junction box, transient suppressors, copper bus bars, and all of the necessary mounting hardware. The suppression devices are printed wiring boards mounted on phenolic mounts and consist of a high-energy level transient suppression circuit and a low-energy level transient suppression circuit. The copper bus bars are mounted so that the printed wiring boards can be mounted directly onto the bars with machine screws furnished with the kit. (Where this is not feasible, the connecting leads to the ground bus shall be kept as short as possible and with no loops, sharp bends or kinks). The ground bus mounted on the left (A bus) is for the high-energy level circuit of the printed wiring board and the ground bus on the right (B bus) is for the low-energy level circuit. The incoming line is connected to a terminal on the left side of the printed wiring board and the outgoing landline is connected to a terminal on the right side of the printed wiring board. The printed wiring boards are designed and manufactured so that the high-energy level ground is connected to the left side bus and the low-energy level ground is connected to the right side bus through the machine screws noted above. The left side high-energy level ground bus is connected directly to the earth electrode system with a 600 volt insulated stranded copper conductor. This conductor shall be as short as possible without any loops, sharp bends or kinks and should be color coded green with a red tracer. The right side low-energy level bus shall be connected to the electronic equipment multipoint grounding conductor with a 600 volt insulated (green with bright orange tracer) No. 6 AWG stranded copper conductor. This conductor shall also be installed without any loops, sharp bends or kinks. The suppressors shall be installed so that they are readily accessible for inspection and replacement as a unit. The ground bus for the high-energy level suppressors shall be electrically isolated from other equipment, including the junction box, by a minimum of 1 megohm DC resistance. Incoming (not yet protected) lines and outgoing (protected) lines should be kept as widely separated as possible and well away from the "A" and "B" buses. This separation prevents the coupling of the transient removed by the protection back into the signal line.

101. TYPES OF TRANSIENT SUPPRESSORS. Four different types of suppressors are available to provide transient suppression as listed below. Operating characteristics for each type are provided in subsequent paragraphs, followed by desirable operating characteristics.

a. Zinc oxide nonlinear resistor (ZNR) or metal oxide varistor (MOV).

b. Silicon avalanche diode suppressor (SAS).

c. Gas-filled spark gap.

d. Surgector combination of SAS and SCR in a single case.

102. OPERATING CHARACTERISTICS OF TRANSIENT SUPPRESSOR TYPES.

a. Characteristics of ZNR Type Suppressors.

(1) Response time: 50 nanoseconds or less, any risetime.

(2) Clamping voltage: 225% of breakdown voltage maximum for surge currents projected.

(3) Breakdown voltage: 22 V DC to 1800 V DC at 1 milliampere.

(4) Standoff voltage: 14 V DC to 1599 V DC.

(5) Surge current dissipation: 500 to 2000 amperes, 8-by-20 microsecond waveform.

(6) Lifetime: Variable, depends on amplitude of surge current, satisfactory for 10-year protection, projected.

b. Characteristics of SAS type Suppressor.

(1) Response time: 1 nanosecond or less, any risetime.

(2) Clamping voltage: 165% of breakdown voltage maximum at rated peak pulse current.

(3) Breakdown voltage: 6.8 V DC to 200 V DC at 1 milliampere.

(4) Standoff voltage: 5.5 V DC to 200 V DC.

(5) Surge current dissipation: Peak pulse current ratings from 139 amperes for 6.8 V DC suppressor to 5.5 amperes for 200 V DC suppressor for 10-by-1000 microsecond waveform.

(6) Lifetime: Not presently defined. Requires current-limiting resistor in series with the protected line to provide required surge current dissipation at facility level.

c. Characteristics of Gas-Filled Spark Gap Suppressors.

(1) Response time: 3 to 5 microseconds for 10-by-1000 microsecond waveform.

(2) Clamping voltage: Arc voltage is 20 volts typical.

(3) Breakdown voltage: 300 to 500 volts typical.

(4) Standoff voltage: 75 V DC to 1000 V DC.

(5) Surge current dissipation: 5,000 amperes for 10-by-50 microsecond waveform.

(6) Lifetime: Varies depending on surge current amplitude, 50 surges of 500 amperes peak current with 10-by-1000 microsecond waveform typical.

d. Characteristics of Surgector combination of SAS and SCR Suppressors.

(1) Response time: 1 nanosecond or less, any risetime.

(2) Clamping voltage: 2 volts.

(3) Breakdown voltage: 166% of standoff voltage max.

(4) Standoff voltage: 30, 60, 230, and 270 volts @ ≤50 nanoamps.

(5) Surge current dissipation: Up to 400 amp for 8 to 20 microsecond waveform. 200 amp for 8 to 20 microsecond pulse for all devices minimum.

(6) Lifetime: Unlimited @200 amps, 8 to 20 microsecond pulse.

103. OPERATING CHARACTERISTICS FOR TRANSIENT SUPPRESSORS. The transient suppressor characteristics listed below are required for effective protection at the facility level:

a. Turnon (response) time: 50 nanoseconds or less.

b. Standoff voltage and leakage current: To ensure that the suppressor remains off except during transient occurrence, standoff voltage should be 20% above normal line voltage. Leakage current should not exceed 100 microamperes at standoff voltage.

c. Polarity: Bipolar or unipolar, depending on line voltage

d. Turnon voltage: 125% of standoff voltage maximum at 1 milliampere.

e. Clamp voltage: Not to exceed 200% of breakdown voltage for transient 100 amperes peak; not to exceed 225% of breakdown voltage for transients in excess of 100 amperes peak.

f. Operating life: Capable of dissipating number and amplitude of transients projected to occur over a 10-year period. See Paragraph 94.

g. Self restoring capability: Essential that suppressor automatically restores to off state when applied voltage drops below turnon voltage.

104. TRANSIENT SUPPRESSOR PACKAGING DESIGN.

a. Individual lines and twisted pairs. Individual packaging of transient suppressors for standard wires and shielded twisted pairs is not required. The key element of design for these devices is the minimization of lead length. Device leads should be routed to minimize bends, kinks and lengths. Protected and unprotected lines should be routed so as to limit coupling from the unprotected lines into the protected lines.

b. Axial cables. Packaging for transient suppression components for axial type cables shall be enclosed in a sealed metal enclosure for each individual line. These enclosures shall have appropriate connectors at each end permitting an in-line installation. Axial line type surge arresters shall be design to minimize insertion loss/signal degradation. Transient suppression enclosures will be one of two types: bulkhead mount and freestanding. The freestanding device shall have a ground connection stud isolated from the suppressor enclosure. This stud shall be grounded directly to an adjacent bus bar with an insulated no. 12 AWG copper wire and this bar shall be grounded to the earth electrode system with a No. 4 AWG insulated stranded copper cable coded green with a bright red tracer. Bulkhead mountable suppression devices shall have the internal components grounded to the enclosure and the enclosure solidly bonded to the bulkhead plate. Exothermic welds or FAA approved connectors shall be used for these connections.

105. METAL BULKHEAD CONNECTOR PLATE. Terminating all RF axial-type cables to a grounded, metal bulkhead connector plate, except when the shield is isolated for proper equipment operation, will provide effective transient protection. This scheme will route transient current from the cable shields to earth ground instead of through terminating equipment to ground thus preventing undesirable changes of electronic equipment earth ground potential. Also, transient surge currents will be shunted to ground before transient energy is cross-coupled to other electronic equipment lines in the facility. The connector plate should be a minimum of 1/4-inch thick, and constructed of tin-plated copper or other metal compatible with the cable connectors. The connector plate must contain the required number of appropriate axial feed through connectors to terminate all applicable incoming lines.

The connectors must also provide a path to ground for connected cable shields except where the shield must be isolated for proper equipment operation. If external and internal coaxial cables are of a different physical size, the changeover in connector size should be accomplished by the feed through connectors of the connector plate. The connector plate should be connected to the earth electrode system with a No. 2/0 AWG (minimum) insulated copper stranded conductor, color coded green with a bright red tracer. (This No. 2/0 AWG conductor is separate from and in addition to the No. 4 AWG conductor noted in Paragraph 104 above.) Additionally, where the building steel is solidly bonded to the earth electrode system, the bulkhead connector plate shall be connected to the building steel with a No. 2/0 AWG (minimum) insulated copper stranded conductor, color coded green with a bright red tracer. The above connections shall be made with exothermic welds or FAA approved connectors.

106. GROUNDING OF UNUSED WIRES. All unused wires of an externally exposed cable run should be connected as directly as possible to earth ground at each end. This may be accomplished by connection to the ground shield at the terminal strip. This action will route transients on unused wires to ground instead of causing the transients to be reflected back and forth on the unused wires, and possibly inducing transients on in-service conductors of the cable run.

107. TRANSIENT SUPPRESSION FOR RF AXIAL LINES. Special attention shall be given to the design of transient protection for axial-type lines. Design may be particularly critical at RF frequencies. Suppression circuits shall be designed using state-of-the-art components which have minimum effect upon the signals being transmitted. Analysis and tests (as necessary) shall be performed to assure that suppression components do not degrade signals to an unacceptable degree or cause marginal operation of the electronic equipment. Particular attention shall be given to the impedance, insertion loss and voltage standing wave ratio for RF signals. When axial lines are installed in end-to-end ferrous metal conduit, transient protection is required only at electronic equipment entrances. Where not run in metal conduit, protection is required at the facility entrance and the electronic equipment. Transient protection shall be provided equally for each conductor and shield that is not grounded directly to the electronic equipment case.

108. ELECTRONIC EQUIPMENT-LEVEL TRANSIENT SUPPRESSION. Electronic equipment-level transient protection is discussed in Chapter 4 of this directive. In general, effective protection is provided by low-value resistors in series with external line inputs, and silicon avalanche diode suppressors connected line-to-ground. Suppressors are currently available as special order items that are suitable for connection line-to-ground on RF lines for signals up to 500 MHz. The suppressors typically consist of a spark gap, a silicon avalanche diode suppressor in parallel with an RF choke, or a combination ZNR and RF choke.

109. - 119. RESERVED.

SECTION 7. COMMON-MODE NOISE AND INSTRUMENTATION

120. GENERAL. Several steps can be taken during the design and construction stages of a facility to minimize subsequent common-mode noise problems in instrumentation, equipment and systems. The recommended steps should be recognized as being appropriate for interference control in general and not limited to common-mode noise.

121. DESIGN PRACTICES.

a. Sensitive data and instrumentation facilities should be located as far as possible from high voltage (66kV and above) transmission lines.

b. The routing of data and signal lines should be perpendicular to main powerlines wherever possible. Where parallel runs cannot be avoided, maximum separation shall be maintained. In many instances, it may be necessary to route the data and signal cables in ferrous conduits.

c. Distribution feeders to the facility should be routed perpendicularly to high voltage powerlines, if possible. In any event, avoid long parallel runs between distribution feeders and the main powerline.

d. Where overhead distribution lines are necessary, preassembled aerial cables are preferred over open wire construction as the conductors of preassembled aerial cables are twisted, thereby greatly reducing the associated magnetic field.

e. Use metallic enclosures for power conductors wherever possible to take advantage of the shielding they offer. In order of preference, the types of enclosures recommended are:

(1) Conduits. Rigid steel conduits, from the standpoint of noise reduction, are the most effective enclosures for power conductors and should be used wherever practical. Electrical metallic tubing and intermediate metal, rigid aluminum or copper, conduits provide effective electrostatic shielding, but their magnetic shielding properties are at least an order-of-magnitude less than rigid steel conduits.

(2) Cable Armor. Armored cable is sometimes used in lieu of conduits and individual insulated conductors. The armor provides an effective electrostatic shield but is not as effective as rigid steel conduits for magnetic shielding. Steel armor is preferable to aluminum or bronze armor.

(3) Flexible Metal Conduits. Flexible metal conduits are a poorer electrostatic shield than either of the above and provides considerably less magnetic shielding than rigid steel conduits. Therefore, flexible metal conduits should be restricted to short lengths and should be used only where required to absorb vibration or to permit position adjustment of the equipment or device served.

(4) Wireway or Cable Tray. Wireways, which are rectangular sheet metal duct-like enclosures, and cable trays are not nearly as effective for electrostatic or magnetic shielding as rigid metal conduits. Unless the wireway or cable tray is made of a ferrous metal and all discontinuities are carefully bonded, its use for the shielding of power conductors should be limited.

f. Power conductors should not be routed in the same conduit, raceway, cable tray, etc., with electronic control or signal conductors or cables. Where such routing can not be avoided, twisting of the power conductors will reduce the magnetic field and hence the pickup by the control or signal conductors will be reduced. Likewise, twisting of the control or signal cables will reduce the pickup from the power cables. Table 2-22 lists the recommended minimum number of twists per foot for both power and control or signal conductors. For conductor sizes larger than No. 2 AWG, or for a greater number of conductors, the number of twists should be to the maximum extent practical.

g. Electrical power equipment such as transformers, line voltage regulators, motors, generators, and switching devices should be separated as far as possible from data system equipment conductors. The architectural arrangement of the facility should allow for the maximum distance between the electrical power equipment and the data system. This requirement also applies to heating, ventilating, and air conditioning equipment which utilize electric motors and high-amperage switching devices. The maximum distance will be limited by the voltage drop in the wiring to the system equipment. This allowable voltage drop shall be limited to meeting the operational voltage of the system equipment and in no case shall the voltage drop be greater than that permitted by the National Electrical Code.

h. Squirrel cage induction motors, which do not utilize slip rings or commutators, shall be used wherever possible.

i. Where the use of motors with commutators is necessary, specify motors properly designed to minimize arcing. Arcing at

TABLE 2-22. MINIMUM NO. OF TWISTS FOR POWER AND SIGNAL CONDUCTORS

Conductor Size (AWG)	No. of Twists per Foot No. of Circuit Conductors					
	2	3	4	5	6	8
22	18	16	10	10	9	8
20	16	12	8	8	8	6
18	12	8	6	6	6	4
16	10	7	5	4	4	3
14	8	6	4	4	3	2.5
12	7	5	4	3	3	2
10	6	4	3	3	2.5	2
8	5	4	3	2	2	1.5
6	4	3	2	2	1	1
4	3	2	1.5	1	1	0.5
2	2.5	2	1.5	1	1	0.5

the commutator or slip rings can be decreased by careful mechanical design such as requiring adequately sized shafts and bearings which maintain concentricity to minimize brush bounce and vibration.

122. INSTRUMENTATION CONSIDERATIONS

a. Where transducers and associated processing devices are to be installed as an integral part of the facility, the instrumentation system shall be designed and installed so that it does not compromise the single-point ground system used by other low frequency systems. In particular, where the systems interface, care must be taken to assure that the grounding integrity of each system is maintained.

b. The AC power for the test equipment shall originate from the same branch circuit supplying the equipment or system being measured. If this practice introduces system reliability problems, breakers or fuses of low ampere ratings should be provided for test equipment outlets. If the outlets for test equipment can not be connected to the branch circuits feeding the primary equipment, then the test equipment branch circuit and outlets should be restricted to the use of the test equipment only. In particular, rotating machinery, industrial machines, and any other non-emi protected equipment should not be connected to that branch circuit.

123. - 129. <u>RESERVED</u>.

SECTION 8. ELECTROMAGNETIC PULSE (EMP) PROTECTION

130. GENERAL. EMP protective measures are based on intercepting the incident energy and dissipating it or reflecting it away from the threatened device, equipment, or facility. These measures are implemented by providing adequate metal shielding around the facility or the equipment inside the facility; by installing fast response surge arresters on power and electronic signal and control lines; by terminating the shields and surge arresters in an earth grounding connection offering a low impulse impedance; by carefully controlling the points of penetration of collectors; and finally, by paying particular attention to all bonds throughout the facility.

131. EARTH CONNECTION.

a. A radial, or star, configuration is preferred to other types of earth electrode systems because of its lower impulse impedance. Where EMP protection is provided in addition to conventional signal and safety protection, supplemental radials may be added to the conventional system.

b. One low impulse impedance radial should be placed at each location where there are over-voltage arresters or protectors on incoming external lines or conductors. An example of such a location is the point where commercial powerlines enter the first stepdown transformer. Another location is at the point where external conductors enter the shelter itself and where arresters or protectors are located.

c. Water pipes or conduits should be connected to the earth counterpoise to prevent ground currents from entering the structure. Furthermore, the AC neutral should be grounded at only one point to prevent the possibility of damage to transformers from circulating currents.

132. EMP SHIELDING APPLICATIONS.

a. Whenever feasible, shielding of the overall building should be done in preference to room or area protection. Individual room or area shield should only be utilized to provide additional protection of critical equipment when normal protective methods will not reduce EMP to an acceptable level, or where, in retrofitting an existing structure, the cost of protecting the entire building is excessive.

b. Commercial enclosures may be used for small rooms and bolted construction is acceptable. For large room construction, however, continuous welded steel is preferred.

c. Electrical wiring and components should be protected from EMP fields by a shield such as ferrous metal conduit, RF shielded raceway, or cable armor that completely surrounds the items to be protected. Electronic components may be shielded with sheet steel housing.

d. All metallic facility penetrations should enter at a common location as illustrated in Figure 2-56. All shielded cables, conduits, and pipes should be grounded at an entry plate as shown in Figure 2-57. This plate should be large enough so that no penetrations will occur within 5 feet (1.5 m) of the nearest edge. The entrance plate should be continuously welded, around its perimeter, to the building shield. The conduit should be of steel with 1/4 inch (6 mm) wall thickness with threaded or welded couplings. The conduit runs should be as short as possible with joints held to a minimum.

133. EMP BONDING PRACTICES.

a. Homogeneous welds should be used whenever possible because they offer the best protection against penetration of the EMP signal.

b. When bolts are used as fasteners, the body of the bolt must be welded or brazed to the outermost shield surface completely around its periphery. The nuts and washers should then be located inside the shield region where they will not be exposed to the incident field.

c. Pipes, conduits, and connector shells should be welded or brazed to the shield completely around their perimeter at the point of penetration of the shielded region.

d. Indirect bonding jumpers and straps should be as wide as practical and as short as possible to minimize the inductance of the path for the EMP induced current.

134. CONSTRUCTION GUIDELINES. The following is a list of additional construction practices which have been proven effective in reducing problems of EMP interference or instrumental damage.

a. Isolate power by using motor-generator sources and installing lightning arresters on lines.

b. Put all external wires in continuous, properly grounded conduits.

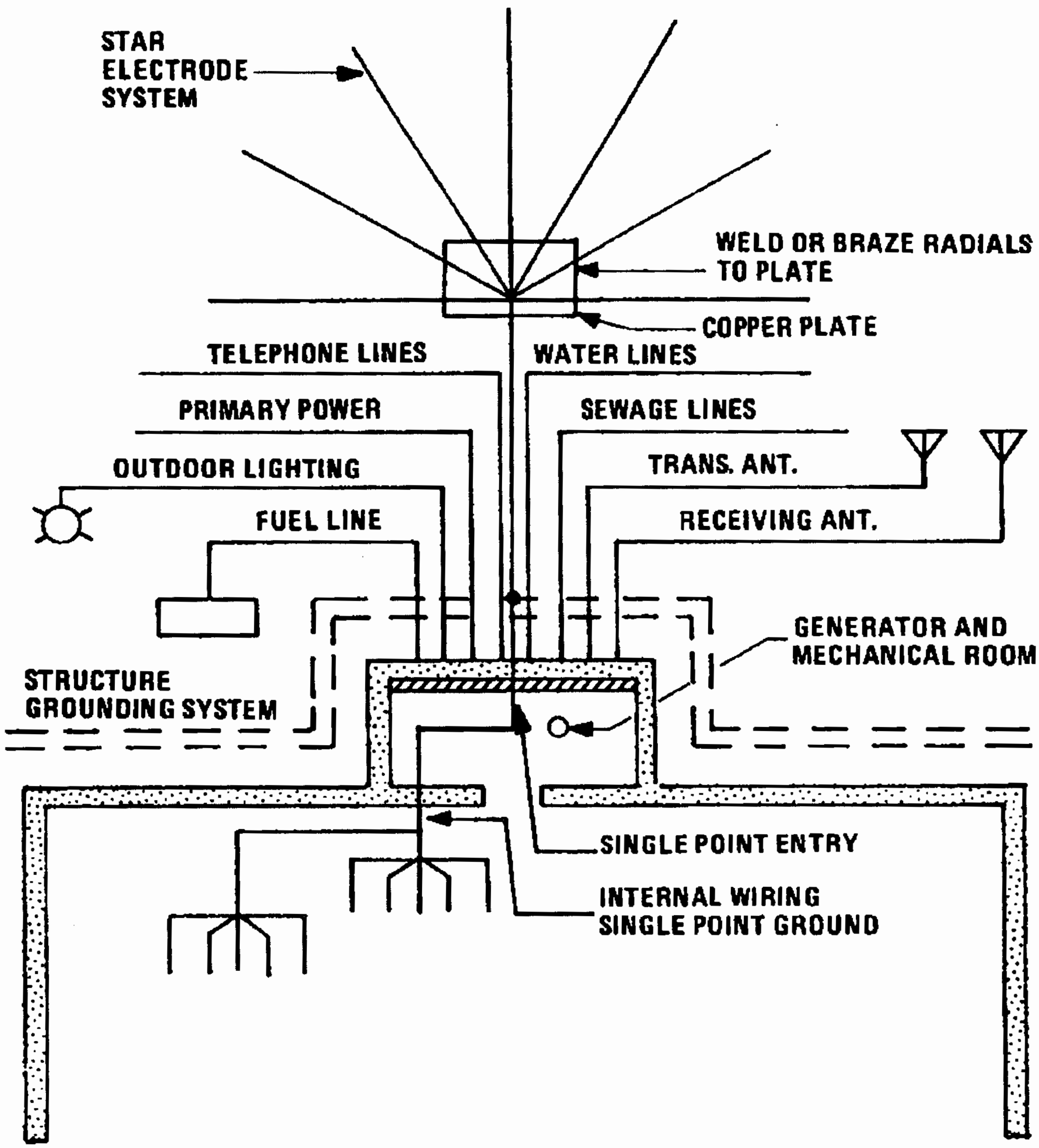
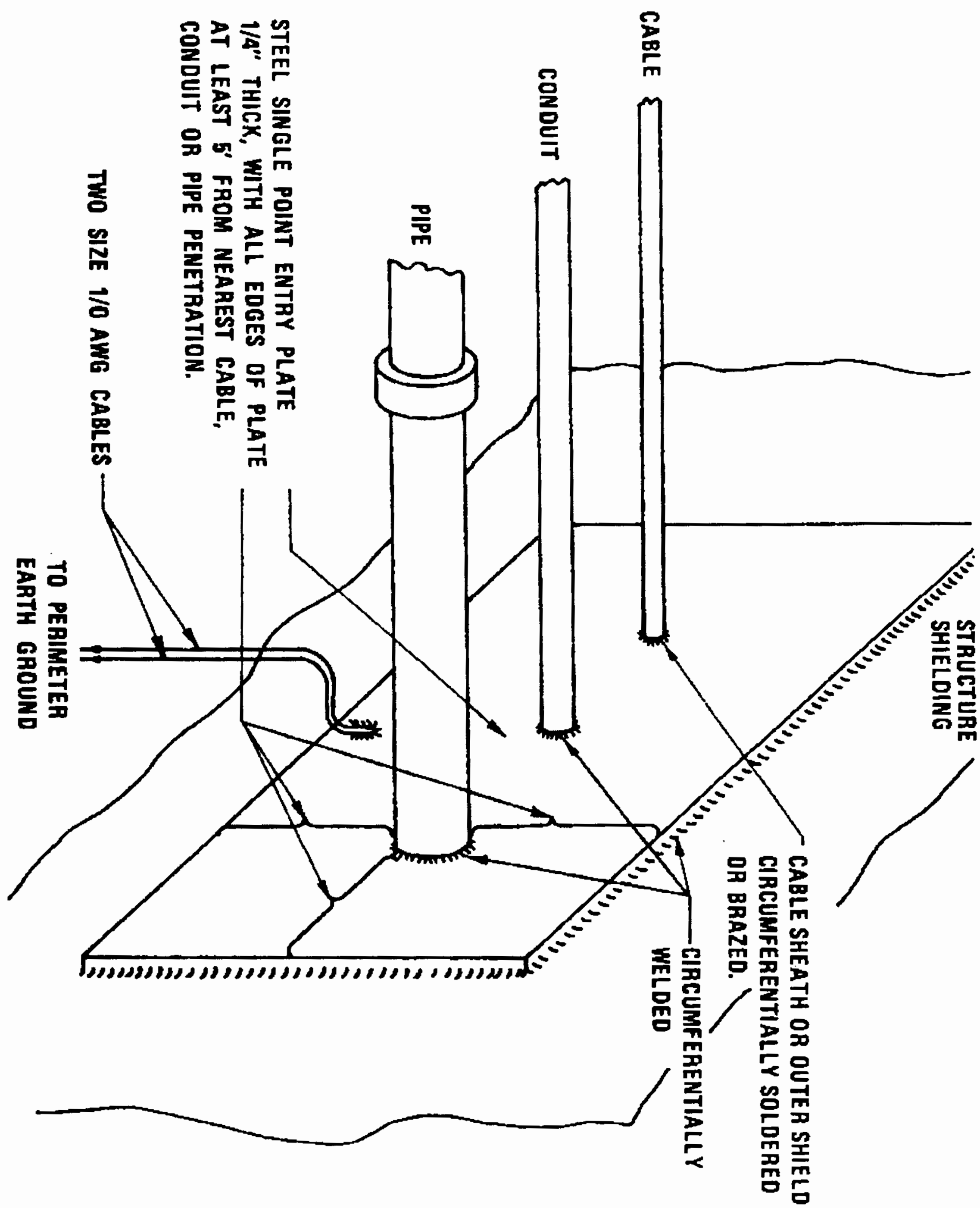


FIGURE 2-56. METHOD OF ENTRY OF EXTERNAL CONDUCTORS INTO EMP-SHIELDED ROOM OR STRUCTURE



<u>FIGURE 2-57. ENTRY PLATE SHOWING RIGID CABLE, CONDUIT AND PIPE PENETRATIONS</u>

c. Use a grounded screen over air conditioning ducts where they enter shielded areas; carefully ground all air conditioning ducts.

d. Interconnect the steel reinforcing bars in concrete into the shielding and grounding systems for the structure.

e. Use largest-rated lightning arresters available on power station transformer.

f. Provide all surge arresters with low-impedance grounds.

g. Ground cable outer shields and insure that the shields are continuous throughout their lengths.

h. Bury power and signal cables in ferrous conduits as deeply as is economically feasible (greater than 3 feet (1 m)) to reduce current surges and to slope wave fronts induced on the cables.

i. Equip antennas with lightning arresters or protectors.

j. Educate personnel in proper protection practices; e.g., extension cords connected to outside plugs should not be brought into shielded areas.

k. Bond together and ground all non-electrical conductors such as elevator cables, metal air ducts, and storage cabinets.

l. Ensure that the entire conduit system is well grounded.

m. Avoid use of nonconducting lubricants when fastening conduit pipes together.

n. Ensure that a low-resistance electrical contact exists between conduits and terminal boxes.

o. Install a grounding strap from the door of the terminal box to the body of the box.

p. Either use adequate surge protection on oil-filled transformers and other high voltage gear to prevent explosions or use only dry type transformers inside the shielded enclosure.

q. Provide adequate surge protection for emergency power equipment.

r. <u>If power equipment is supplied</u> for several sites, install low value fuses at the equipment end (rather than the power end of a system).

s. <u>Use circuit breakers</u> rather than fuses, since breakers can be set more closely and reset more quickly.

t. <u>Do not use</u> slow-blow or delay fuses or breakers.

u. <u>Design breakers</u> (where feasible) to take not more than the largest expected load.

v. <u>Provide automatically closing doors</u> in preference to manually closed doors.

w. <u>Put single phase protection</u> on each phase of three-phase power systems.

x. <u>Use passive</u> low-pass inductance-capacitance radio interference filters on signal, control and telephone lines to provide sloping of pulse wave fronts.

y. <u>The EMP fields</u> in the corners of a shielded structure are usually higher than in other parts of the structure. Do not locate sensitive equipment in corners.

135. - 139. <u>RESERVED</u>.

SECTION 9. INSPECTION AND TEST PROCEDURES FOR A NEW FACILITY

140. GENERAL. The lightning protection, grounding, surge and transient protection, bonding and shielding practices and procedures recommended in this chapter should be implemented as integral elements of the facility during the construction of the building or structure. To ensure that the implementation is accomplished in a timely manner, the construction efforts should be carefully monitored and inspected from the onset of excavation through completion of the facility. The Facility Design Checklist provided in Appendix 1, although furnished for guidance when performing the design of a facility, may also be used for the Inspection function during construction when manpower is available. The following guidelines are provided to aid in the inspection and check-out of the facility. Appendix 3 is furnished for the Joint Acceptance Inspection (JAI) and may be used when appropriate for inspection during the construction of the facility.

141. EARTH ELECTRODE SYSTEM. The following shall be accomplished prior to backfilling and covering the earth electrode system. Appendix 1, Part 1 and Appendix 3, Section 1 may be used for guidance during this inspection.

a. Observe installation procedures. Specifically see that the recommendations of Section 1 are observed. Verify that ground rods conforming with the sizes specified in the building plans, drawings, or specifications are used. If the ground rods are driven in place, see that driving collars or nuts are used to prevent damage to the ground rods. Watch for bent and broken or bulged couplings between sections. Seriously weakened or damaged couplings should be replaced before driving below grade.

b. See that the counterpoise cable interconnecting the ground rods in an earth electrode system are of the correct size (No. 4/0 AWG or as specified on the building drawings or in the applicable specifications or standards). Inspect all connections between cable sections and between the counterpoise cable, lightning protection and surge protection cables, and power system and electronic systems grounding conductors and the ground rods. All connections to the earth electrode system shall be made with exothermic welds or FAA approved pressure connectors (lightning protection system connections to the earth electrode system shall be only by exothermic welds terminating on ground rods).

c. Check to see that provisions are made for interconnecting the earth electrode system with metal utility lines, buried metal tanks, and other underground metals.

d. Verify that the risers or cables installed for the various systems being connected to the earth electrode system are of the appropriate size, material, and where insulated, correctly color coded. (See appropriate Sections of this chapter).

e. Spot check the resistance of the earth electrode system prior to covering the counterpoise and ground rods. Use the fall-of-potential method (see Chapter 3, Paragraph 151c) to determine earth electrode system resistance. This will provide information needed to determine if it is necessary to adjust the earth electrode system configuration to achieve a lower resistance (see Section 1) and to confirm the design calculations obtained from the soil resistivity test performed per Paragraph 13 of this Order. If the measured value is greater than the design value and cannot be attributed to abnormal soil conditions,i.e., frozen, arid, etc., the office responsible for the design should be consulted to determine whether or not modifications to the installed EES is required.

f. Insure that all changes or modifications are properly indicated on the facility drawings.

142. LIGHTNING PROTECTION SYSTEM.

a. Determine the zone of protection established by the air terminals, or by the mast or overhead ground wire (if separately installed system is provided). Locate air terminals on a scaled drawing of the structure. Include all views. Using the procedures in Section 2, determine if all parts of the facility are included within the zones of protection established by the air terminals. If deficient areas exist, determine what additional measures, if any, need to be taken. Refer to Section 2 for guidance.

b. Inspect air terminals for type of materials, for correct diameter and height, and for proper placement. Refer to Section 2 for guidance.

c. Inspect roof conductors for proper size, correct materials, proper routing, and proper type and use of fasteners. Refer to NFPA 780, Lightning Protection Code, and Section 2 as required.

d. Inspect down conductors for proper size (Tables in NFPA 780, Lightning Protection Code) and correct use of materials. Verify that the routing of the down conductors conforms to the requirements of Section 2. Structural steel members are not to be used as the down conductors, however,the requirements to bond the steel columns to the earth electrode system as called for in Section 2 shall be observed. Inspect fasteners for proper spacings and fasteners and hardware for accessibility, strength, and corrosion resistance as required in Section 2.

e. Verify that adequate guards are provided where required. See Section 2 for guidance.

143. ELECTRONIC EQUIPMENT GROUNDING SYSTEMS.

a. Single Point Grounding System.

(1) Inspect the network for configuration in agreement with Section 3. Verify that the main grounding plate, branch ground plates and feeder ground plates described in Section 3 are correctly mounted on insulating spacers.

(2) Check to see that the lengths and cross-sectional areas of trunk, branch and electronic equipment ground cables conform to the criteria in Section 3. Insure that these cables are carefully insulated or otherwise protected from contact with conducting materials, either structural or electrical supporting members, except through the intentional contact made through the Main Grounding Plate.

(3) After installation of the single point grounding system but before any electronic equipment connections are made either at a branch or feeder ground plate, disconnect the trunk ground cable from the main ground plate and measure the resistance between the trunk ground cable and the main ground plate (see Figure 2-20). A resistance of 10 megohms or greater indicates that the isolation of the network is adequate.

(4) Evaluate the layout and routing of the grounding network conductors in light of the requirements of Section 3. Compare the network configuration and the placement of branch and feeder ground plates with the intended use of the facility.

(5) Verify that labels, protective covers, and color coding of conductors and ground plates are provided as specified by the facility drawings and specifications, applicable standards and Section 3 of this Chapter.

b. Multipoint Grounding System.

(1) In steel frame buildings, verify that structural steel elements are adequately bonded at joints to produce a low-resistance joint, less than 1 milliohm. Review Section 3 for fastening procedures. Welded joints conforming to Section 4

criteria are preferred. Mechanically-fastened joints shall be carefully cleaned, bolts adequately torqued (see Table 2-3) and proper bond protection provided. Verify cleaning procedures, spot check torque measurements, and verify that paints and sealants are applied as needed. Perform spot check measurements of the bond resistance at structural joints using a four-terminal milliohmmeter. The maximum bond resistance shall be 1 milliohm. Where bond resistances greater than 1 milliohm are encountered, require that the bond surfaces be recleaned, bolts re-torqued, or supplemental jumpers provided to achieve 1 milliohm.

(2) In non-steel frame buildings, inspect the installation of the copper cable system used to replace structural steel members for the multipoint ground system interconnections for conformance to the requirements of Section 3. In particular, verify that the grounding cables provide the 2000 circular mils per running foot of conductor. Verify that the cables are color coded in accordance with Section 3.

(3) Verify that electronic equipment ground plates are installed as specified on the facility drawings. In particular, inspect the location for accessibility and verify that the plates are securely mounted. Verify that the plates are adequately protected and color coded in accordance with Section 3.

(4) Verify that at least two electrical paths exist between any two points in the multipoint ground system. Measure the resistance between selected points on the network to verify that the total resistance does not exceed 5 milliohms. If the resistance does exceed 5 milliohms, check interconnecting cables for correct size and check all joints for proper bonding. See that all deficient cables are replaced and that all poor bonds are reworked.

(5) Inspect metal pipes and tubes for electrical continuity and bond as required by Section 3.

(6) Verify that all electrical supporting structures are interconnected and bonded as required by Section 3.

(7) Where equipotential planes are used, make certain that all interconnections are properly bonded, leads from equipment to the equipotential plane kept as short as practicable and properly bonded to the plane and that the plane is properly bonded to building steel and to the earth electrode system.

(8) Where Signal Reference Grids are used, make certain that the raised floor is of the bolted grid (stringer) or

rigid grid system and that all interconnections are properly bonded and connected, the mesh is sized, installed, and grounded as required by Section 3. Verify that the power system is properly installed to meet the requirements of the National Electrical Code and that the Signal Reference Grid is not used as a replacement for the electrical power system equipment grounding conductors.

144. POWER DISTRIBUTION GROUNDING.

a. Inspect the grounding of electrical distribution systems for conformance with Section 3.

b. Verify that a separate equipment grounding conductor is utilized for grounding all equipment, electrical and electronic, when fed from an AC power circuit. Neither the grounding conductors of the multipoint ground system nor the grounding conductors of the Signal Reference Grid may be used as the equipment grounding conductor required by the National Electrical Code.

c. Verify that the system neutral is grounded only at the service disconnecting means or at the source of a separately derived system.

d. Verify that the neutral of a standby engine generator is not grounded at the frame or controller of the engine generator, unless the engine generator is connected as a separately derived source. The engine generator is grounded with a separate equipment grounding conductor and the neutral of the engine generator is isolated from any metal bodies except for its connection at the service disconnecting means of the facility housing the engine generator.

145. BONDS AND BONDING.

a. In addition to the inspection of structural joints, generally inspect all bonds for proper cleaning, correct fastening or assembly, and for adequate corrosion protection. Be particularly alert for conformance with the recommendations of Section 4.

b. Perform resistance checks on selected bonds. Use a four-terminal milliohmmeter. The selected bonds shall exhibit a resistance less than or equal to the values in FAA-STD-019. Those that do not meet this criteria must be reworked.

146. LIGHTNING INDUCED SURGE AND TRANSIENT PROTECTION.

a. Be thoroughly familiar with the surge and transient protection requirements of Section 6.

b. During construction, if at all feasible, verify that:

(1) Incoming AC service conductors are underground and are enclosed end-to-end (transformer to service disconnecting means) in watertight, electrically continuous ferrous metal conduits, effectively grounded and bonded at each end. If service entrance conductors must be installed overhead, check that a metal guard wire has been installed to provide the proper zone of protection and that the guard wire is grounded at each end.

(2) Electronic cable runs of 300 feet (90 m) or less that directly interface electronic equipment are enclosed in watertight, electrically continuous, ferrous metal conduits. The conduits shall be effectively grounded and bonded at each end. Enclosing cable runs of more than 300 feet (90 m) in length provides effective transient protection, but the cost may become prohibitive. Each case should be analyzed to determine the cost effectiveness. Where conduits exceed 300 feet (90 m) in length, additional ground connections shall be made as defined in Section 6.

(3) Buried cables not enclosed end-to-end in ferrous metal conduits have a No. 6 AWG solid copper guard wire buried a minimum of 10 inches (25 cm) above and parallel to the buried cable or duct run. Where the buried cable or duct run exceeds 3 feet (1 m) in width, a second guard wire shall be installed. The guard wire(s) shall be effectively bonded to the ground system at each end. Lengths of guard wires exceeding 300 feet (90 m) shall have an additional connection to earth ground. For each 300 feet (90 m) or portion thereof in excess of 300 feet, an earth ground connection shall be made utilizing 3/4 inch by 10 foot ground rods located not less then six (6) feet from the guard wire. These connections to earth should be located at approximately equal spacings between the ground connections at each end of the guard wire installation.

(4) Where conductors to a facility are direct buried or in non-metallic conduit, verify that they exit and/or enter the externally mounted equipment or the structure in rigid steel conduit which is effectively bonded and grounded at each end and extend a minimum of 5 feet past the earth electrode system at each end.

c. Surge Protection, Verify that:

(1) An adequate surge arrester is installed not more than 12 inches (30 cm) from the service disconnecting means.

(2) The surge arrester is connected on the line side of the service disconnecting means with properly sized conductors, installed to be as short as practicable and having no loops, sharp bends or kinks.

(3) When the AC service has no neutral conductor, the surge arrester installed provides both line-to-ground and line-to-line protection.

(4) The connection from the AC surge arrester to the ground bus (delta service) or to the grounded neutral bus (wye service) of the service disconnecting means is as short and direct as practicable and has no loops, sharp bends or kinks.

d. Transient Protection, Verify that:

(1) Transient suppressors are installed as required in Section 6.

(2) The ground connections of the transient protection devices are as short as possible with no loops, sharp bends or kinks.

(3) The high-energy component of the transient suppressor is connected directly to the earth electrode system and that the low-energy component is connected to the electronic equipment multipoint ground system.

(4) All externally exposed axial (RF) cables, not enclosed in metal conduits, are terminated on metal bulkhead plates as defined in Section 6.

(5) The connector plate is connected to the earth electrode system with a No. 2/0 AWG insulated copper cable, color coded green with a bright red tracer, installed as short and direct as practicable with no loops, sharp bend or kinks.

(6) The connector plate is tin-plated copper or other metal compatible with the cable connectors.

147. - 149. RESERVED.

CHAPTER 3. EXISTING FACILITIES

150. INTRODUCTION. This chapter presents detailed procedures for performing a transient protection, grounding, bonding and shielding survey at existing FAA air traffic control and air navigation facilities. The inspections and tests presented will identify transient protection, grounding, bonding, and shielding deficiencies and deviations from the National Electrical Code (NEC), Lightning Protection Code (NFPA 780) and the Installation Requirements for Master Labeled Lightning Protection Systems (UL 96A). Where a major modification or a significant change out of electronic equipment is anticipated, the results of the survey should be used to correct deficiencies and upgrade the facility. Table 3-1 lists test equipment normally required to accomplish the survey.

TABLE 3-1. SURVEY EQUIPMENT REQUIRED

Procedures	Equipment
Lightning Protection	100-ft. measuring tape
Earth Electrode System	Biddle Megger Earth tester, 100-ft. measuring tape
Transient Protection	None - physical inspection
NEC Compliance and Current Measurements	Clamp-on Ammeter Volt-ohmmeter
Bond Evaluation and Resistance Measurements	Digital Milliohmeter, four-terminal
Signal Reference Network and Multipoint Ground System	None - physical inspection
Shielding Evaluation	None - physical inspection

SECTION 1. EARTH ELECTRODE SYSTEM

151. GENERAL. This portion of the procedure is performed to determine what the earth electrode system consists of, its configuration, and its effectiveness. The procedure consists of a review of facility drawings, inspections, and measurements. Appendix 3 may be used as applicable to the following surveys and inspections.

a. Facility Drawings. Review the facility drawings and identify the various electrodes (ground rods, counterpoise cables or grids, water pipes, power grounds) and note their interconnections. Prepare a sketch showing these electrodes and their interconnections. From the sketches made during the inspection of each system, redline the facility drawings with respect to any discrepancies found.

b. Inspections.

(1) Make a general classification of the type of soil that exists around the facility or in the case of a large facility, e.g., an Air Route Traffic Control Center (ARTCC), around each structure if conditions vary.

(2) Utilizing the sketch prepared from the facility drawings, inspect the facility to determine if any corrections should be made. Make the corrections on the sketch or attach a set of notes that define the corrections required to the data.

(3) Inspect all accessible above-ground bonds associated with the earth electrode system. Connections (down conductors to ground rods, ground rods to counterpoise cable, etc.) buried under the soil should be inspected, at least on a sampling basis, in order to determine their general condition.

c. Measurements

(1) Earth Electrode System Resistance. The procedure described below is the fall of potential method (three terminal test). The P1 and C1 terminals on the test instrument are jumpered and connected to the earth electrode being tested. The test potential probe (P2) is placed at 62 percent of the spacing between a point on the electrode system being measured and the current probe (C2). See Figure 3-1.

(a) Utilizing the prepared sketch of the earth electrode system and the facility drawings, select a point on the earth electrode system and a direction of measurement away from

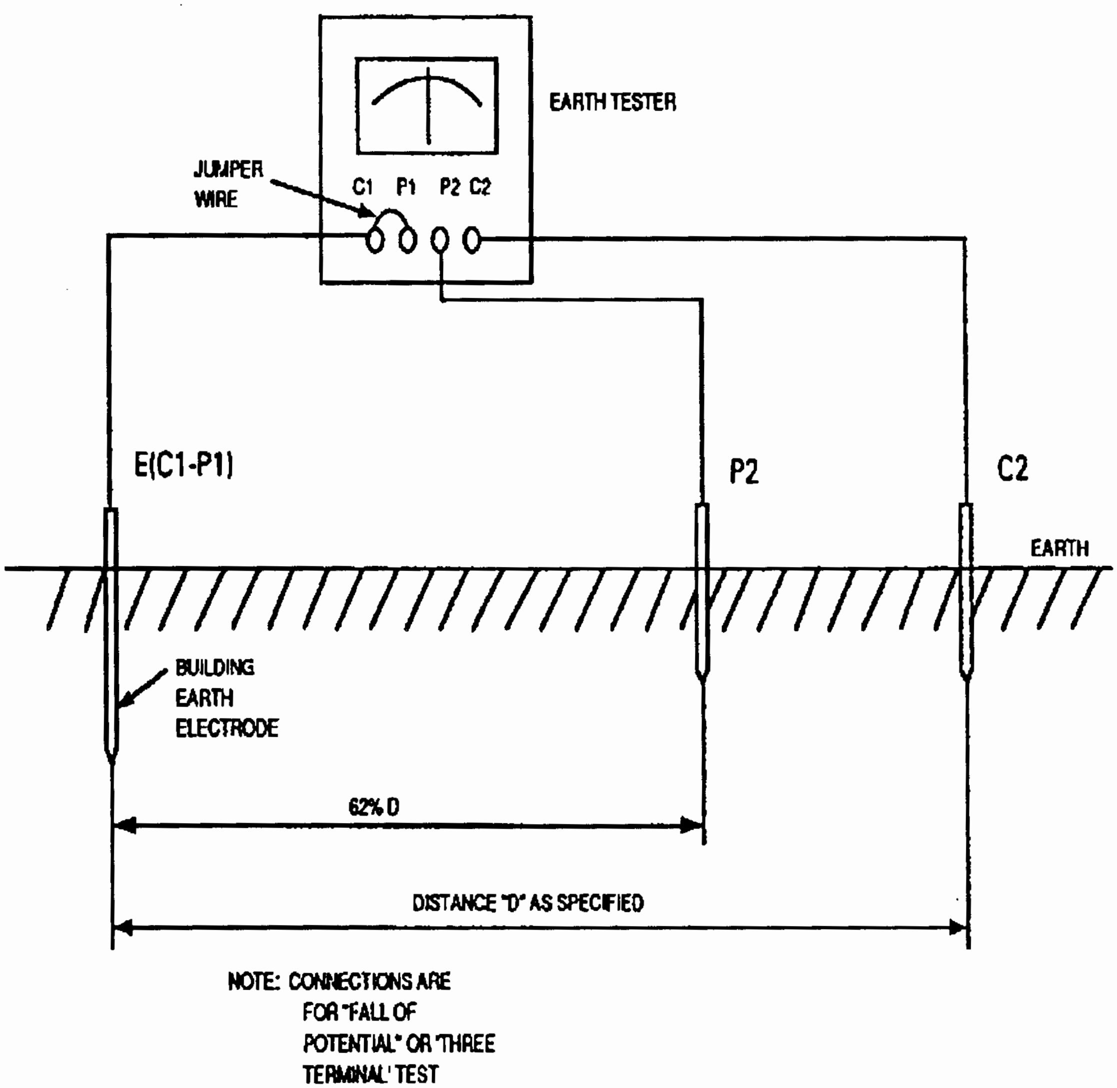


FIGURE 3-1. TEST SETUP

the earth electrode system under test, and known underground metallic objects (water pipes, cables, etc.).

(b) Connect the jumpered C1-P1 lead to the earth electrode E (or point on the electrode system from which measurements are to be made).

(c) From the selected electrode or point and in the chosen direction, position the current probe (C2) at a convenient distance (D) from the measurement point. Suggested distances are 100 feet for a single electrode or an earth electrode system consisting of three or less ground rods. A distance of 5 times the diagonal of the grounding system or a minimum of 200 feet should be used for earth electrode systems consisting of more ground rods, and for larger complex earth electrode systems. (NOTE: The greater the E-C2 (C1-C2) spacing the more accurate the value obtained for the facility ground resistance. The distance chosen may be limited by the area available.)

(d) Position the potential probe (P2) at a distance of 62% of the distance (D) between the current probe (C2) and the measurement point (E). See Figure 3-1.

(e) Measure the resistance in accordance with the instrument manufacturer's instructions. Potential Point (P2) is driven in at several points on a straight line between the measurement point (E) and the current probe (C2). Correct earth resistance is normally read from the curve for the distance that is 62% of the distance between point (E) and probe (C2). When performing these measurements the resistance read should increase to a certain point, level off, and increase again. A plot of Resistance to Earth vs. Distance may be drawn by using the values obtained as the P2 probe is moved toward or away from the C2 probe. The correct resistance to earth at the electrode being measured (E) is the value of the leveled off portion of curve (which is normally at the 62% distance noted above). See Figure 3-2. This test is done to verify correct readings. If the curve does not level off, the current probe (C2) must be placed at an increased distance from the measurement point (E).

(f) Repeat the above measurements in other directions at least 60 degrees from the first line of measurement and from other earth electrodes of the earth electrode system being checked. Whenever the test probe locations are moved to other areas, there may be a difference in soil conditions which will result in a change to the resistance values in both, the

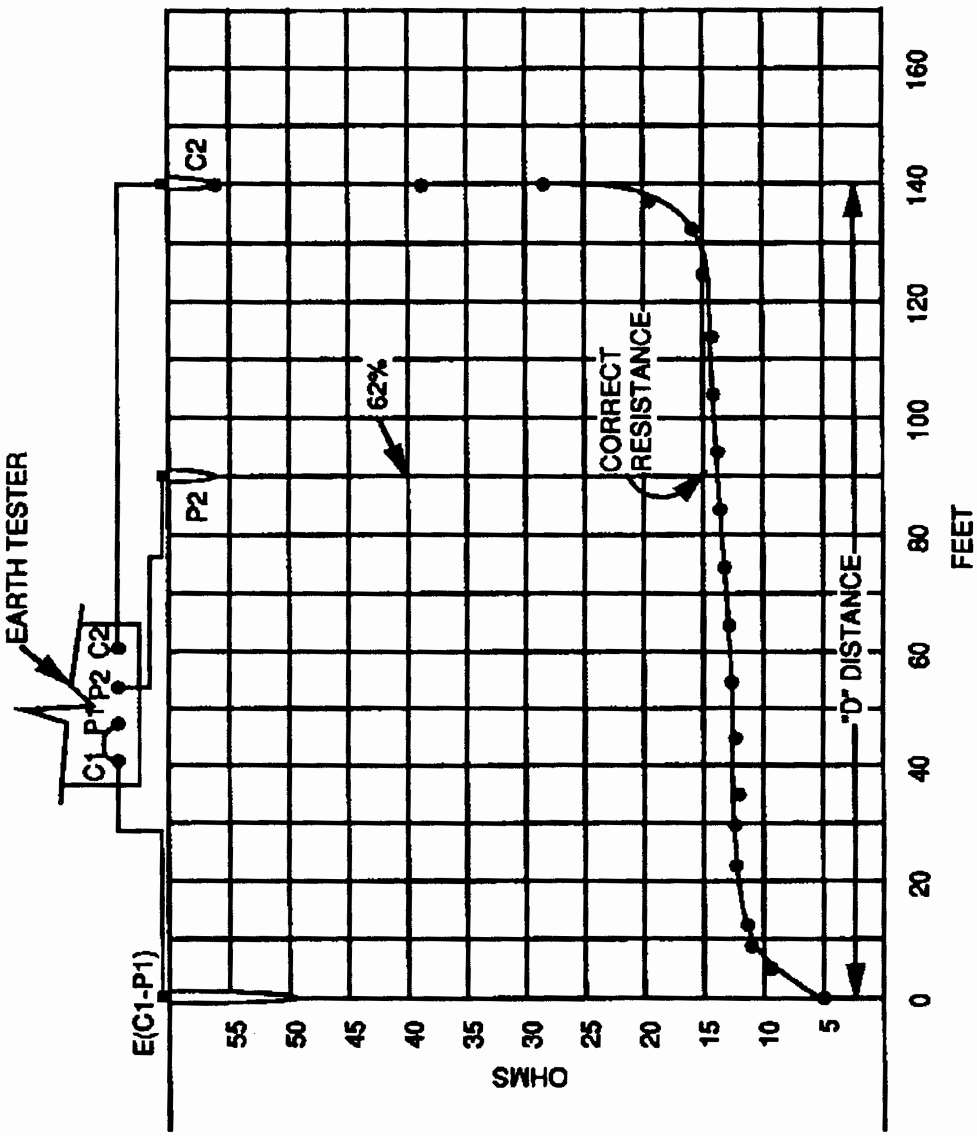


FIGURE 3-2. CURVE OF GROUND RESISTANCE VERSUS DISTANCE

single 62% reading and/or the derived plot obtained in Paragraph 151c(1)(e) above.

(2) Bond Resistance. Using a four-terminal milliohmmeter, measure the resistance (in accordance with the manufacturer's instructions) across bonds associated with the earth electrode system. Measurements should be made not only on individual bonds but also between various points such as between two buildings. When making a measurement between two points that are widely separated, reverse the probe connections to the meter. If a different reading is obtained, average the two readings and record this value on the data sheet.

d. Evaluation and Updating. Compare the earth resistance values obtained with previously measured, or calculated values. In making the comparison, disregard such values as zero or other unobtainable values. The resistance measured by the above method may vary from those measured if a different method was initially used. For example, if the current probe was not placed far enough away from the electrode being measured and the potential probe was placed midway between the electrode and the current probe, the resistance measured will probably be lower than that measured by the method given here. Also, if either the current probe or potential probe was placed near any underground metallic object of considerable size (water pipes, cables, etc.) the value obtained could be greatly different. Additionally, the amount of soil moisture and/or soil temperature could result in a significant difference. If possible, determine the soil moisture and temperature conditions of the previous measurements for comparison to the present measurements. Refer to Chapter 2, Section 1, for additional information on earth electrode measurements. The continuity of the system can be determined by repeating the test with the P2 and C2 probes remaining in their present location and connecting the test lead from the C1P1 terminals to another location such as the opposite corner of the counterpoise, or the service disconnect switch's grounding conductor, etc.. Note that the readings from different test locations should be the same as the original reading. If the readings differ thoroughly inspect the system for discontinuity or corrosive bonding.

(1) Varying Resistance. If the measured resistance is significantly greater than those measured previously, repeat the measurement using the direction, distance, and techniques of the previous measurements if they are known. Also, if possible, compare the soil moisture and temperature conditions of this measurement against those of the previous measurements. If this measurement gives a resistance significantly greater than

previous values and the soil conditions are similar, the electrode system may have deteriorated.

To determine if the electrode system has deteriorated, the electrode system should be thoroughly inspected to determine if there are any broken conductors or broken and/or corroded connections. The inspection should first be made on all above-ground conductors and connections. If below ground inspections must be made, these should be made first on those that are relatively accessible (i.e. buried in soil). Broken conductors and connections should be repaired and corroded connections should be disassembled, cleaned, reassembled, and protected from further corrosion.

(2) Desired Resistance. The desired resistance for an electrode system is 10 ohms or as noted on the facility specifications. If the results indicate that inspections in inaccessible locations (i.e. under concrete) are necessary because the electrode system has deteriorated, a determination must be made to see if it would be better to make these inspections or to improve the electrode system by the addition of ground rods and/or counterpoise cables without baring the existing electrode system.

(3) High Resistance. If the resistance is above the desired 10 ohms, and the electrode system has not been degraded, then a study should be made to determine if it would be economically feasible to obtain the 10 ohms. In making the final decision, the past history of the site in regard to lightning strikes or damage should be considered. If the 10-ohm goal does not appear feasible, one should consider improving the performance of the electrode system by the addition of ground rods and counterpoise cables so as to spread any lightning or fault current over a large area. Refer to Chapter 2, Section 1 for information on earth electrode designs and configurations.

152. - 159. RESERVED.

SECTION 2. LIGHTNING PROTECTION SYSTEM

160. GENERAL. This portion of the survey is performed to verify the integrity of the lightning protection system in accordance with NFPA 780 and UL 96A. The survey consists of a visual inspection and resistance measurements.

a. Visual Inspection.

(1) Obtain the lightning protection drawings for the facility if available. If drawings are not available, make a sketch of the facility. At a large facility it may be desirable to make a sketch of the entire facility on a small scale and then sectionalize the sketch and draw each section to a larger scale.

(2) On the sketch, indicate all air terminals, roof conductors and down conductors, and the type of material.

(3) Indicate the height and diameter of the air terminals.

(4) Indicate whether or not the air terminals are solid.

(5) Measure the distance between the air terminals and show this distance on the sketch.

(6) Inspect air terminals for evidence of burning, pitting or melting, and indicate such conditions on the sketch. Also indicate any leaning, bent or broken air terminals.

(7) Indicate the size and type of cable used for all main (roof and down) and secondary bonding conductors.

(8) Show any location where aluminum and copper are joined and indicate whether bimetallic connectors are used.

(9) Inspect all bends in roof and down conductors and verify that the bend radius is not less than eight inches and the included angle is not less than 90 degrees. Show any discrepancy on the sketch.

(10) Measure the distance between the down conductors and indicate this distance on the sketch.

(11) Indicate on the sketch all objects on the roof subject to a direct strike. Then indicate whether or not they are bonded to the roof conductors, the size and type of bonding

conductor and the type and area of contact of the bonding connector.

(12) Indicate on the sketch all objects subject to a sideflash (Refer to Chapter 2, Section 3) that are within six feet of any air terminal, roof or down conductor. Then indicate whether or not they are connected to roof or down conductors, the size and type of the bonding (secondary) conductor or strap and the bonding surface area and the type of connector.

(13) Verify that all metal antenna masts are bonded to the roof conductors.

(14) Inspect all connections for signs of corrosion. Indicate on the sketch any place where corrosion was found.

(15) Check all fasteners and hardware for secure mounting, corrosion, and mechanical damage and that maximum spacing between fasteners for all main conductors does not exceed three (3) feet. Indicate any deficiencies on the sketch.

(16) Verify that copper lightning protection materials are not in contact with aluminum roofing, siding, or other aluminum surfaces.

(17) Check all aluminum lightning protection equipment and verify that they are not in direct contact with copper surfaces or alkaline-base paints and are not exposed to runoff from copper surfaces. Indicate any deficiencies on the sketch.

(18) Verify that all aluminum down conductors are connected to a copper conductor before entering the earth and that the connection employs bimetallic connectors.

(19) Verify that any guards for down conductors are nonmetallic, or, if metallic, are bonded to the down conductor at both ends. Indicate any discrepancies on the sketch.

(20) Update the facility drawings with the data from the sketches made during the survey.

(21) Inspect the roof conductor and make certain that it is a closed loop.

b. Resistance Measurements. Using a four-terminal milliohmmeter, measure the resistance across all bonds that show any evidence of corrosion or appear to be questionable. Also measure a representative number of other bonds. Data Sheet

No. 5, Appendix 3, is furnished for guidance in making the measurements.

c. Evaluation. The inspection record provided in Appendix 4 is furnished for guidance when evaluating the lightning protection system.

d. Correction of Deficiencies. The results of the survey should be thoroughly reviewed to determine the feasibility of immediately correcting all deficiencies. Complete and strict compliance with the requirements of NFPA 780 and UL 96A is a requirement. However, it may not be economically feasible to correct some or all deficiencies immediately. The need for urgency and the method of correcting each discrepancy will have to be determined for each case. In making the determination, consideration should be given to the importance of the facility in the NAS operations and the frequency and severity of thunderstorms in the area of the facility. In any case, all deficiencies should be scheduled for correction as soon as practicable.

161. - 169. RESERVED.

SECTION 3. ELECTRONIC SYSTEM GROUNDING NETWORKS

170. GENERAL. This portion of the survey is performed to define the configuration and effectiveness of the electronic equipment grounding systems. The survey is comprised of visual inspections and resistance and stray current measurements. In a large facility (e.g., an ARTCC) it is suggested that the survey be done on an area-by-area basis and then the interconnections between the various areas be investigated. Applicable parts of Appendices 1, 2 and 3 may be used in accomplishing the following.

a. Visual inspection.

(1) Multipoint Ground System. To determine the configuration of the multipoint ground system, perform the following:

(a) Draw a block diagram of the facility, or each area of a large facility, showing all equipment including power panels and the electric service. To the extent possible, show the equipment layout.

(b) On the diagram, show how the equipment is interconnected. The diagram should include wire size, routing and any variations of grounding such as grounding through cable trays, raceways, ground buses, etc. Distinguish between any conductors that appear to be dedicated ground buses for the electronic equipment ground system(s) from those that are the equipment grounding conductors required by the National Electrical Code for the power system (See Section 7). Indicate where any electronic ground system conductor is used in lieu of the power system equipment grounding conductor. Also include any connections to the building structure and earth electrodes. In a small facility, this will be readily accomplished. However, in a large facility, it will be a considerable effort and will involve tracing out many conductors. Make the survey as comprehensive as possible.

(2) Single Point Ground System. To determine the configuration of the single point grounding system, follow the same general procedure given above, except indicate the single point grounding paths including all ground plates. Visually verify that the ground plates are electrically isolated from the structure. Indicate any interconnections between the single point and multipoint grounding networks. Also include the grounding of any cable shields.

(3) Update the facility drawings with data from the sketches.

b. Measurements.

(1) Resistance. Using a four-terminal milliohmmeter, measure the resistance between representative units of equipment in the facility or within any one area of a large facility. In a large facility, measure the resistance between the various areas to the extent possible. When making the measurements, reverse the leads to the meter and if there is any difference in the two values, average them and record this value for future reference and possible corrective action.

(2) Stray current. Using a clamp-on ammeter, probe signal ground wires, cable shields, or other conductors likely to be carrying stray power currents. Note particularly the current levels in the grounds of low-frequency equipment and in the shields of cables carrying video, data, or other types of signals with operating frequencies in the power frequency range.

171. EVALUATION AND CORRECTIVE ACTION.

a. Grounding Networks. There is no one equipment and/or signal grounding configuration that will guarantee a noise or problem-free installation for all equipment or systems. There are, however, certain configurations with basic requirements that have been found to be more effective than others in the majority of installations.

(1) Basic Requirements.

(a) Low-frequency circuits (less than 100 kHz cw and greater than 10 microsecond rise time) should be connected to ground only once.

(b) Low-frequency circuits should not utilize the multipoint ground system (chassis) as a signal return.

(c) All equipment noncurrent-carrying metal parts should be grounded as effectively as possible. This includes multiple grounding through the mounting surfaces and by means of equipment grounding conductors (NEC "safety" or "green" wire) and by means of grounding jumpers.

(d) The length and size of all electronic system grounding conductors and/or jumpers should be as short as possible and of a large cross section area sized to meet requirements of Chapter 2, Section 3. The electronic system grounding conductors shall not be used in lieu of the power system equipment grounding conductor which should be sized in accordance with the requirements of the NEC.

(e) All bonds should be made through surfaces that are free of insulating materials, and the surface area should be large.

(2) Identifying Deficiencies. The drawing made of the multipoint ground system and single point grounding system should be reviewed to identify any inconsistencies between the same or similar equipment installed in the facility. Also compare the facility configuration with that described above. Correlate, if possible, any differences in the grounding configuration with any noise or operational problems as indicated by maintenance records or operator comments.

(3) Correcting Deficiencies. Based upon the results of the review, plan any changes that are warranted or indicated as desirable. Such changes should be planned in an orderly fashion and be made while monitoring the equipment or system to determine if the operation is improved or degraded. It is suggested that such changes first be made on a temporary basis, and if an improvement, or at least no deterioration in the equipment or system is noted, then request that the changes be made in a permanent fashion.

b. Stray Current. There is no set criteria on a limit or acceptable level of stray current. The ideal value is zero. However, this value is seldom obtained. The source of all currents in excess of 0.1 ampere should be investigated to determine its source. In some cases it may be normal. For example, it may be caused by a radio frequency interference (RFI) filter due to the fact that the filter uses a large capacitor connected between the power lines and the chassis of an equipment. In other cases, it may be caused by a neutral conductor being grounded internally to a piece of equipment or at a power panel (other than the service disconnect). The corrective action to be taken will depend upon what is determined during the investigations.

172. - 179. RESERVED.

SECTION 4. BOND EVALUATION AND RESISTANCE MEASUREMENTS

180. GENERAL. This part of the survey must be accomplished to evaluate and determine deficiencies in bonding in the facility. The survey of existing bonds consists primarily of a visual inspection and resistance measurements. A general listing of corrective actions that may be required is also provided.

a. Visual Inspection. Visually inspect the facility and equipment to determine the adequacy of all bonds (ground connections). In a large facility, it will be impossible to inspect all bonds. Therefore, the inspection will have to be limited. The overall indication of the condition of the bonding and grounding at a facility is directly proportional to the number of bonds inspected and measurements taken.

Particular attention should be directed toward the electronic equipment grounding conductors and the power system equipment grounding conductors. Some of the things to look for are listed below.

During the inspection, it may be desirable to correct a deficiency when it is discovered (e.g., tightening a loose connection). In such cases, note the discrepancy on the data sheet, and note the corrective action taken.

(1) Welded, brazed, or silver soldered connections should be examined for broken or cracked seams, presence of voids, size of filler deposit, length and number of deposits (if discontinuous), and evidence of corrosion.

(2) Soft-soldered bonds should be inspected for broken connections, evidence of cold solder joints (crystalline, grainy appearance), and signs of overheating. Soft solder should only be used to improve conductivity at load bearing joints; it should not be used to provide mechanical restraint. There should be no solder joints in either the fault protection grounding system (this includes the equipment grounding conductors) or in the lightning protection system.

(3) Bolted joints should be checked for looseness, inadequately sized fasteners, corrosion of either the fastener or main member, improper use of washers and locknuts, absence of or inadequate coverage with protective coatings, damaged or missing hardware, and improperly cleaned mating surfaces. Be particularly thorough in the inspection of bolted connections in areas open or exposed to the weather.

(4) Joints using rivets, clamps, and other type fasteners should generally be examined for looseness and corrosion.

(5) Broken grounding conductors.

(6) Ground bonding conductors that are not direct and as short as possible.

(7) Corroded connections and connections between dissimilar metals which are exposed to water or moisture and are not sealed.

(8) Bond connections that are made through faying (mating) surfaces which have not been cleaned of insulating finishes such as paint, etc.

b. Resistance Measurements. Concurrent with accomplishment of the visual inspection, make sample bonding resistance measurements using a four-terminal milliohmmeter. Measure the resistance across all suspected deficient bonds noted when completing the visual inspection.

c. Corrective Actions. Typical corrective actions that may be required are presented below. Each deficiency must be evaluated individually to determine the most 'appropriate' corrective action.

(1) Welded, brazed, or soldered connections that are broken or cracked should be remade.

(2) Welded or brazed connections that are corroded should have the corrosion products cleaned with sandpaper, steel wool, wire brush, etc. The area should then be protected from further corrosion with paint or other sealing material.

(3) Broken grounding conductors should be replaced.

(4) Ground bonding conductors should be shortened to be as direct and short as possible.

(5) Bonds whose mating surfaces have not been cleaned of nonconducting materials should be disassembled, the material removed and the bond reassembled.

(6) Cold-soldered connections should be reheated until the solder melts. The connection should then be allowed to cool without disturbing the members being soldered.

(7) For every bond exhibiting a resistance greater than 1 milliohm check for looseness; if the connection is loose, tighten the fastener. Measure the resistance again after tightening. If the resistance is still greater than 1 milliohm and the joint can be readily disassembled, disassemble the joint and check for corrosion, debris, paint, or other nonconductive materials. Remove the material, reassemble the bond, and remeasure the resistance. If the resistance is still greater than 1 milliohm, an alternate bonding method should be employed. Refer to Order 6950.20 for information on bonding methods.

(8) Bonding jumpers using wires, cables, or wide metal straps are frequently used for fault grounding, signal grounding, and lightning bonding. Fault protection jumpers should conform to Article 250 of the NEC and lightning bonding should conform to NFPA 780, Lightning Protection Code. If they do not conform to the above noted codes, the jumpers should be replaced with cables or straps of the sizes specified by the related NEC and NFPA 780. Electronic systems grounding straps should be only as long as needed to bridge the physical distance and should exhibit a length-to-width ratio of not greater than 5-to-1. (Refer to Order 6950.20).

181.- 189. RESERVED.

SECTION 5. SHIELDING EVALUATION

190. GENERAL. The shielding survey is performed to identify the presence, purpose, and condition of both equipment and facility shields. Electromagnetic shields to reduce unwanted coupling and personnel protection shields to prevent shock and radiation hazards should both be evaluated. The facility drawings should be referenced to identify all of the items that should be inspected to ensure that no items of importance are overlooked.

a. Visual Inspection. Within each facility, visually inspect equipment and facility shields installed to provide shock and radiation hazard protection for personnel. Also inspect electromagnetic shields at the equipment and facility levels that are installed to provide system compatibility. Within a large facility (e.g., an ARTCC) the inspection will be best accomplished on an area-by-area basis. Conduct the inspection in accordance with the following.

(1) Inspect distribution/junction boxes and raceways for missing covers and hardware.

(2) Insure shields provide adequate protection to inadvertent contact with DC and power frequency hazardous voltages. If metal shields are used to provide shock protection, they must be well grounded to an equipment grounding conductor.

(3) Inspect shields which provide protection from radiation hazards for discrepancies such as missing covers or hardware.

(4) Inspect screens, shielded cabinets, doors, covers, etc., for wear, damage, corrosion, broken bond straps, broken or damaged bonds, and loose gaskets. Observe equipment operation for evidence of interference, noise, or malfunctions.

(5) Examine cables and connectors for broken or frayed shields, improper mounting, and evidence of corrosion.

(6) Examine cable termination noting means of connecting shields to ground and pigtail length.

(7) Note method of grounding for high- and low-frequency signal line shield(s) on the source and load ends.

b. Evaluation and Corrections. Where shielding deficiencies exist, determine if the need is for additional shielding or for improved maintenance of the existing shields. If no shielding is present, design and install shields as needed.

See Chapter 2, Section 5 for design assistance. If the existing shields have simply degraded through aperture control and poor bond or seam maintenance, implement corrective measures immediately. Refer to Chapter 2, Sections 4 and 5, and also Chapter 4, Sections 2 and 3.

191. - 199. RESERVED.

SECTION 6. LIGHTNING-INDUCED SURGE AND TRANSIENT PROTECTION EVALUATION

200. GENERAL. This portion of the procedure is performed to determine whether effective and adequate surge and transient suppression is provided for protection to electronic equipment against damage from lightning-induced surges and transients. The procedure consists of a detailed review of facility drawings and a detailed visual inspection. The survey is required only at facilities where solid-state equipment is installed.

a. Facility Drawings. Review facility drawings required to determine the following. Sketch items of interest to aid in subsequent visual examination.

(1) Lightning protectors installed on primary and secondary of commercial AC service transformer(s).

(2) Buried, incoming AC power service lines enclosed in watertight, ferrous metal conduit which is effectively bonded to the earth ground system at the service transformer and to the earth electrode system at the facility end by being solidly bonded to the housings of the transformer and the service disconnecting means respectively which in turn are properly bonded to the earth electrode system. The jumpers are sized to meet requirements of the National Electrical Code.

(3) Overhead incoming AC power service lines protected by an overhead guard wire from service transformer to facility service entrance. Guard wire connected to earth ground at each end. Guard wire provides a zone of protection that meets the requirements of NFPA 780 for incoming service lines.

(4) AC surge arrester installed at facility service disconnecting means (each main disconnect if more than one). Note manufacturer and part number on sketch.

(5) External landlines and lines terminated at exterior electronic equipment, including RF coaxial lines that connect to facility equipment, are enclosed in watertight, ferrous metal conduits if cable runs are 300 feet or less in length. Conduits should be connected to applicable earth electrode system at each end.

(6) Buried landlines that connect to facility equipment, more than 300 feet in length, and not enclosed in ferrous metal conduits, have guard wire installed end-to-end over the buried landlines in cable/trench. The Guard wire(s) shall be connected to the earth electrode system at each end. Lengths of

guard wires exceeding 300 feet (90 m) shall have an additional connection to earth ground. For each 300 feet (90 m) or portion thereof in excess of 300 feet, an earth ground connection shall be made utilizing 3/4 inch by 10 foot ground rods located not less then six (6) feet from the guard wire. These connections to earth should be located at approximately equal spacings between the ground connections at each end of the guard wire installation.

(7) Buried landlines enter the facility in rigid steel conduits that extend 5 feet past the earth electrode system. Ends of conduits should be bonded to the earth electrode system.

(8) All RF coaxial cables whose shields are bonded to a grounded, metal bulkhead connector plate at building penetration.

(9) The armor of buried armored cables is bonded to the earth electrode system at the point of entry to the facility with No. 2 AWG bare copper conductor. Where this is not feasible, cable armor is bonded to the Main Ground Plate. If none of the above are available, the armor is bonded to the ground bus in the service disconnecting means. If armor is continuous on to the electronic equipment, it is bonded to the multipoint ground system of the electronic equipment unless equipment is to be isolated.

(10) Transient suppressors shall be provided for all landlines not installed in ferrous metal conduit, at both, the entrance to the facility (high energy) and at the entrance to the electronic equipment (low energy), or at the entrance to the facility when both, the high energy and the low energy transient suppressors, are installed in the same housing, except for RF lines carrying signals above 3 MHz. Landlines installed in ferrous metal conduits may require transient protection only at the electronic equipment entrances. Landlines include all signal, control, status and interfacility electronic equipment power lines installed above and below grade between facility structures and to externally mounted electronic equipment.

b. Inspection. Detailed written notes fully describing all noted deficiencies should be made.

c. Corrective Action. Specific corrective action in accomplishing the response to each noted deficiency is difficult to detail. For instance, existing cable runs less than 300 feet in length may not be enclosed end-to-end in electrically continuous, watertight, ferrous metal conduit. Intensity and incidence of lightning in the immediate area, together with economic feasibility and operational requirements, are normally the overriding factors in determining whether the installation of metal conduit is justified and feasible. In most cases, for the example cited, installation of transient suppression circuits on each end of externally exposed electronic equipment lines is the most feasible solution. However, installation of transient suppression directly at the line-electronic equipment interface may also be warranted, depending on equipment susceptibility and lightning incidence. Consider each deficiency individually. Refer to Section 6 of Chapters 2 and 4 as required, and correct deficiencies in the most feasible manner. Some typical and required corrective actions are listed below:

(1) <u>If a secondary AC surge arrester</u> is not installed at the facility, and there is any history of lightning incidence in the area, install a surge arrester on the line side of the service disconnecting means. Refer to Section 6, Chapter 2, to determine that the surge arrester selected will be adequate and effective. Also determine that it is properly installed with leads as short as practical without any loops, sharp bends or kinks.

(2) <u>If the surge arrester</u> and the transient suppression device do not have proper low-impedance, effective paths to earth ground, take whatever action is necessary to provide effective grounding. Neither the surge arrester or the transient suppression device will provide effective protection from surges or transients, respectively, if an effective ground is not available. Remove any loops, sharp bends or kinks in any lines to the protective devices and from the protective devices to ground. Refer to Section 6 of Chapters 2 and 4 as required.

(3) <u>If no transient suppression</u> is installed on externally exposed electronic equipment lines not enclosed end-to-end in metal conduit, and the lines interface susceptible electronic equipment, as a minimum install transient suppression devices on each end of each line that interfaces susceptible equipment. Refer to Section 6 of Chapters 2 and 4 as required.

201. <u>FAILURE MODE ANALYSIS</u>. Significant information can be gained by examining facility logs, records of components damaged, and equipment schematics. This information may reveal how the lightning related damage occurred. This knowledge should facilitate the development of recommendations aimed at preventing a recurrence of the damage.

202. - 209. RESERVED.

SECTION 7. NEC COMPLIANCE EVALUATION

210. GENERAL. This portion of the survey is performed to determine if the facility complies with the requirements of the National Electrical Code (NEC) as applicable to FAA installations in regard to grounding, bonding, and shielding. Powerline and equipment grounding conductor current measurements, not related to the NEC, are made at the time of the survey for convenience. Prepare sketches, as appropriate, that may aid in explaining the results of the survey or illustrating the installation. Attach the sketches to the survey data. Applicable parts of the Appendices may be used for this evaluation. (NOTE: Paragraphs 211a(1), 211a(10), 211d(9), and 211d(15) are not required by the NEC. They are included herein as an aid and information in making the survey.)

a. The verification required by some steps may involve more than an inspection. For example, in verifying that all neutral conductors are color-coded white or natural gray, if a green colored wire is found connected to the neutral bus it will be necessary to trace out the conductor to determine its proper function. If the verification is not accomplished at the time of the inspection, the discrepancy should be recorded on the data sheet and noted as a violation.

b. During the inspection, it may be desirable to correct a deficiency at that time (e.g., cleaning a bond area of paint). In such cases, record the discrepancy on the data sheet and note the corrective action taken.

211. NEC COMPLIANCE INSPECTION.

a. Service Entrance. Perform the following to determine that wiring at service entrances is in accordance with NEC requirements.

(1) Determine if the input to the facility, from the power company, is single phase or three phase. If three phase, is it delta or wye? Determine if one of the service conductors is identified and (grounded). The identified grounded conductor will be the neutral.

(2) Verify that each run of cable, conduit, etc., contains all phases and the grounded neutral conductor and that each neutral conductor is connected to a grounding electrode conductor at an accessible point at or in the vicinity of and ahead of the service disconnecting means. For example, if the source is a transformer whose secondary is a 3-phase, 4-wire wye with the neutral grounded and the power is routed to the service

disconnecting means through 3 conduits, each conduit must contain all 3 phases and neutral, and the three neutral conductors must be grounded at the same point at or in the vicinity of and ahead of the service disconnecting means. The above statement meets the requirements of the NEC, however the FAA requires the grounding electrode conductor to be connected to the grounded neutral conductor or conductors on the neutral bus of the service disconnecting means.

(3) For each separate building or service supplied by a single source, verify that the neutral conductor is routed to each service disconnecting means and that the conductor is connected to the earth electrode at each building with a grounding electrode conductor sized in accordance with the NEC except that it shall be not smaller than No. 4 AWG copper.

(4) Where one facility receives its electric power from another facility, the equipment grounding conductor shall be carried with the phase and neutral conductors in the same conduit or raceway and the grounded conductor (neutral) of the receiving facility shall not be grounded at that facility.

(5) If the grounding electrode conductor is routed through a metallic enclosure (conduit, etc.) verify that the enclosure is bonded to the conductor at both ends.

NOTE: It may not be possible to verify this connection at the electrode end as it may be inaccessible.

(6) Verify that the color of the grounded (neutral) conductor is white or natural gray, or if larger than a No. 6 AWG and of a different color, not green, has been re-identified white or natural gray with paint or tape.

(7) Verify that the equipment grounding conductors are green, or if larger than No. 6 AWG and of a color other than green, not white, or natural grey, has been re-identified with green tape or paint.

(8) Verify that all metal non-current carrying service equipment is effectively bonded by one of the methods specified below and that all non-conductive coating in the bonding path has been removed:

(a) Bonding jumpers connected by approved pressure connector, clamps, or other means.

(b) Threaded couplings and threaded bosses on enclosures with joints that are tight when rigid conduit is involved.

(c) Threaded coupling used for metallic tubing and rigid conduit is tight.

(d) Bonding jumpers are used around knockouts that are punched or otherwise formed so as to impair the electrical connection.

(e) Bonding-type locknuts and bushings on other devices.

(9) Verify that all covers for wireways, junction and pullboxes, surface raceways, etc., are installed and secured.

(10) Using a clamp-on ammeter, measure the current in each phase conductor and the grounded service conductors. Also measure the current in the grounding electrode conductor. Record the current levels and wire sizes.

b. Separately Derived Power Sources. A separately derived system is a premise wiring system whose power is derived from transformer, generator, or converter windings and has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

(1) Verify that the neutral of the separately derived source is grounded directly to the earth electrode system. Where this is not practical, as in a large facility, the neutral is grounded to a nearby properly grounded structural column.

(2) The grounding electrode conductor connecting the neutral of the separately derived system to ground shall be copper and shall be sized in accordance with the requirements of the NEC except that in no case shall it be smaller than No. 6 AWG.

(3) Verify that the grounding electrode conductor, bonding jumper, grounded (neutral) conductor, source housing, and the equipment grounding conductors are all connected together at the source housing.

c. Power Transfer and Bypass Switches. If the facility contains power transfer and/or bypass switches, for each switch, verify that:

(1) A grounded (neutral) conductor, if used, is brought into the switch from each power source.

(2) The grounded (neutral) conductors are not grounded within the switch.

(3) The grounded (neutral) conductors are white or natural gray or if larger than No. 6 AWG and of another color, not green, have been re-identified white or natural gray with paint or tape or by other means such as tags or labels.

(4) All raceways, conduits, enclosures, etc., are adequately grounded.

(5) The input phase, grounded (neutral) and equipment grounding conductors brought into the switch from each source are routed together.

(6) The output phase, grounded (neutral) and equipment grounding conductors exiting the switch are routed together.

d. Power Panels. For all power panels, verify the conditions listed below. In some instances, steps 11 through 14 may be more readily accomplished by working back from the equipment or load end.

(1) Verify that the phase, grounded (neutral) and equipment grounding conductors are routed into the panel together through the same conduit, raceway cable, etc.

(2) Verify that the grounded (neutral) conductor is connected to the neutral bus.

(3) Verify that the neutral bus is not grounded.

(4) Verify that all wires connected to the neutral bus are white or natural gray or if larger than a No. 6 AWG and of a different color, not green, have been re-identified with white or natural gray paint or tape.

(5) Verify that no green wires are used as phase conductors and that white or natural gray wires used as phase conductors are re-identified with paint or tape.

(6) If an equipment grounding conductor is a separate conductor brought into the panel, verify that it is bare, or if insulated, that it is green, or if larger than a No. 6 AWG and of another color, not white, it has been re-identified with paint or

tape. The FAA requires the use of a separate equipment grounding conductor.

(7) If the equipment grounding conductor is an insulated or bare conductor, verify that it is connected either to the ground bus or if the bus is not existent, that it is connected to the frame of the panel with UL-approved connectors. The FAA requires an insulated equipment grounding conductor.

NOTE: Where required for the reduction of electrical noise on the grounding circuit, a receptacle approved for the purpose utilizing separate equipment grounding conductors may be used. This approved receptacle has a ground terminal purposely insulated from the receptacle mounting means or separately derived source. This grounding terminal is grounded by a separate equipment grounding conductor run in the same raceway as its related phase and neutral conductors. The equipment grounding conductor passes through one or more power panels without being connected to the ground bus of the panelboards and terminates on the ground bus of the service disconnecting means, or separately derived source. This conductor shall be insulated and color coded green with yellow and red bands at each end and wherever exposed in any box. A second equipment grounding conductor, also run with its related phase and neutral conductor and the first equipment grounding conductor, terminates on the ground lug of the outlet box housing the receptacle at one end and on the ground bus in the panelboard housing the protective device for this receptacle at the other end. This equipment grounding conductor should be insulated and color coded green.

(8) If the equipment grounding conductor is not a separate conductor run in the same conduit as the feeder to the panel, but is one of the items listed below, verify that the path is electrically continuous to the grounding electrode conductor in the service disconnecting means and that any insulating finishes in the grounding path have been removed.

(a) Rigid metal conduit.

(b) Intermediate metal conduit.

(c) Electrical metallic tubing.

(d) Approved flexible metal conduit with approved fittings.

(e) Armor of type AC metal-clad cable (cable with flexible metal tape armor).

(f) The sheath of type ALS cable (cable with aluminum sheath).

(g) The sheath of type AC copper-sheathed cable.

(h) Cable trays.

(9) Using a clamp-on ammeter, measure the current in each input phase conductor, the grounded (neutral) conductor, and the equipment grounding conductor. Record the data.

(10) Verify that no connections utilize solder for the electrical and mechanical connection.

(11) Verify that all related phase, grounded (neutral) and equipment grounding conductors to all circuits supplied by the panel are routed through the same conduit, raceway, cable, etc.

(12) Verify that all separate equipment grounding conductors leaving the panel are bare, or if insulated, are green. If larger than No. 6 AWG and of another color, not white, they have been re-identified green with paint or tape at each end and at all places where the conductor is accessible.

(13) Verify that the equipment grounding conductor for each circuit is sized to meet the requirements of the NEC

(14) Verify that all bonding connections are made through surfaces that have been cleaned of insulating finishes or by some method, i.e., gouging locknuts fully tightened, that inherently accomplishes the same result.

(15) Using a clamp-on ammeter, measure the current in each equipment grounding conductor leaving the panel.

e. Wireways, Raceways, Cable Trays, Etc. For all wireways, raceways, cable trays, etc., verify the following.

(1) All covers, where applicable, are in place and properly secured.

(2) All sections are electrically connected and any insulating finishes in the bonding path have been removed.

(3) If the wireway, raceway, cable tray, etc., contains neutral or equipment grounding conductors that have been re-identified, verify that re-identification is accomplished at various intervals throughout their length.

(4) Verify that the neutral is not connected to the chassis or frame of the equipment. This may be verified visually or with an ohmmeter.

f. Equipment. For all equipment, verify the items listed below. In some instances, verification may require that the equipment be shut down.

(1) Where the equipment grounding conductor is a separate conductor, verify that the conductor is routed through the same conduit, raceway, etc., as the phase and neutral conductors.

(2) Verify that the equipment grounding path back to the power panel is electrically continuous and that any insulating finishes in the grounding path have been removed.

(3) Verify that the separate equipment grounding conductor is sized to meet the requirements of the NEC for the overcurrent device serving the equipment.

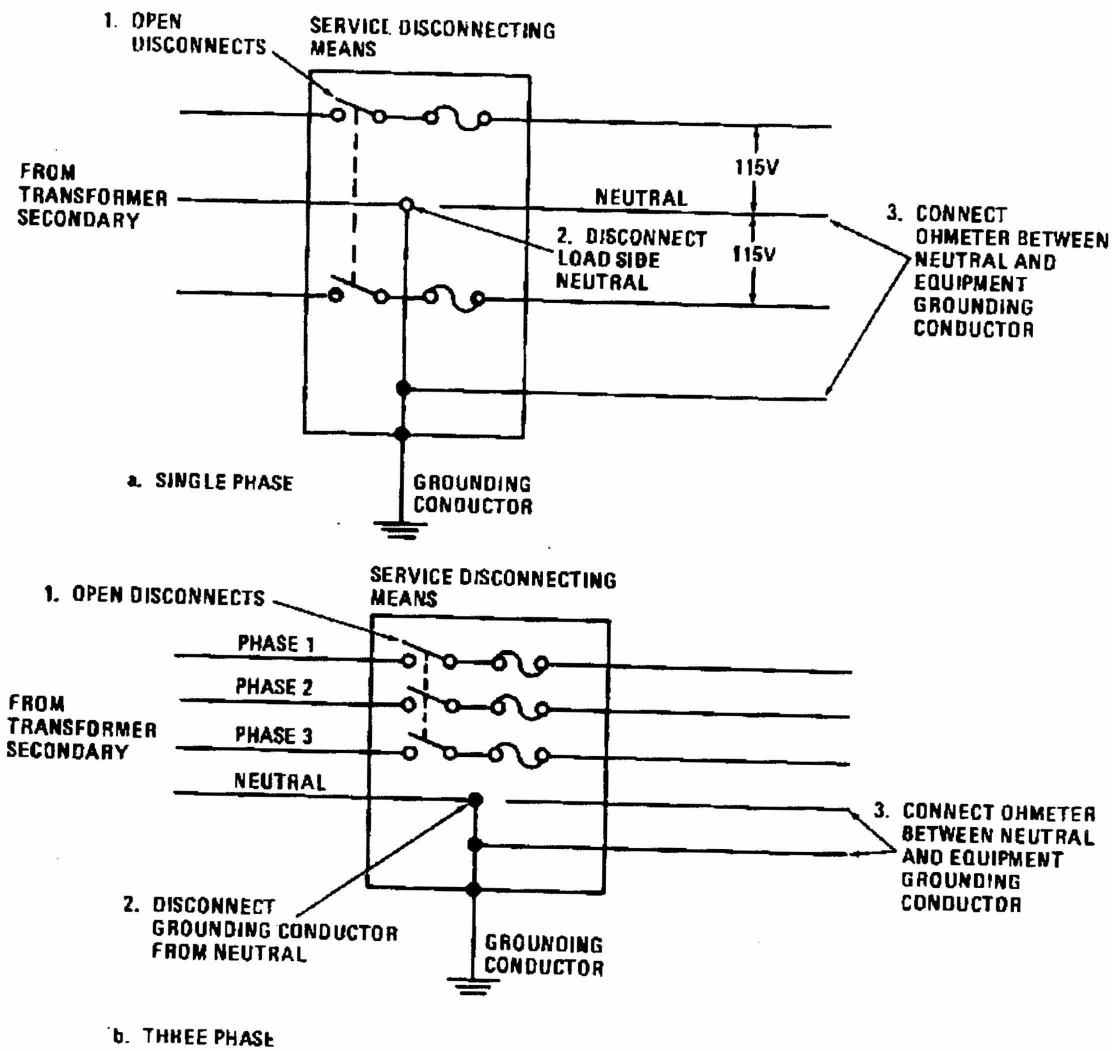
(4) Verify that the neutral is not connected to the chassis or frame of the equipment. This may be verified visually or with an ohmmeter.

g. Isolation of neutral conductor. When it is possible to de-energize a facility, or a portion thereof, perform the following test:

(1) With the electrical power removed disconnect the facility neutral from ground or in the case of a portion of the facility (e.g., a power panel) the incoming neutral. See Figure 3-3.

(2) Measure the resistance between the neutral bus and the equipment grounding conductor or panel frame. A value of resistance less than 20 kohms indicates that the neutral is grounded at some place other than at the service disconnect. Grounding of the neutral at places other than at the service disconnect violates the NEC and will result in power current flow through the equipment ground network.

212. CORRECTION OF DEFICIENCIES. The results of the survey should be thoroughly reviewed to determine the overall impact of correcting the deficiencies. Complete and strict compliance with the requirements of the NEC is required for new construction or modification to the power system. Deficiencies in existing facilities which present a safety hazard or adversely affect facility performance should be corrected as soon as possible.



<u>FIGURE 3-3. METHOD FOR DETERMINING THE EXISTENCE OF IMPROPER NEUTRAL GROUND CONNECTIONS</u>

Presented below is a listing of violations that could be encountered and possible corrective actions.

a. <u>Undersized equipment</u> grounding conductor, replace with proper size conductor.

b. <u>Equipment grounding conductor</u> and/or neutral conductor not routed with phase conductors. Reroute the grounding and/or neutral conductor to be in the same raceway as the phase conductors.

c. Equipment is not grounded by means of an equipment grounding conductor meeting the requirements of 211d(7) or 211d(8). Ground the equipment by means of a separate green or re-identified conductor routed with the phase and neutral conductors where feasible. Where the installation of a separate conductor is not feasible, ground the equipment through a path meeting the requirements of 211d(8).

d. Neutral bus in power panel (other than service entrance) is grounded to the panel frame. Remove the connection from ground and verify that the neutral bus is isolated in the panel.

e. A green wire connected to the neutral bus is found to be connected to an equipment chassis and is supposed to be the equipment grounding conductor. Disconnect the conductor from the neutral bus and reconnect it to the ground bus or panel frame with UL-approved connectors.

f. Bond is obtained through a painted surface. Disassemble, remove paint and reassemble. Protect with waterproof paint if exposed to moisture.

g. A black wire, not re-identified, is found to be used as an equipment grounding conductor. If it is larger than a No. 6 AWG, it may be re-identified with green paint or tape at each end and wherever accessible. If smaller than No. 6, it should be replaced to comply with the NEC. However, an acceptable substitute would be to re-identify it with green paint or tape if replacement is impractical or expensive.

h. Grounding electrode conductor is routed through metal conduit and the conduit is not grounded. Ground the conduit at each end by means of a grounding bushing or clamp, a jumper wire, and a split-bolt connector or preferably, an exothermic weld at the connection below grade. The jumper wire is to be the same size as the grounding conductor.

i. Service neutral is not grounded but service disconnecting means is grounded by means of a grounding electrode conductor. Ground the neutral by connecting the grounding electrode conductor to the neutral in the enclosure and installing a jumper from the above connection to the ground bus of the service disconnecting means.

j. Conductor insulation is damaged and conductor is exposed. Conductor should be replaced. Alternate correction is to cover damaged area with dielectric tape that has a dielectric strength equal to or greater than that of the insulation of the conductor.

k. Power panel is grounded by a soldered connection. Install proper grounding by means of a bolted grounding connector.

l. Ground bus is not grounded and equipment grounding conductors terminate at equipment frame. Connect ground bus to panel frame by means of UL-approved connectors and reconnect equipment grounding conductors to the panelboard ground bus.

m. Raceway contains neutral and grounding conductors of different systems (e.g., commercial and conditioned power) and conductors are not distinguishable. Distinguish conductors from each other by means of paint, tape or tags. Alternately, tie wrap the phase, neutral and equipment grounding conductors of each system together.

213. - 219. RESERVED.

CHAPTER 4. ELECTRONIC EQUIPMENT DESIGN CRITERIA

220. INTRODUCTION.

a. Equipment. This chapter presents recommended grounding, bonding, transient protection, and shielding practices for use in electronic equipment design to subsystem installation. Also presented is a set of inspection and test procedures for verifying that proper grounding, bonding, and shielding practices have been employed in the design and construction of the electronic equipment. The design of the electronic equipment should emphasize careful grounding, bonding, transient protection, and shielding along with other interference and noise control measures in order to achieve compatible operation within the electronic system in which it is installed. This emphasis must continue to be maintained during the manufacture, installation, and operation of the electronic equipment or system. For example, during manufacture, careful attention should be given to the routing of cables, the choice and mounting of cable connectors, the selection of signal and ground conductors, the correct implementation of all bonds within the electronic equipment, etc. When the piece of electronic equipment is installed, the configuration of the facility ground networks, and the integrity of the shields within the facility must be maintained. Correspondingly, the ground systems and shields in the facility should not be allowed to degrade during the operation of electronic equipment. For example, ground connections should not be randomly changed in efforts to improve electronic equipment operation without considering what effect such changes will have on the overall system. This recommendation applies to changes internal to the electronic equipment as strongly as it applies to changes made external to the electronic equipment.

b. Personnel Protection. Basic personnel protection measures should also be incorporated. Inadvertent contact with metal parts operating at hazardous voltages must be prevented. Likewise, exposure to harmful emissions of either the ionizing or non-ionizing type must be avoided by the provision of appropriate shields or barriers. In addition, protection must be provided against internal powerline faults through the installation of equipment grounding conductors sized and installed in accordance with the requirements of the National Electrical Code (NEC) and the incorporation of appropriately sized fuses or circuit breakers into the design.

Overvoltage and overcurrent protection should be provided on powerlines, signal lines, and control lines. A variety of measures may be used singularly or in combination to provide the needed protection. Efficient grounding, bonding, and shielding in accordance with the recommendations set forth in the following sections are important factors in the achievement of this protection.

SECTION 1. GROUNDING PROCEDURES

221. ELECTRONIC SIGNAL GROUNDS. Grounding of electronic equipment must be given the same careful attention as is given to amplifier design; filter selection, component selection, and mechanical layout. In electronic equipment, the signal grounding philosophy presented in Order 6950.20 and the practices recommended in Chapter 2 of this order for electronic facilities are to be applied on a smaller scale. The grounding techniques and practices used in the design of the electronic equipment must ensure that the signal reference points or planes internal to the electronic equipment can be properly interfaced with those of other electronic equipment and those of the facility as a whole without compromising the signal ground system of either the individual unit or the total system. A basic signal reference point or plane is an important requirement for reliable, interference-free electronic equipment operation. Unfortunately, the ideal ground plane does not exist and some difference of potential will always exist between different ground points. The following paragraphs present techniques and procedures for minimizing this potential difference in both low-and high-frequency electronic equipment.

222. ELECTRONIC EQUIPMENT.

a. Single Point Ground System Electronic Equipment.

(1) Single Point Grounding System Configuration. Install a single-point grounding system in low frequency equipment, i.e., electronic equipment operating at 100 kHz or less. Isolate the single point grounds and planes established internal to the equipment from the electronic equipment case. The functional requirements of the internal circuitry of the electronic equipment will determine the actual methods and techniques which must be used in establishing the individual reference points and planes. Because of the wide variability of design requirements, the final selection must be left to the individual designer. The designer should become thoroughly familiar with the fundamental design principles contained in Order 6950.20.

NOTE: Some battery systems are designed with the isolated ground connected to chassis or cabinet ground which is also connected to one of the DC supply buses. It is recommended that such systems be isolated from the structure and from the racks and cabinets of other low-frequency electronic equipment and systems. All interfaces between these "common battery" systems and other electronic equipment and systems should be balanced. Shield grounding must be controlled to ensure that the desired isolation be maintained.

(2) Single Point Ground Terminals.

(a) Install an isolated single point ground terminal on each electronic equipment case as illustrated by Figure 4-1 to provide a path for interconnecting the single point ground inside the equipment to the facility single point grounding network.

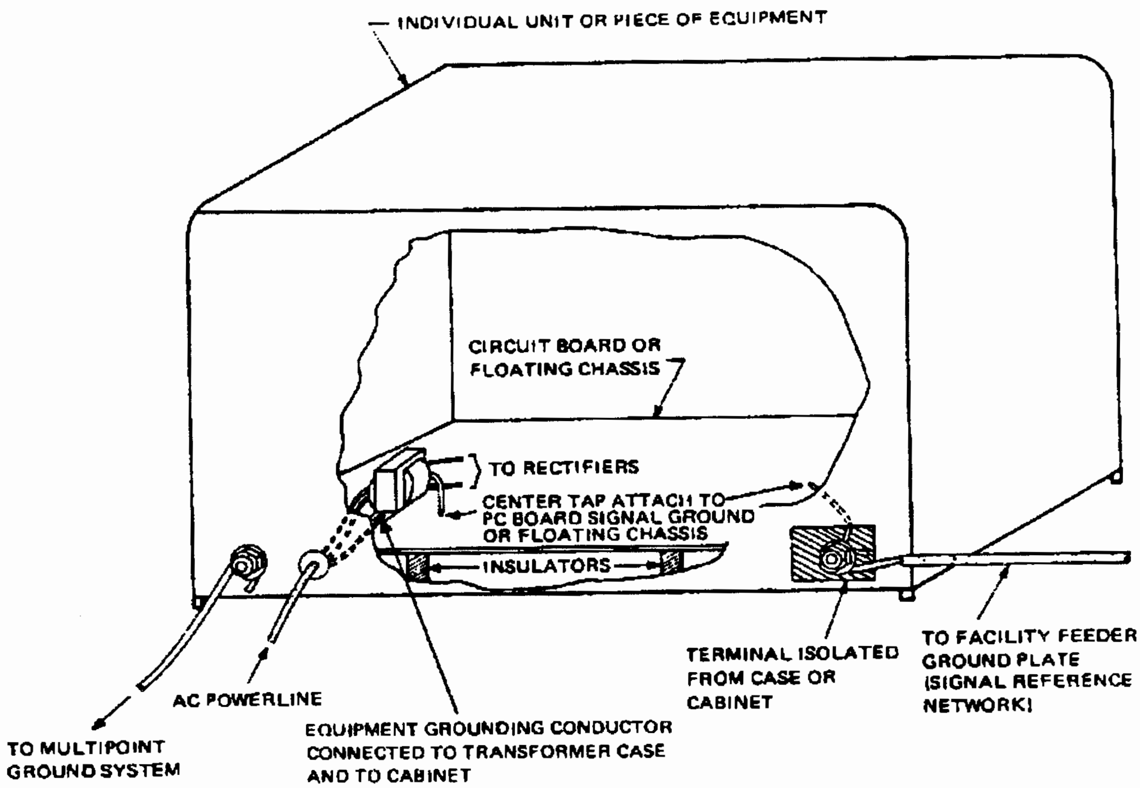


FIGURE 4-1. GROUNDING IN SINGLE POINT GROUND EQUIPMENT

(b) The isolated ground terminals can be a connector pin, a screw or pin in the isolated terminal strip, an insulated wire, an insulated stud, jack, or feedthrough. Where an insulated wire is used as the terminal, it should be sized in accordance with paragraph 222a(4)(c).

(c) Where an insulated ground wire penetrates a metal sheet such as the electronic equipment case, adequate physical protection must be provided with grommets, plastic sleeves, or other protectors.

(d) To aid in distinguishing the single point ground terminal from other terminals on the electronic equipment, it should be clearly marked with a permanent label or color code that is green with a bright yellow tracer.

(3) Connections to Facility Single Point Ground System. When the electronic equipment is installed within a facility, connect the isolated single point ground terminal of the electronic equipment to the nearest feeder ground plate (branch ground plate if there is no a need for a feeder ground plate in the cable run). See Figure 4-2. Care must be taken to locate a ground plate close to the electronic equipment so that the electronic equipment ground cable is kept small enough to avoid problems with connections to the electronic equipment. The cable shall be in accordance with Paragraph 222a(4)(c) below.

(4) Cabinet Bus Bar.

(a) Each rack or cabinet containing two or more separate pieces of low frequency electronic equipment should have a single point bus bar installed that is insulated from the rack or cabinet. The bus bar should provide a minimum cross-sectional area of 125,000 square mils. The bus bar should be drilled and tapped for No. 10 screws.

(b) Connect the single point ground terminal of each unit of electronic equipment with a bonding jumper to the single point ground bus bar in the manner illustrated in Figure 4-3. To provide adequate mechanical strength and low impedance path, a broad, flat copper flexible, braided strap should be used between the single point ground bar and the single point ground terminal on each unit of electronic equipment. A stranded copper wire, No. 12 AWG or larger, may also be used. This bonding jumper must be insulated or otherwise kept from contacting either the electronic equipment case or the rack or cabinet.

(c) An insulated copper cable, color coded green with a bright yellow tracer, providing at least 500 cmil per running foot, but not less than No. 12 AWG, should be used to connect the single point ground bus in the rack or cabinet to the nearest feeder ground plate of the single point ground system (See Chapter 2, Section 3). If the shielding integrity of the enclosure is maintained, an insulated single point ground terminal must be provided. Feedthrough capacitors may be used for this terminal, or supplemental filtering may be applied at

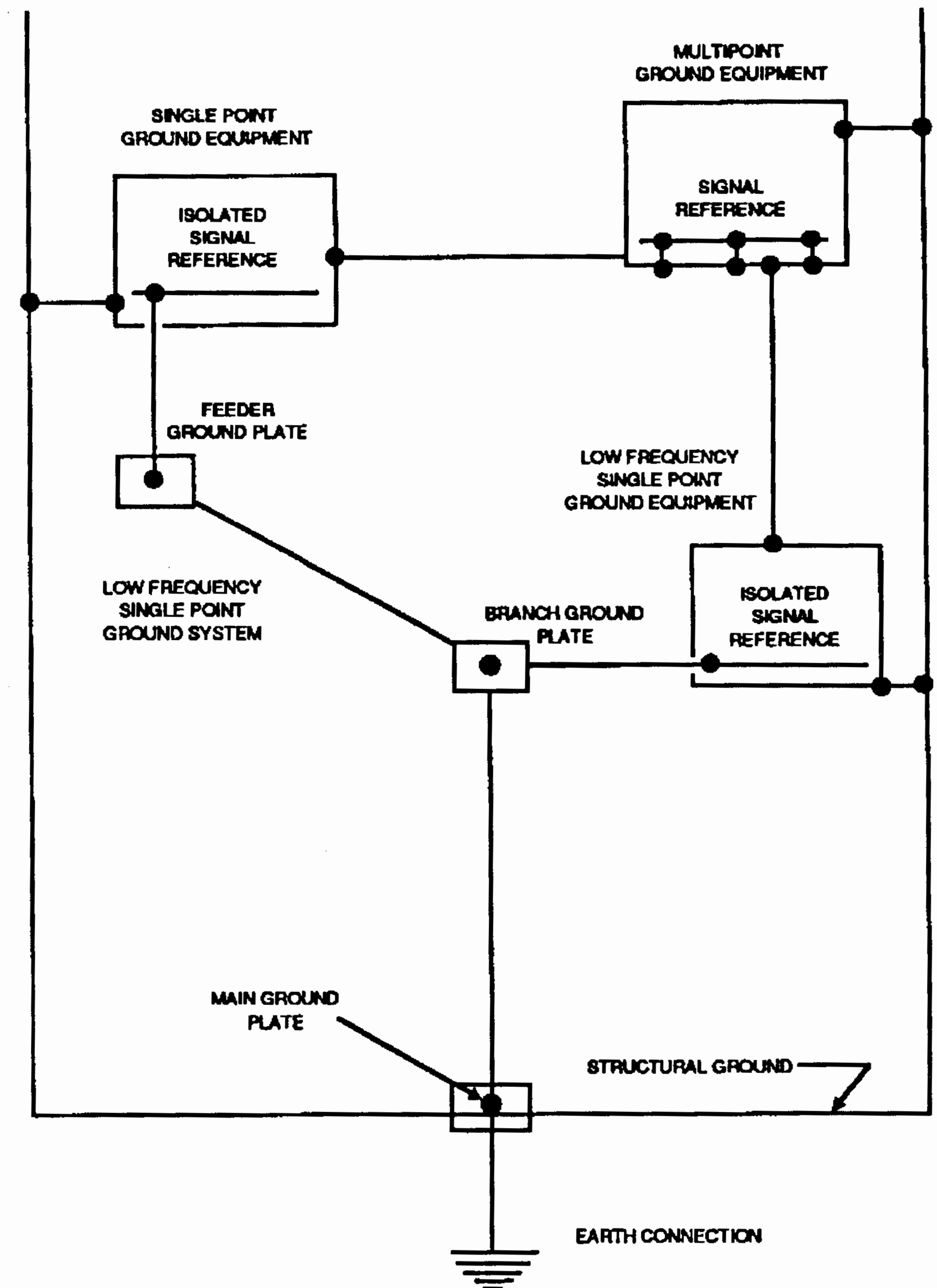


FIGURE 4-2. COMPOSITE SIGNAL REFERENCE NETWORK FOR AN ELECTRONIC FACILITY

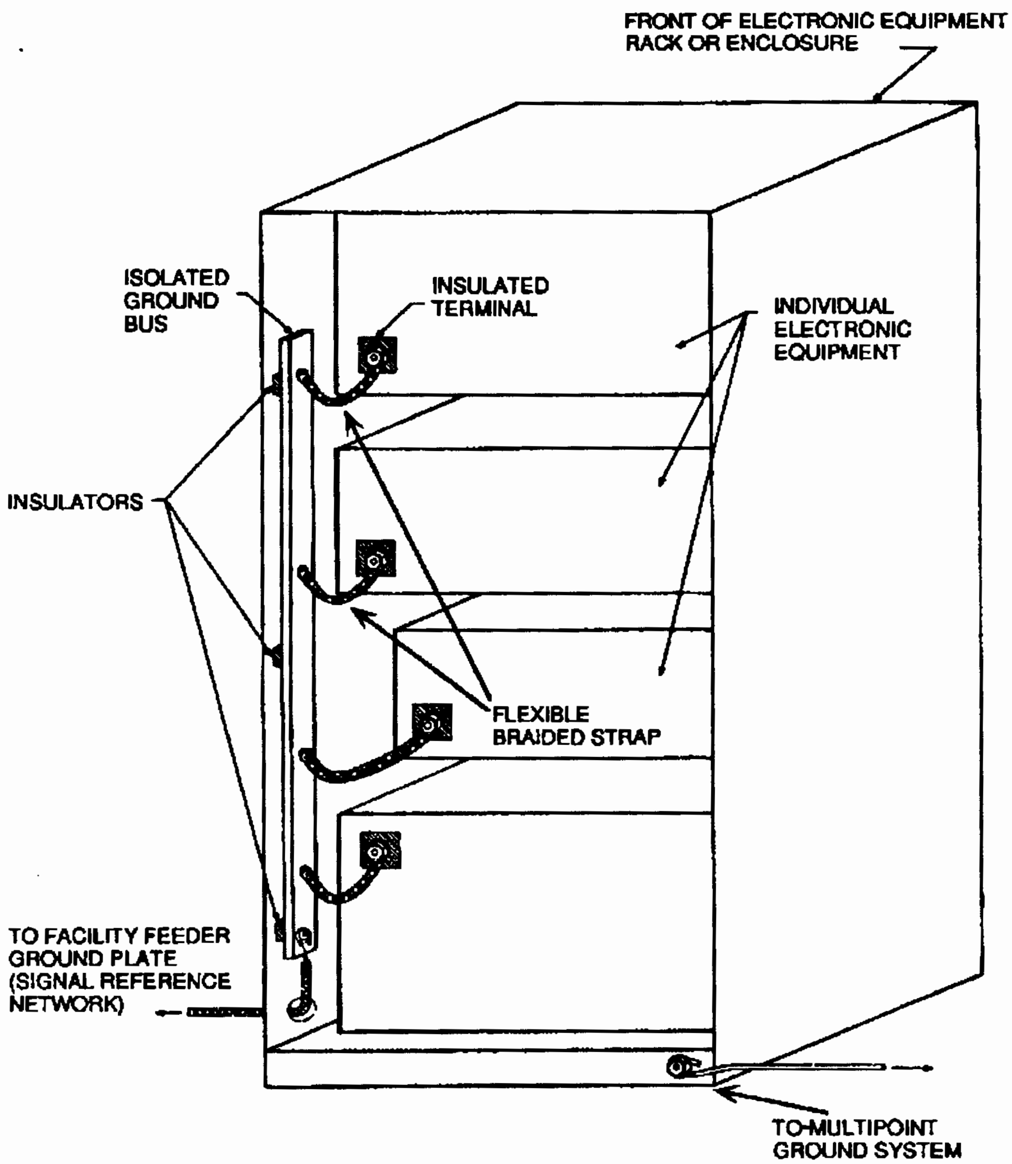


FIGURE 4-3. SINGLE POINT GROUND BUS BAR INSTALLATION IN RACK OR CABINET

the point of penetration of the single point grounding cable, in order to prevent high-frequency signals from penetrating the cabinet via the cable. In extreme pickup situations, it may be necessary to enclose the single point grounding cable in conduit.

(5) Isolation.

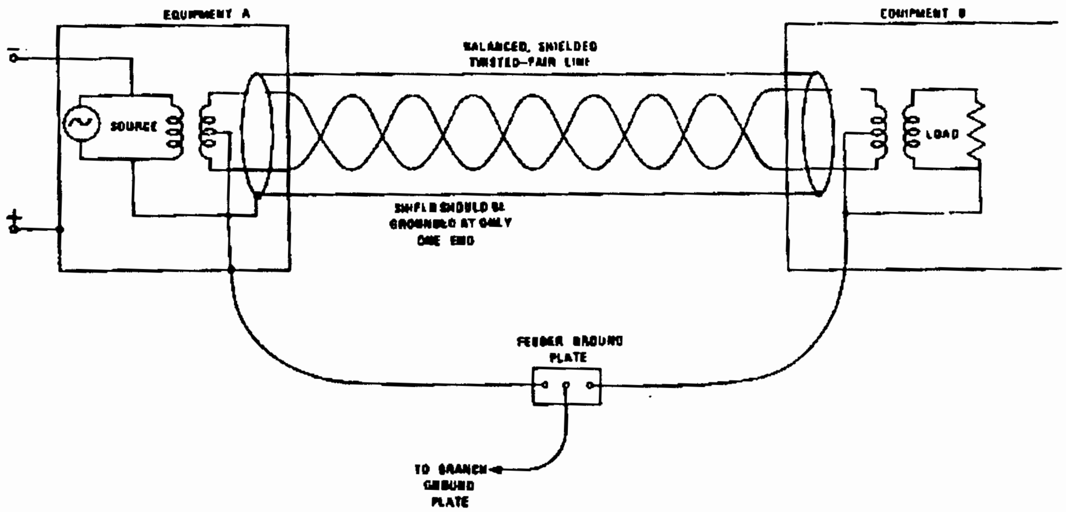
(a) The single point grounding system in low-frequency electronic equipment must be designed and installed to provide complete electrical isolation between this network and the electronic equipment case (Figure 4-1). For example, the single point ground on printed circuit boards must not be connected to the chassis. On the other hand, if the designer determines that the metal chassis can be used as a signal reference for the low-frequency circuits without creating interference problems and it is desirable to do so, the chassis then must be floated from the electronic equipment case through the use of insulating spacers or standoffs. Care must be exercised in the mechanical layout of the electronic equipment to insure that screws and fasteners do not compromise this isolation.

(b) Controls, readout and indicating devices, fuses and surge protectors, monitoring jacks, and signal connectors must be installed in ways that do not compromise this isolation. Both sides of the AC powerline ("hot" and neutral) must be isolated from the single point ground and from the electronic equipment case. Only transformer-type power supplies should be used; the commercial AC/DC practice should never be used. The metal portions of electronic equipment exposed to human contact must be grounded with an equipment grounding conductor installed and sized in accordance with the NEC.

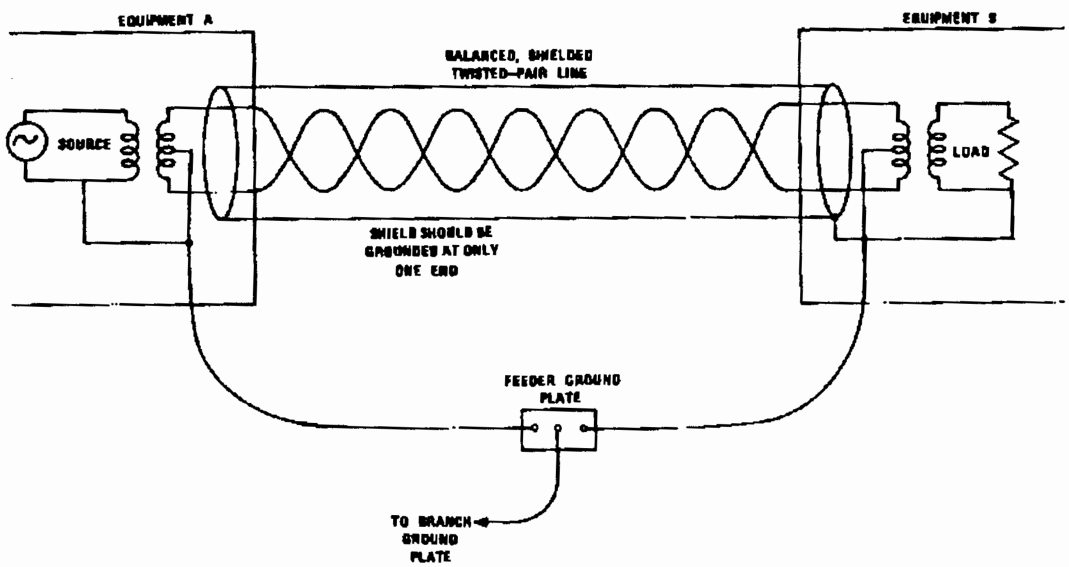
(c) To verify that this isolation is maintained, measure the resistance between the electronic equipment's ground terminal and the case, between the rack ground bus and the rack frame, and between each side of the AC powerline and the electronic equipment case (Figure 4-3). Each of these measurements should show a resistance of 10 megohms or greater. Before making these tests, be sure powerlines are not connected and all interfacing cables are disconnected.

(6) Signal Interfacing.

(a) The preferred method of interfacing low-frequency electronic equipment is to use balanced lines. All signal inputs and outputs should be balanced with respect to the signal ground; the signal paths between such equipment should



a. COMMON BATTERY SYSTEM



b. CONVENTIONAL SYSTEM

FIGURE 4-4. USE OF BALANCED LINES TO AVOID GROUND LOOPS employ balanced, shielded, twisted pair lines in the manner illustrated in Figure 4-4. The twisting should be as tight as feasible with 18 twists per foot the desired goal for small wires. When the balanced signals are connected to the single point ground, care should be taken to insure that this connection is made at the source or load end only to take maximum advantage of the common-mode rejection characteristics offered by balanced circuits.

(b) Where unbalanced signal lines must be used, the signal return must be grounded at one end or the other, but not both (Figure 4-5). Deciding in advance to ground the signal line at only the source (the driving end) or the load (the receiving end) generally leads to implementation problems in complex installations. For example, some electronic equipment will be the load for one signal circuit while being, at the same time, the source for another load as shown in Figure 4-6. In this case, if each line is grounded at the source or at the load, the single-point ground will be compromised. Most modern electronic installations are so complex and widely distributed that even if unbalanced interfaces could be implemented which did not violate the single point ground system in the facility, it is improbable that the single-point ground system could be maintained during future equipment additions and modifications.

(7) Shield Grounding.

(a) The shields of low-frequency signal lines should be grounded at only one end to the single point ground internal to the electronic equipment as shown in Figure 4-4. The ground connection may be made at either the source or the load end. In general:

1. Shields of sensitive data lines should be grounded at the load end.

2. Shields of high-level signal lines should be grounded at the source end.

NOTE: High level versus low level is a matter of degree and will depend upon the characteristics of the particular system under consideration. A suggested rule of thumb is that if the voltage levels of two signals differ by a factor greater than 10 to 1, then the larger should be treated as high-level relative to the smaller.

3. Shields on lines from high-impedance DC sources such as strain gauges, thermocouples, etc., should be

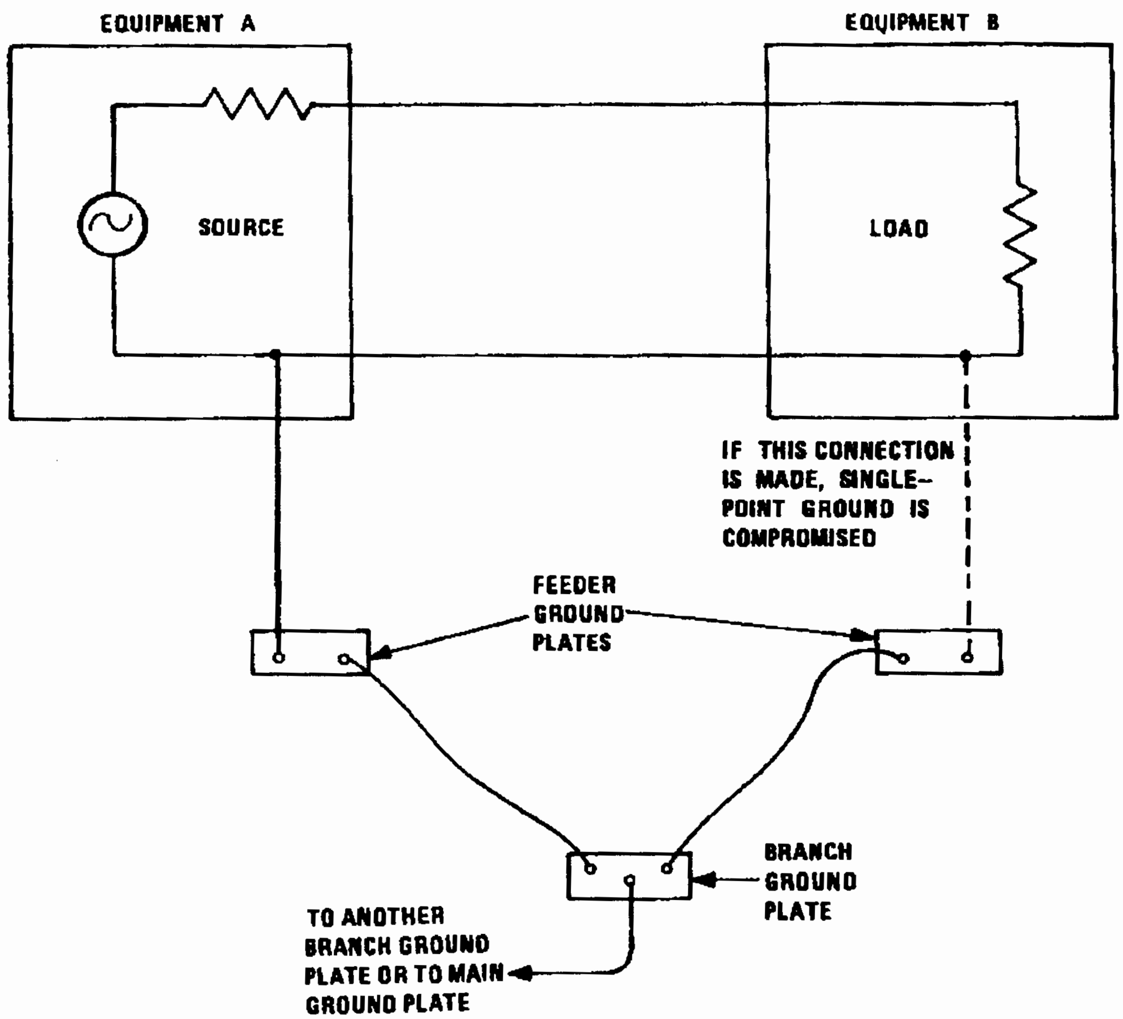


FIGURE 4-5. EFFECT OF AN UNBALANCED CABLE ON THE SINGLE POINT GROUND

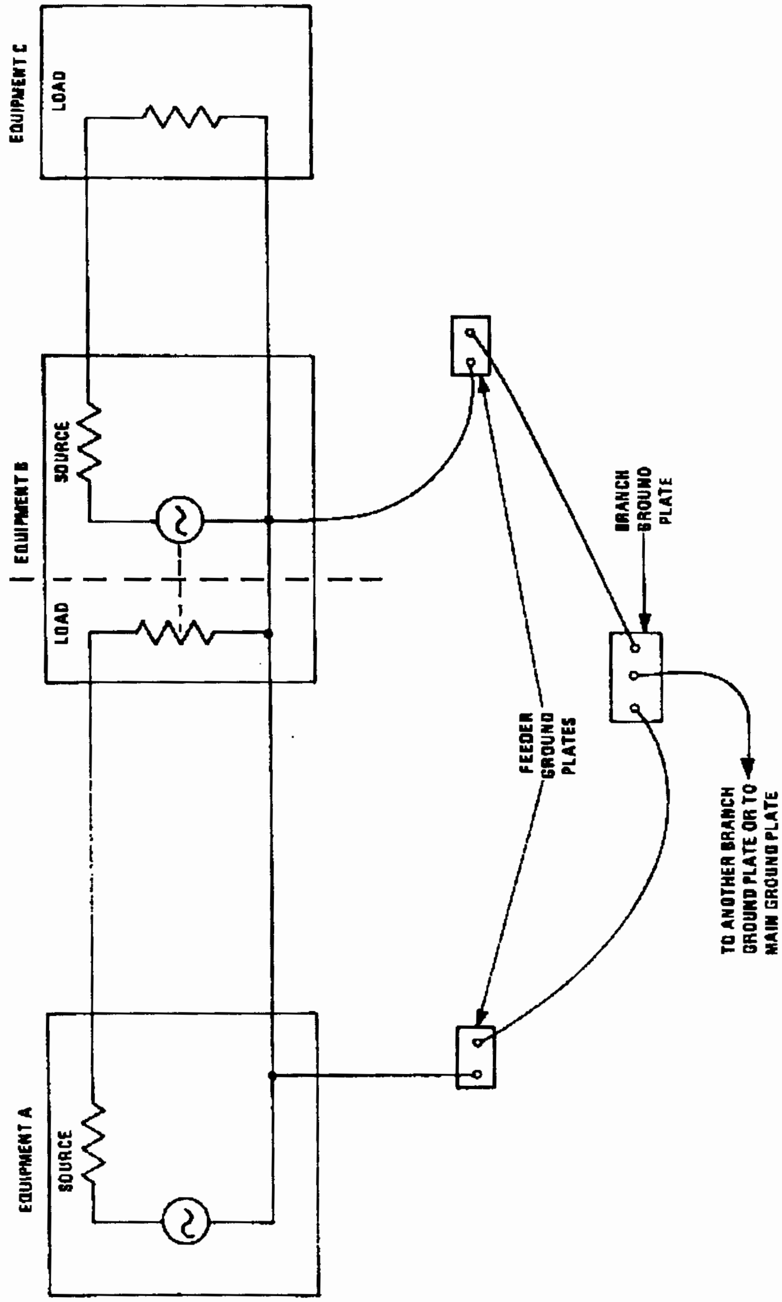


FIGURE 4-6. EFFECT OF ARBITRARILY GROUNDING THE SOURCE END OF UNBALANCED ELECTRONIC EQUIPMENT INTERCONNECTING CABLES

grounded at the source end. Further details on shield grounding for date acquisition systems are given in Section 4.

(b) All individual shields of low-frequency signal lines within a cable bundle must be insulated from each other to minimize cross coupling. Furthermore, these individual shields must be isolated from the overall bundle shield, electronic equipment chassis and enclosures, junction boxes, conduits, cable trays, and all other elements of the multipoint ground system. When cables are long, extra attention must be directed toward maintaining the isolation of the individual shields at the ungrounded end and at all intermediate connectors throughout the cable run.

(c) At terminating electronic equipment, the shields of individual low-frequency signal lines may be carried into the case or cabinet on separate pins or may be grounded together to be carried in (or out) on a common connector pin, depending upon the characteristics of the equipment involved. If the common pin arrangement is used, it must not comprise the single-point grounding principle. It is advisable to use one pin for low-level signal shields with a different pin used for high-level signal lines. These individual shields should be terminated to the low-frequency single point ground system.

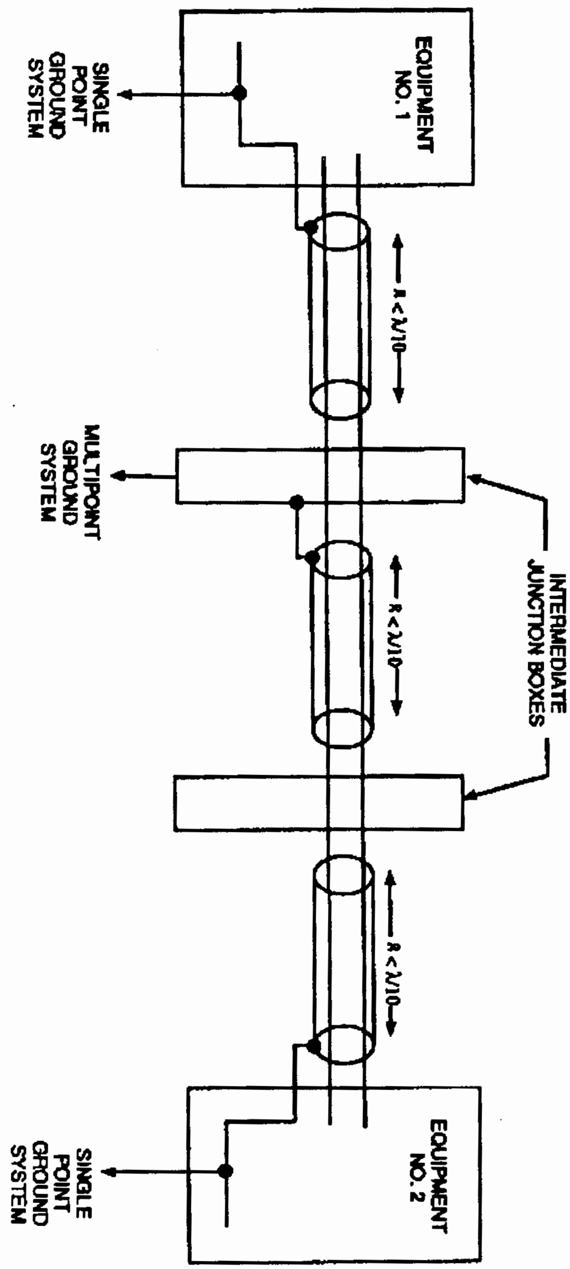
(d) The pigtail between the shield breakout and the connector pin should be as short as physically practical.

(e) In multiconductor cables, some of the individually shielded signal lines may be grounded at one end while other shields may be grounded at the other end. Careful attention must be given to the installation of such cables to prevent grounding of shields at both ends.

(f) Pickup or radiation problems may arise because the shield is longer than lambda/10 at critical frequencies. To avoid this problem, the shield should be divided into segments in the manner illustrated in Figure 4-7, with each section grounded at one end only. The length may be determined by:

$$\text{Length (in feet)} = (9.84 \times 10^7) / f \text{ (Hertz)}$$

(g) Multiconductor cables which contain unshielded or individually shielded wires, or both, frequently have an overall shield provided for both physical protection and to provide supplemental electromagnetic shielding. Such overall shields should be grounded at each end of the cable run to provide a continuous RF shield with no breaks.



<u>FIGURE 4-7. METHOD OF GROUNDING THE INDIVIDUAL SHIELDS ON LONG LOW - FREQUENCY SIGNAL CABLES</u>

(h) For long cable runs, where the cable is routed through one or more intermediate connectors, the overall shield should be grounded to the frame or case of junction boxes, patch panels, and distribution boxes along the cable run.

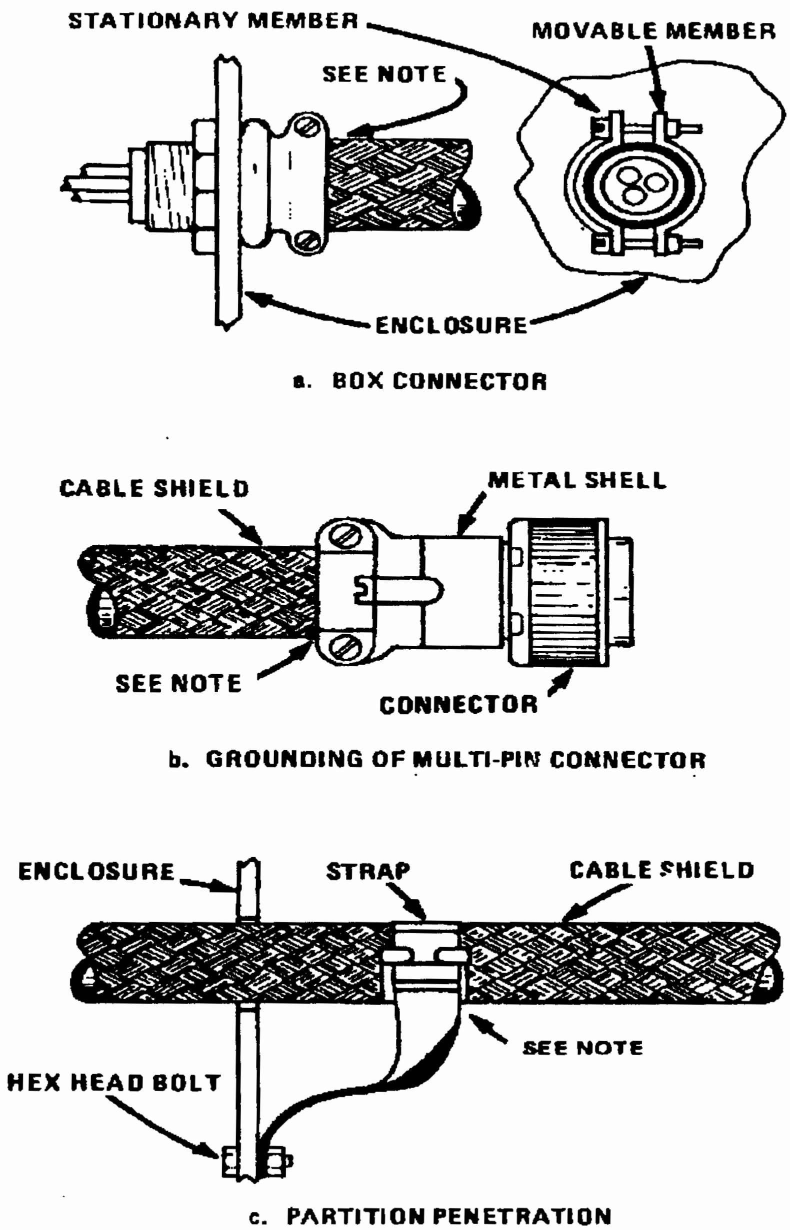
(i) For maximum shielding effectiveness, the overall shield should be effectively bonded as shown in Figure 4-8 with a low-impedance connection to the electronic equipment case, enclosure wall, or other penetrated (metal) shield. The best way to bond the overall shield to a connector is to run the shield well inside the connector shell and provide clean metal-to-metal circumferential contact between the shield and the shell. If the connector is not involved, shortest practical lengths of connecting strap or jumper should be used. Where the overall shield terminates on a terminal strip, it may be grounded as shown in Figure 4-9.

b. High-Frequency Equipment. In high-frequency electronic equipment, multiple-point grounding is more practical than single-point grounding. The various signal pairs internal to the electronic equipment are referenced as required to a metallic common or ground plane with minimum length conductors. The electronic equipment chassis is normally used as the multipoint ground system signal reference plane. The electronic equipment chassis is grounded through the case or cabinet to the multipoint ground system as illustrated in Figure 4-2.

(1) Signal Interfaces. For high-frequency signals, the interfacing lines between electronic equipment will normally be unbalanced, constant impedance, transmission lines such as coaxial cables. The current return conductor, (e.g., the shield in the case of a standard coaxial cable) should be grounded to the electronic equipment enclosure at both ends of the cable and at intermediate points along the cable run. This multiple-point grounding of the shield maintains the RF shielding effectiveness of the cables and simplifies electronic equipment design.

NOTE: In low-level, wide band (particularly video) systems, noise voltages arising from stray power currents (or from currents induced in cable shields by incident RF fields, i.e., the antenna effect), flowing through the cable shield can be troublesome.

A way to combat the RF pickup problem is to, in effect, enclose the shield carrying the signal return current inside of another shield or use a balanced type of transmission line. To accomplish the first of these alternatives, either a triaxial type cable can be used or the coaxial cable can be routed in metallic conduit. The inner shield of the triaxial cable or the shield of the conduit-protected coaxial cable should be



NOTE: INSURE THAT CABLE SHIELD IS CLEAN AND THAT SECURING CLAMP IS TIGHTENED TO PROVIDE A GOOD GROUND.

<u>FIGURE 4-8. GROUNDING OF OVERALL CABLE SHIELDS TO CONNECTORS AND PENETRATED WALLS</u>

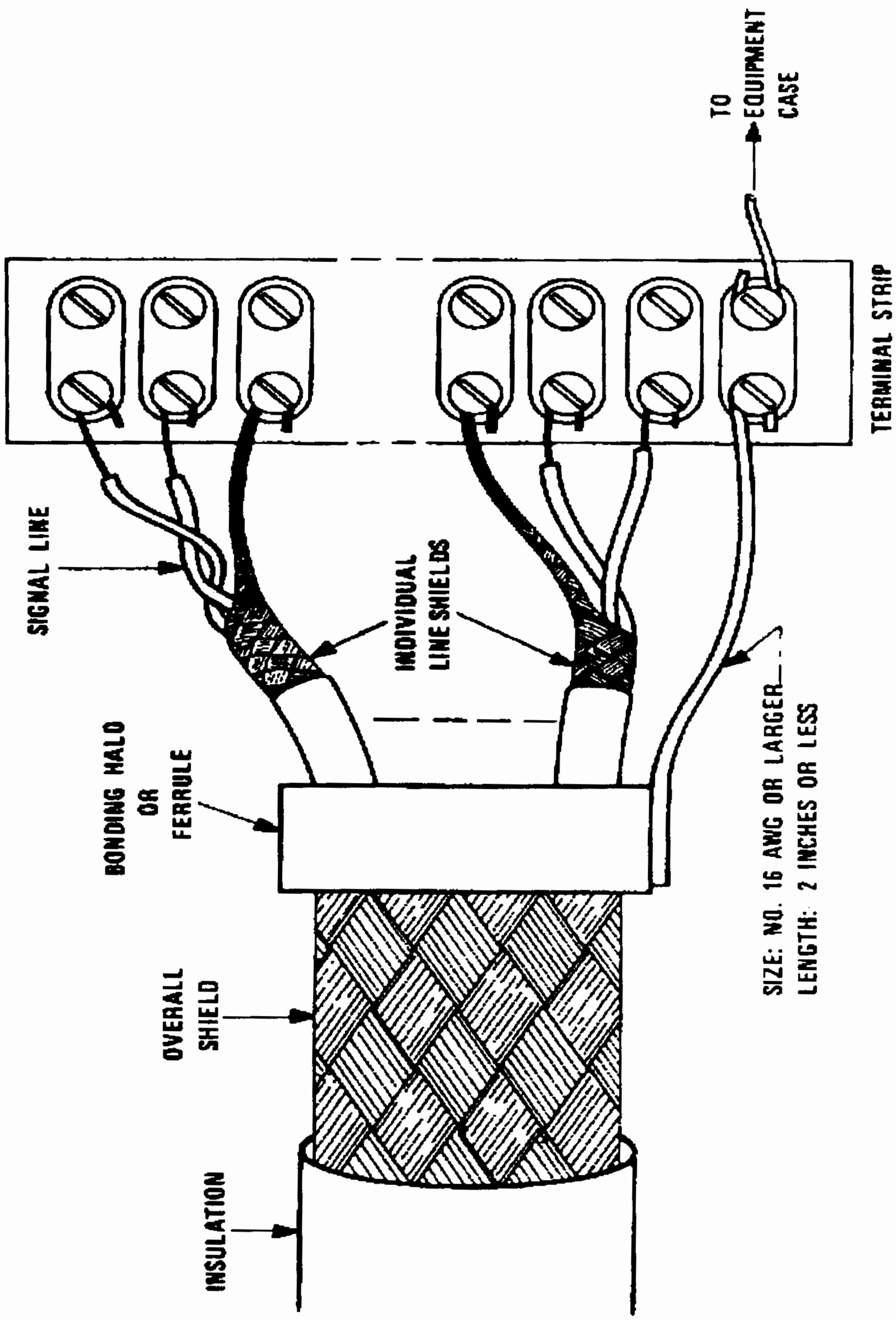


FIGURE 4-9. GROUNDING OF OVERALL CABLE SHIELDS TO TERMINAL STRIPS

terminated to the signal reference on the inside of the equipment. The outer shield of the triaxial cable and the conduit should be peripherally bonded to the case or cabinet of the terminating equipment.

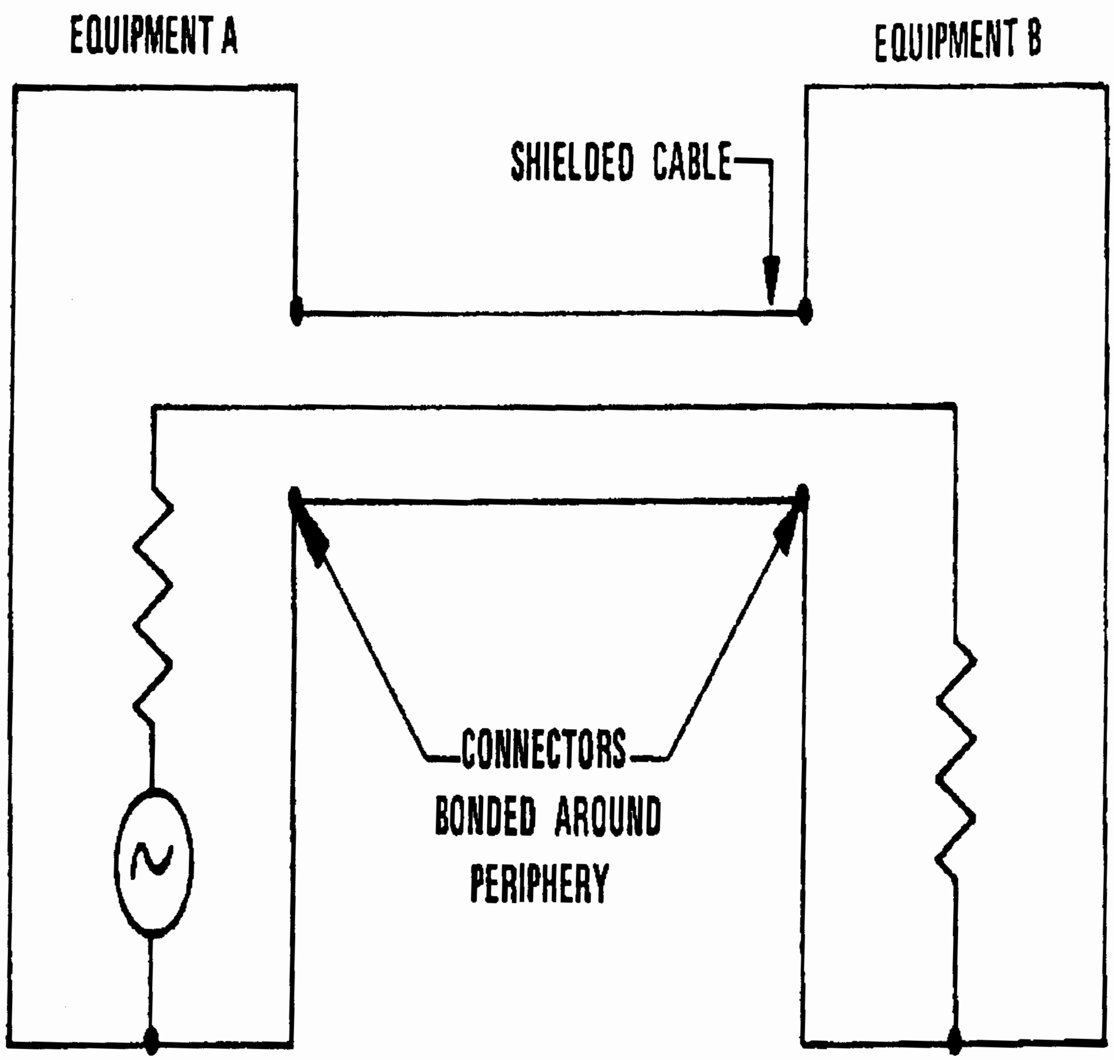
If the interference is the result of stray power currents, the current path through the shield must be interrupted or a twinaxial type of cable must be used. To interrupt the path for stray power currents, the system's signal reference must be connected to the structure at only one end. Thus, either the source or load end signal reference must be isolated from structure and the AC ground. The isolation can be effected either by floating the electronic equipment or its internal circuitry. Generally, however, either process is very difficult to implement and maintain, and it is preferable to resort to a balanced interface or locate the source and reduce the magnitude of the stray current.

(2) Cable Connectors.

(a) Cable connectors must have less than 1 milliohm contact resistance to provide a low-impedance path between the cable shield and the electronic equipment case on which the connector is mounted. Bond the shield completely around its periphery of the cable to the connector shell with a tight compression or soldered bond. Soldered connections are preferred over clamps. High-frequency shield terminations must maintain the RF-tightness of the interconnected system (see Figure 4-10).

(b) If direct grounding of high-frequency circuits and sub-assemblies to the chassis is not used, a shielded, constant-impedance cable that does not use the outer shield as a signal return must be used. A typical twinaxial, triaxial, or quadraxial cable is recommended to provide the required isolation for the signal while providing overall shielding. Proper connections that do not compromise the DC isolation must be employed. For example, triaxial cable interfaces require the use of triaxial connectors to maintain isolation between the two shields.

FIGURE 4-10. ESTABLISHMENT OF SHIELD CONTINUITY BETWEEN HIGH FREQUENCY EQUIPMENT



c. Equipment Containing Both Low-and High-Frequency Circuits. Some types of equipment will necessarily contain both low- and high-frequency signal circuits in the same enclosure because of specific design or operational requirements. For example, a typical very high frequency (VHF) or ultra high frequency (UHF) receiver will require both a high-frequency input from the antenna and a low-frequency output for audio amplifiers as illustrated in Figure 4-11. If the low-and high-frequency circuits are functionally independent and can be separated, the low-frequency single point ground reference should be designed and installed in accordance with requirements of this section, and the high-frequency multipoint grounds should also conform to requirements of this section.

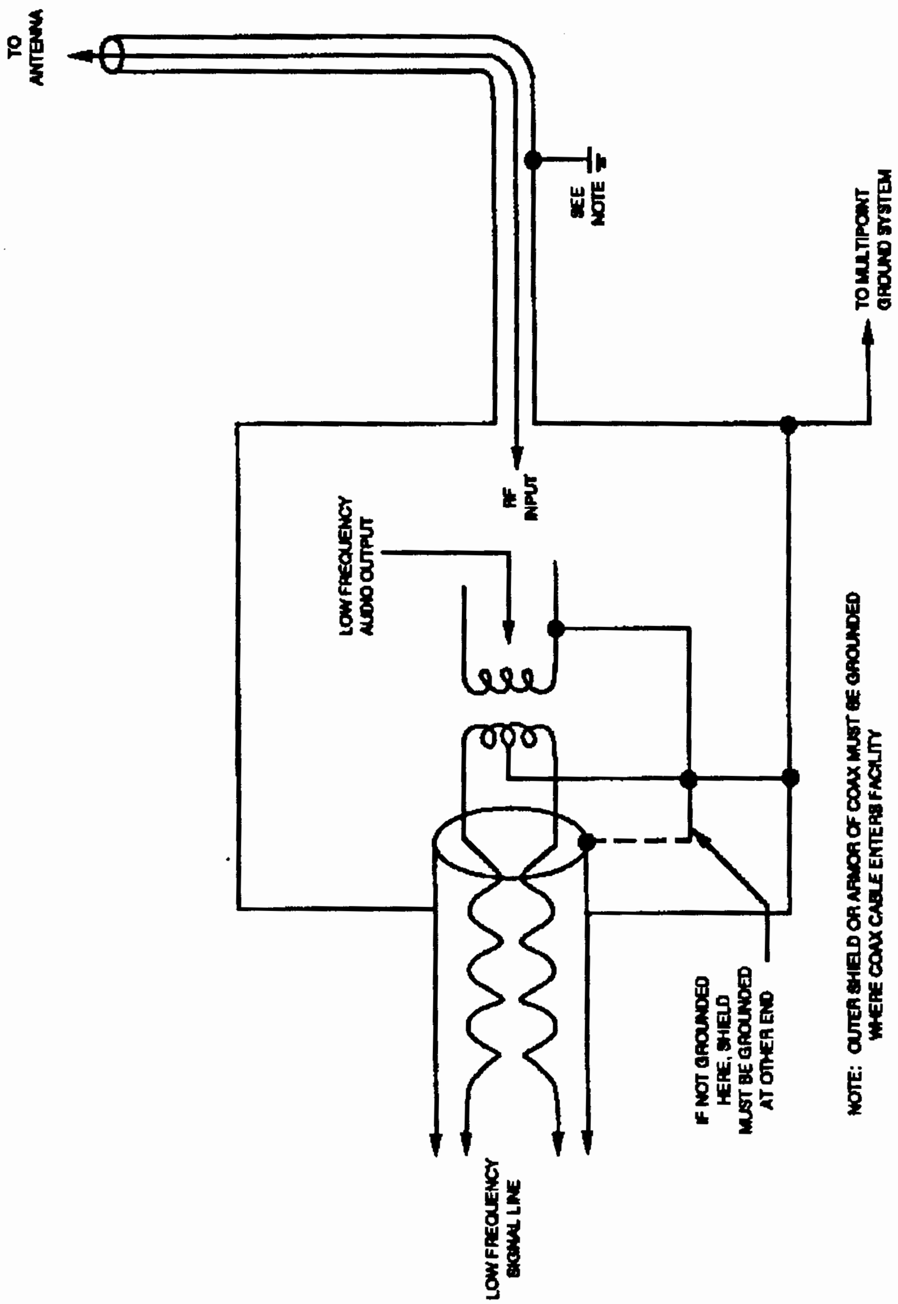
However, in equipment where both low-and high-frequency circuits must share a common signal reference because of design, construction or performance requirements, both signal circuits should be grounded as in high-frequency equipment. The high-frequency interfaces to all transitional type equipment should be constant impedance, shielded lines with the shield grounded around its periphery to the chassis or cabinet. The low-frequency interfaces should be shielded, balanced, twisted pair lines, as illustrated in Figure 4-11, with the shield grounded at one end only.

223. FAULT PROTECTION. Connect each unit or piece of electrical and electronic equipment and all exposed conductive parts to other nearby conductive objects, such as the building structural steel, to prevent hazardous voltages from existing on the equipment relative to its surroundings. Also, each item of equipment, including electronic equipment, fed by an AC power source shall be grounded by means of the equipment grounding conductor run in the same raceway as its related phase and neutral conductors to provide a return path for fault currents back to the protection device in the AC distribution system.

a. Ground exposed non-current-carrying metal parts of electrical and electronic equipment for fault protection in accordance with the requirements of the National Electrical Code (NEC). This shall be done with a separate equipment grounding conductor run in the same conduit as the branch circuit conductors.

b. Convenience outlets which are provided as an integral part of a piece of equipment must be grounded in accordance with the NEC. Connect the ground terminal of such outlets to the equipment grounding conductor specified by the NEC. This grounding conductor is to be installed in addition to any grounding connection made by the receptacle mounting means.

FIGURE 4-11. GROUNDING PRACTICES IN ELECTRONIC EQUIPMENT CONTAINING BOTH HIGH-FREQUENCY AND LOW-FREQUENCY CIRCUITS



Where required for the reduction of electrical noise, outlets in which the grounding terminal is purposely isolated from the receptacle mounting means should be considered. The receptacle grounding terminal shall be grounded by means of an insulated equipment grounding conductor run with the circuit conductors (phase and neutral). The grounding conductors shall be permitted to pass through one or more panelboards (light and/or power panels) without connection to the panelboard ground terminal so as to terminate directly at the equipment grounding conductor terminal of the applicable derived system or service. This equipment grounding conductor shall be color coded green with yellow and red bands at each end of the conductor and whenever it passes through a box. A second separate equipment grounding conductor shall be installed in the same conduit as the phase and neutral and the first equipment grounding conductor. This second equipment grounding conductor shall terminate on the ground terminal of the outlet box housing the receptacle and on the ground bus of the panelboard housing the protective device for the receptacle. This equipment grounding conductor shall be color coded green.

c. In wire mold and plug mold strips, serrated and spring connection between the receptacle ground terminal and the enclosure, because such contacts frequently fail to provide a stable low-resistance connection, should not be relied upon. Instead, connect the ground terminal of the receptacles directly to the enclosure with an equipment grounding conductor meeting the requirements of the NEC.

d. Accessible conductive extensions from each equipment must be grounded to the equipment case to prevent such parts from becoming electrically energized in case of a powerline fault or component failure. For example, metal control shafts must be grounded with close-fitting gaskets, with metal finger stock, or through the mounting hardware.

e. The AC neutral, i.e., the identified (white) wire, must not be connected to any non-current-carrying metal parts of the equipment.

224. CABINET GROUNDING. The case or cabinet of each individual unit or piece of electronic equipment must be electrically bonded to the cases of other nearby equipment and to nearby building metal to minimize noise voltages produced by stray currents.

a. Each unit or piece of electronic equipment that is not rack-mounted should have its case or enclosure connected to the nearest point on the multipoint ground system with a low-resistance ground cable. To ensure that this ground cable has sufficiently low resistance, the size of copper ground cable should provide at least 2,000 cmil per running foot. To determine the necessary wire size, first compute its required cross-sectional area from: Required area in circular mils = Run length in feet x 2,000 cmil per foot.

Using a standard wire table, determine the standard AWG size having the required (or larger) cross-sectional area. For example, assume the run length is 20 feet (6 m). The minimum necessary cross-sectional area is then

20 ft x 2,000 cmil/ft = 40,000 cmil.

The wire tables show that a No. 4 AWG wire has a cross-sectional area of 41,740 circular mils and should be used for a run of 20 feet. If aluminum wire is used, the cross-sectional area must be 3,300 cmil per foot.

b. If the electronic equipment is mounted in a rack, frame, or a cabinet, the electronic equipment case must be directly bonded to the rack, frame, or cabinet in accordance with the recommendations of Section 2. The rack, frame, or cabinet must then be grounded to the nearest point on the multipoint ground system within the facility with a ground conductor providing 2,000 cmil per running foot for copper wire and 3,300 cmil per running foot for aluminum wire.

225. - 229. RESERVED.

SECTION 2. BONDING PRACTICES

230. GENERAL. Equipment emission and susceptibility requirements for proper system operation should be accomplished with the most cost-effective combination of interference reduction techniques. Bonding is an essential element of the interference control effort. This section presents design and construction guidelines to aid in the implementation of effective bonding of electronic equipment circuits, electronic equipment enclosures, and cabling. These guidelines are not intended as step-by-step procedures for meeting EMC specifications. Rather, they are aimed at focusing attention on those principles and techniques which lead to increased compatibility between circuits, assemblies, and equipment.

a. Welded seams should be used wherever possible because they are permanent, offer a low-impedance bond, and achieve the highest degree of RF tightness.

b. Spot welds may be used where RF tightness is not necessary. Spot welding is less desirable than continuous welding because of the tendency for buckling and the possibility of corrosion occurring between welds.

c. Soldering should not be used where high mechanical strength is required. If mechanical strength is required, the solder should be supplemented with fasteners such as screws or bolts.

d. Solder must not be used to form bonds which may be reasonably expected to carry large currents, such as those produced by powerline faults or lightning currents.

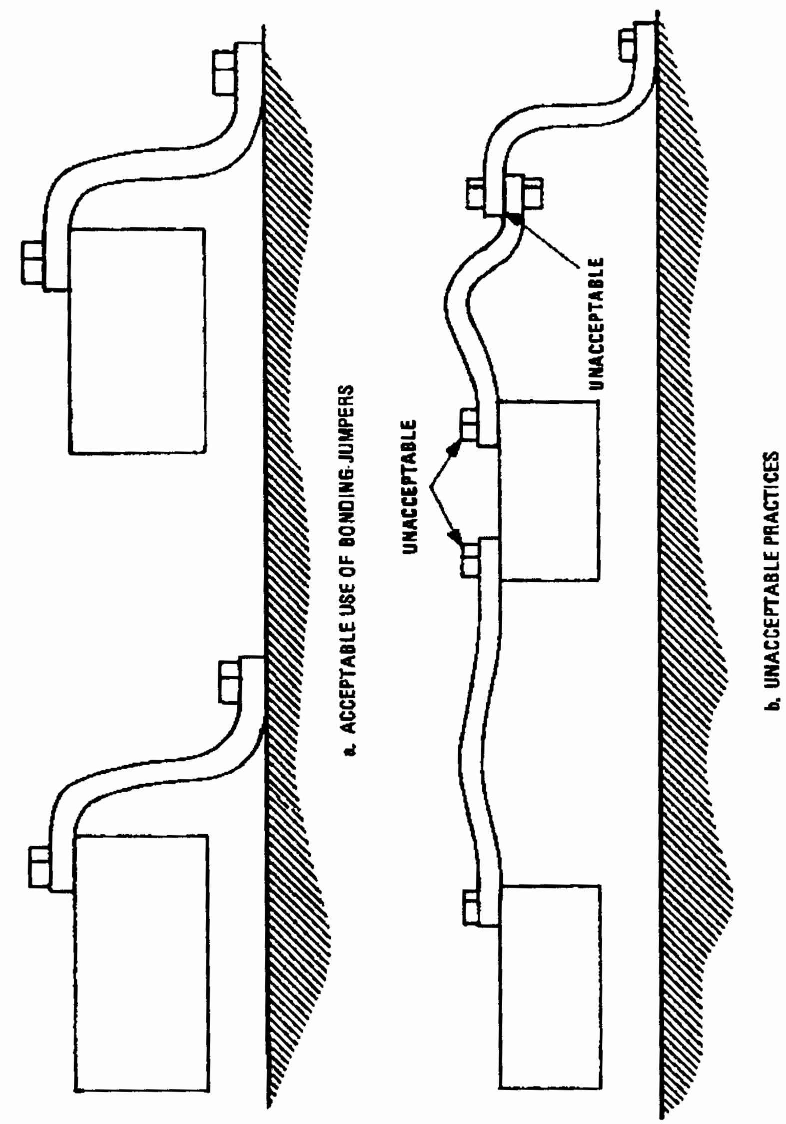
e. Fasteners such as bolts, rivets, or screws should not be relied upon to provide the primary current path through a joint.

f. Rivets should be used primarily to provide mechanical strength to soldered bonds in electronic circuits.

g. Sheet metal screws should be used only for the fastening of dust covers on equipment or for the attachment of covers to discourage unauthorized access by untrained personnel.

h. Bonds that cannot be made through direct metal-to-metal contact must use auxiliary straps or jumpers. The following precautions should be observed when employing bonding straps or jumpers (See Figure 4-12).

FIGURE 4-12. ACCEPTABLE AND UNACCEPTABLE USES OF BONDING JUMPERS



(1) Jumpers should be bonded directly to the basic structure rather than through an adjacent part.

(2) Jumpers should not be installed two or more in series.

(3) Jumpers should be as short as possible.

(4) Jumpers should not be fastened with self-tapping screws.

(5) Jumpers should be installed so that vibration or motion will not affect the impedance of the bonding path.

(6) Jumpers should be made of tinned copper, cadmium-plated phosphor bronze, aluminum, or cadmium-plated steel.

(7) Mating metals should be selected to offer maximum galvanic compatibility (See Section 4, Chapter 2).

i. Where electrical continuity across the shock mounts is necessary, bonding jumpers should be installed across each shock mount. Jumpers for this application should have a maximum thickness of 0.025 in. (0.63 mm) so that the damping efficiency of the mount is not impaired. In severe shock and vibration environments, solid straps may be corrugated, or flexible wire braid may be used.

j. Where RF tightness is required and welded joints cannot be used, the bond surfaces must be machined smooth to establish a high degree of surface contact throughout the joint area. Fasteners must be positioned to maintain uniform pressure throughout the bond area.

k. Chassis-mounted subassemblies should utilize the full mounting area for the bond as illustrated in Figures 4-13 and 4-14. Separate jumpers should not be used for this purpose.

l. Equipment attached to frames or racks by means of flange-mounted quick-disconnect fasteners must be bonded about the entire flange periphery as shown in Figure 4-15. Both the flange surface and the mating rack surface must be cleaned over the entire contact area.

m. Rack-mounted packages employing one or more dagger pins should be bonded as shown in Figure 4-16.

n. The recommended practices for effective bonding of equipment racks are shown in Figure 4-17. Bonding between the

FIGURE 4-13. BONDING OF SUBASSEMBLIES TO EQUIPMENT CHASSIS

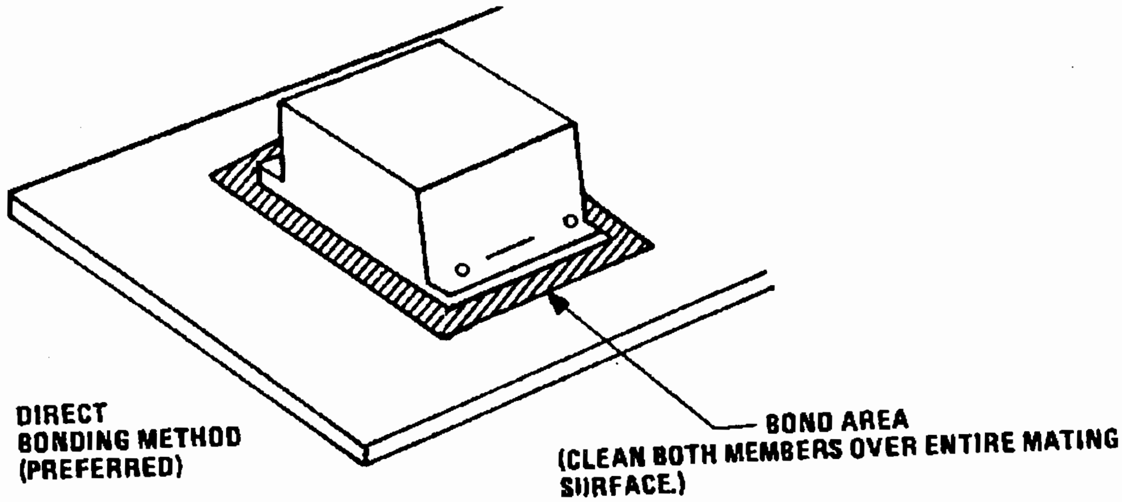


FIGURE 4-14. BONDING OF EQUIPMENT TO MOUNTING SURFACE

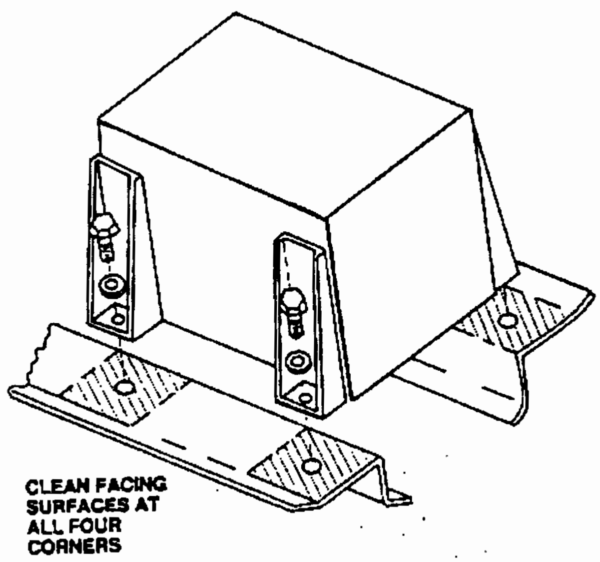


FIGURE 4-15. TYPICAL METHOD OF BONDING EQUIPMENT FLANGES TO FRAME OR RACK

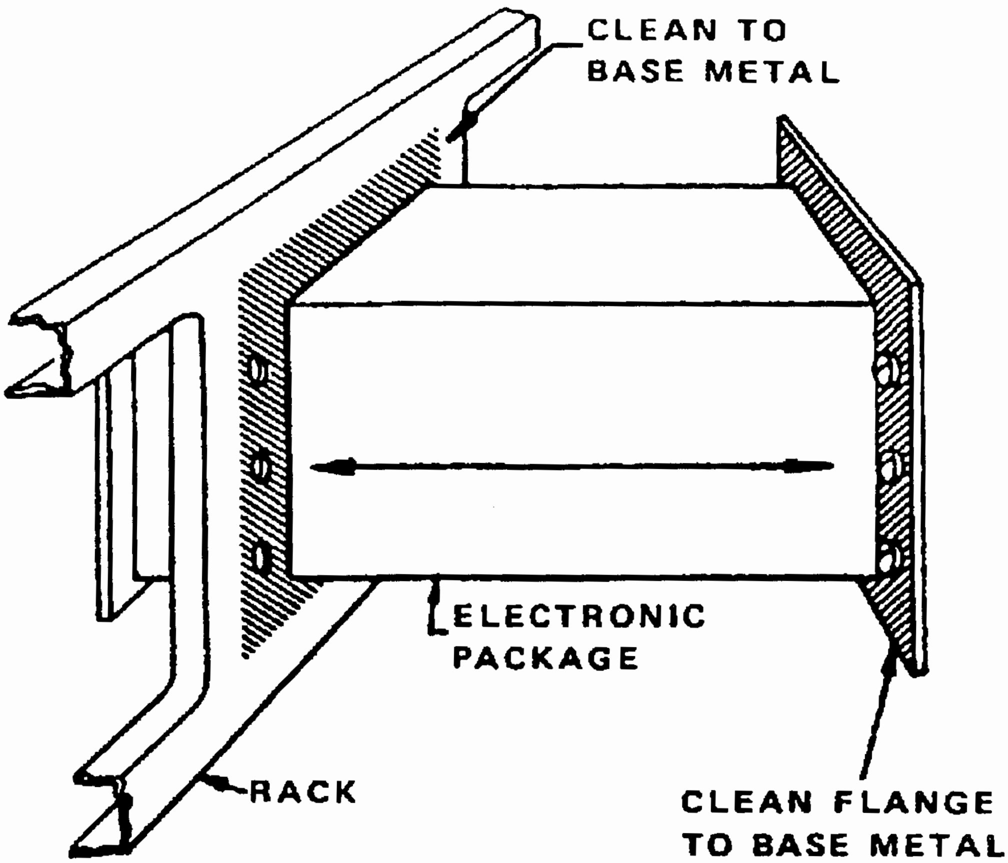


FIGURE 4-16. BONDING OF RACK-MOUNTED EQUIPMENTS EMPLOYING DAGGER PINS

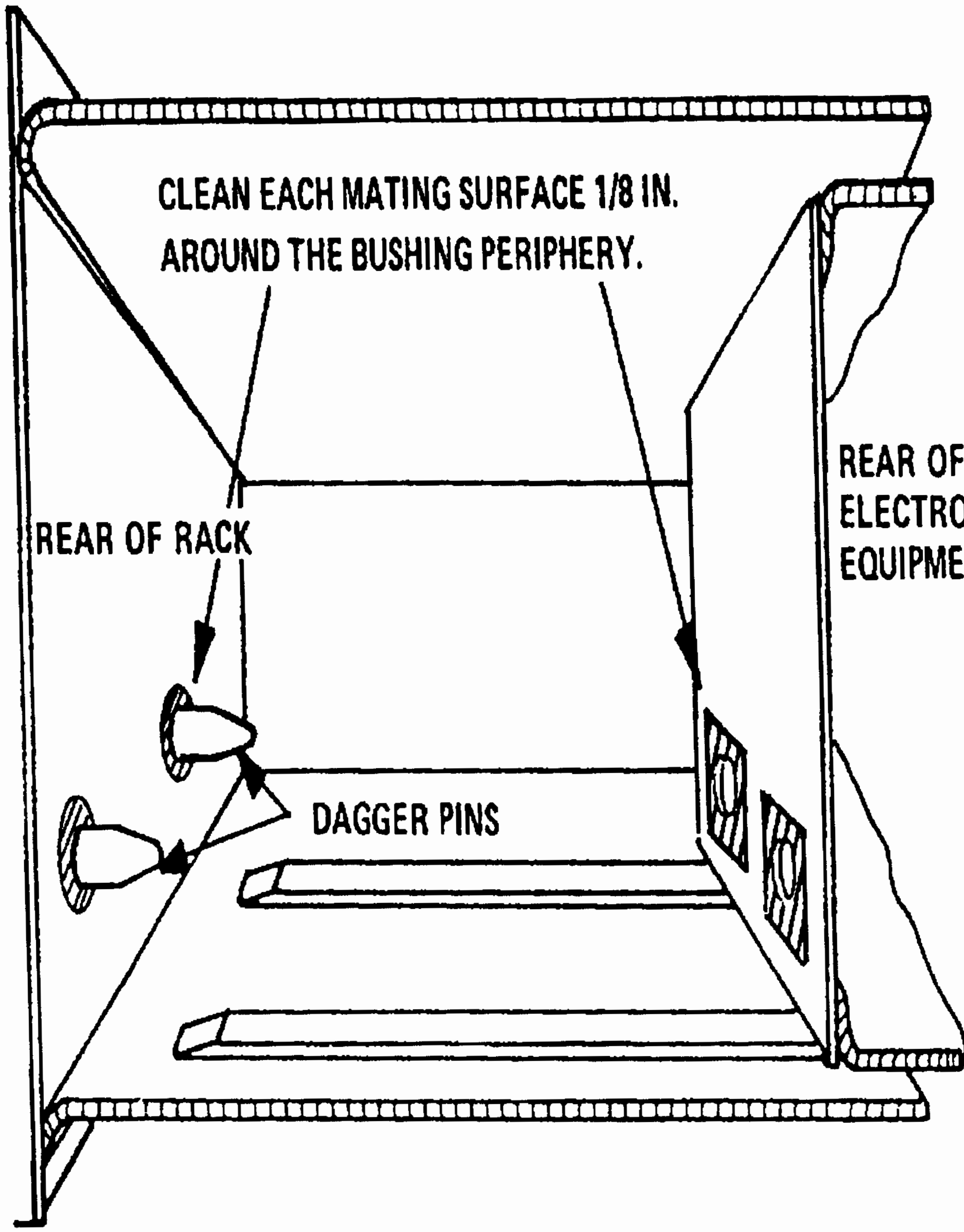
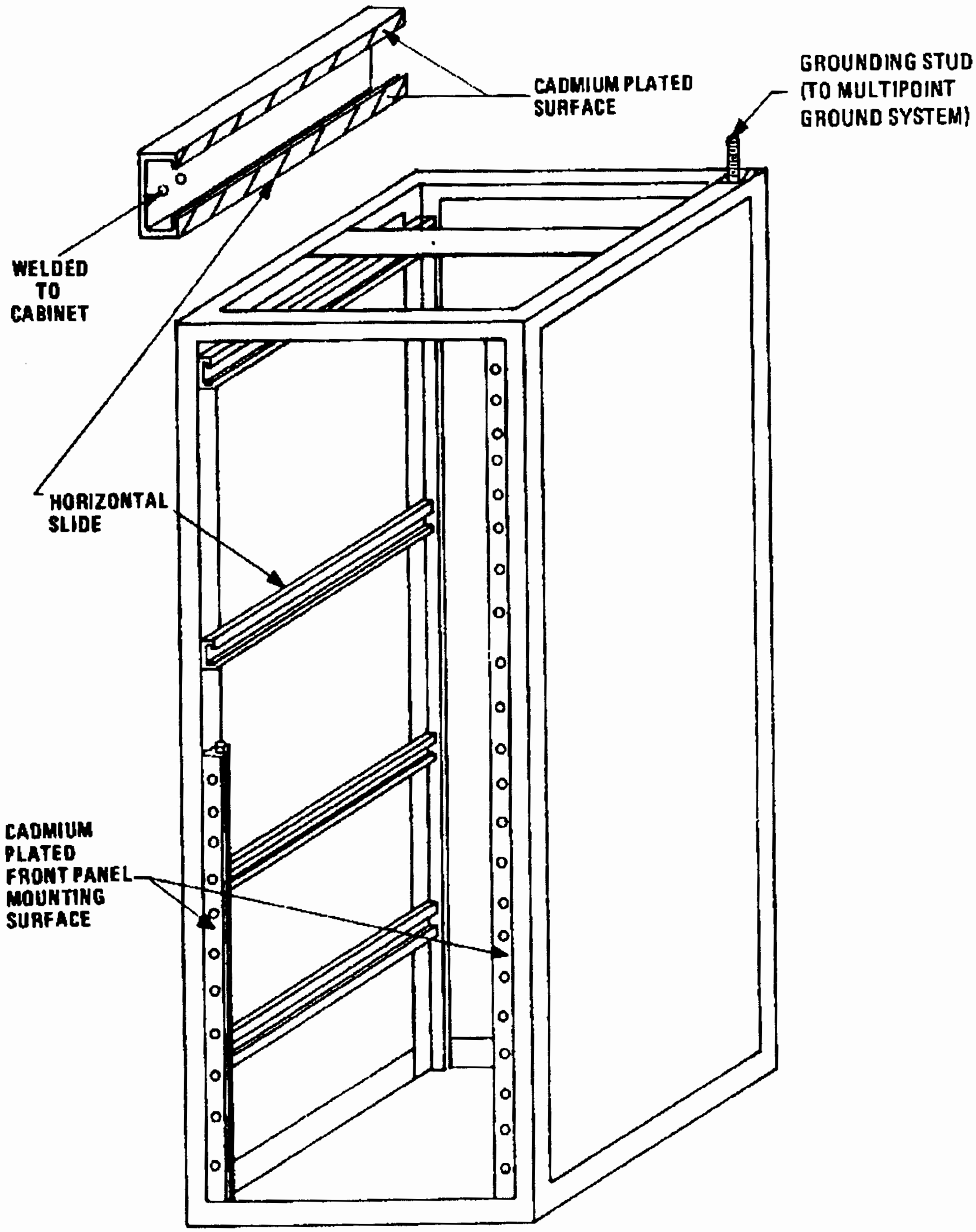


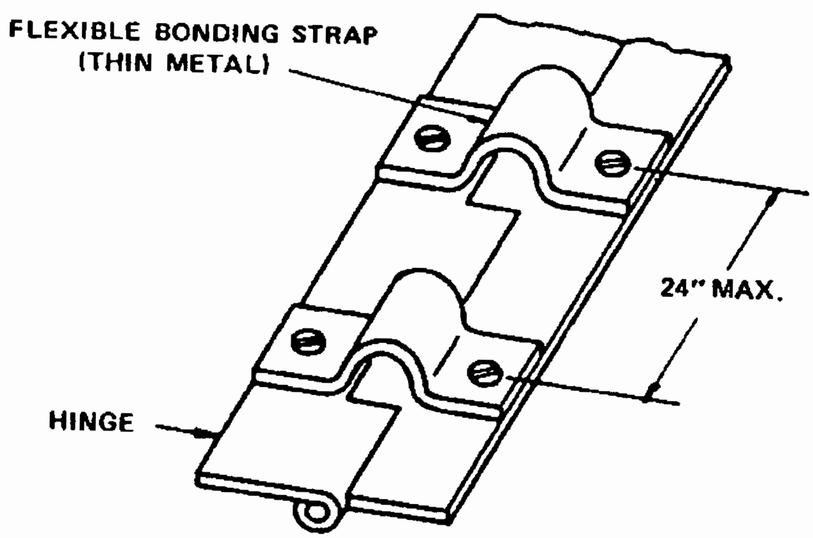
FIGURE 4-17. RECOMMENDED PRACTICES FOR EFFECTIVE BONDING IN CABINETS



equipment chassis and the rack is achieved through contact between the equipment front panel and the rack front brackets. These brackets are bonded to the horizontal slide which is in turn welded to the rack frame. The ground stud at the top of the rack is used to interconnect the rack structure to the multipoint ground system.

o. Where hinges are used, establish an alternate electrical path through the use of thin, flexible straps across the hinges as shown in Figure 4-18.

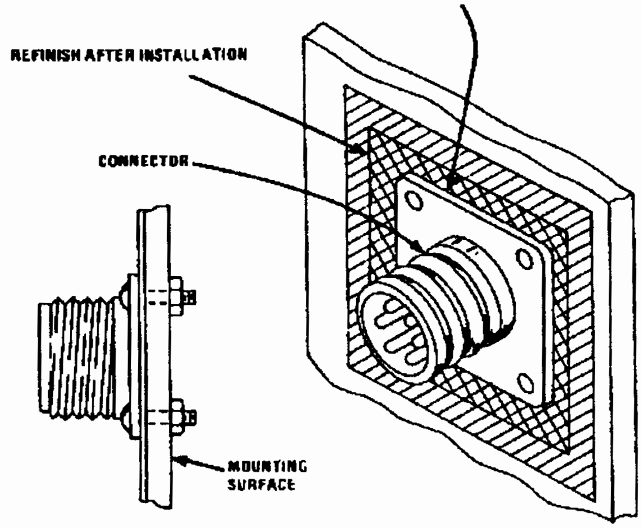
FIGURE 4-18. METHOD OF BONDING ACROSS HINGES



p. Standard military specification (MS) type connectors and coaxial connectors must be bonded to their respective panels over the entire mating surface as illustrated in Figure 4-19. Panel surfaces must be cleaned to the base metal for no less than 1/8-in. (3 mm) beyond the periphery of the mating connector.

q. Individual shields on low-frequency signal lines should be soldered to the appropriate pins of the connector. If solderless terminals must be used, a compressed fitting that provides maximum contact between the shield and the terminal sleeve should be used. Pigtails on individual low-frequency signal line shields should be kept as short as possible.

FIGURE 4-19. BONDING OF CONNECTOR TO MOUNTING SURFACE



r. The overall cable shields on low-frequency cables and the shields of high-frequency signal lines must be bonded to the connector shell completely around the periphery of the shield with either compression or, preferably, soldered bonds.

s. When an RF-tight joint is required at seams, access covers, removable partitions, and other shield discontinuities, conductive gaskets should be used. They may also be used to improve the bond between irregular or rough bonding surfaces. Gaskets should be sufficiently resilient to allow for frequent opening and closing of the joint, and yet be stiff enough to penetrate any conductive films on surfaces.

t. Gaskets should be firmly affixed to one of the bond members with screws, conductive cement, or any other means which does not interfere with their operation. The gaskets may be placed in a milled slot to prevent lateral movement.

u. All bonds must be protected from corrosion and mechanical deterioration. Corrosion protection should be provided by insuring galvanic compatibility of metals and by sealing bonded joints against moisture. See Chapter 2, Section 4.

231. - 239. RESERVED.

SECTION 3. SHIELDING GUIDELINES

240. GENERAL. Even during the circuit design phase of the electronic equipment, shielding requirements should be considered. In this way, electromagnetic compatibility can be achieved during design, thus alleviating much of the post-construction retrofit sometimes required for successful operation. However, a properly designed circuit can be compromised in the transition from a breadboard design to a packaged end item unless appropriate control measures are taken. Thus it is important that components be carefully selected with due regard to their sensitivity characteristics and shielding requirements. Then careful attention must be directed to the installation of these components to either take advantage of their inherent shielding properties or to overcome their shortcomings. In this way, coupling between circuits internal to the electronic equipment and between internal circuits and external emitters or receptors can be controlled.

241. PARTS SELECTION.

a. In circuits where stray coupling may be detrimental, use shielded inductors.

b. Wherever possible, use shielded relays and electrically ground the shield.

c. The input transformer for isolation amplifiers should have electrically shielded primary windings. The shield should be grounded at the center as opposed to one end.

d. Power transformers for susceptible circuits should have an electrostatic shield between the primary and secondary windings. This shield and the transformer case should be grounded to the equipment chassis. The shield should be grounded at the center as opposed to one end.

e. Use shielded hookup wire for high-level leads inside the chassis to prevent interference signals from coupling to other internal leads which extend through the chassis. Low-level leads may also require shielded hookup wire to prevent coupling from high level sources.

f. Select connector types which will provide a sufficient number of pins for individual shield terminations.

g. Select connectors which will be able to withstand environmental conditions without degradation of the shielding characteristics of the connector.

242. LAYOUT AND CONSTRUCTION.

a. Do not place low-level signal paths adjacent to high-level signal paths or unfiltered power supply conductors.

b. Avoid the use of long, parallel conductor runs simply because they look good.

c. Where long parallel runs cannot be avoided, e.g., on mother boards, arrange conductor functions so that they successively progress from the low-level, most sensitive leads to the highest level leads. The filtered DC power leads and low rate control functions (potentiometer leads reference voltages, etc.) may run down the middle.

d. For RF and high-speed digital paths, use double-sided board and employ microstrip transmission lines properly matched to the terminal impedance.

e. Insure that excessive conductor parallelism does not occur between adjacent boards.

f. Effectively ground large unetched portions of boards and utilize the grounded portions as shields.

g. Consider carefully the positions of transformers and inductors on adjacent boards to assure that undesired magnetic coupling does not occur between circuits.

h. Assign circuit functions on boards following the principle of physically separating the most sensitive networks from the high-level or transient-producing networks.

i. Arrange or shield magnetic components to avoid interacting stray fields.

j. Orient the winding axes of adjacent transformers at 90° with respect to each other to minimize coupling due to the concentration of leakage flux along the winding axis and, hence, to minimize the required shielding.

k. Exercise care in placing shields close to circuits in which the circuit Q is a critical factor since losses in the shield can lower circuit Q.

l. Ground any shields on printed circuit boards directly to the main chassis independently of any ground located on the board.

m. The shields on printed circuit boards must never be used as a circuit return conductor since current flowing in the surface of the shield can result in radiated RF energy.

n. Use modularized construction wherever possible. In particular, place powerline input filters in shielded modules.

o. Extreme high-and-low-level stages should be isolated in separate compartments.

p. Circumferentially bond powerline filter cases to the chassis. If the surfaces are aluminum, the surfaces should be iridited, never anodized. Mounting ears of studs must exhibit firm and positive contact over the entire area of the mounting surface.

q. Most common low-frequency interference is the so-called "hum" from power conductors and is predominately magnetic. The shielding of a circuit from power frequency interference may require the use of a high-permeability magnetic shield completely surrounding the sensitive circuit.

r. Provide for effective electric and magnetic field shielding of the power supply.

s. High-voltage power supplies should be adequately shielded and carefully isolated from highly sensitive circuits.

243. EQUIPMENT ENCLOSURES. The shielding effectiveness of the enclosure depends on the structural material and on the mechanical design, construction and installation of the equipment. The choice of material depends primarily on the ambient field and on the degree of shielding required (see Order 6950.20). The main problems with shielding, however, are usually not with the material but with the control of leakage through openings at seams, apertures, and wire penetrations. The following guidelines are suggested as aids toward controlling this high leakage.

a. Seams.

(1) Hold mechanical discontinuities to a minimum.

(2) Bond equipment enclosures at every seam and discontinuity.

(3) Recognize that the poorest electrical joint will determine the shielding effectiveness of the enclosure.

(4) Obtain clean metal-to-metal contact at seams to prevent leakage and radiation of energy.

(5) Where possible, seams should be welded, brazed, or soldered such that the joint is continuous; however, satisfactory results for some applications can be obtained with closely spaced rivets, spot welding, or nuts and bolts.

(6) Provide as much overlap as possible and closely space fasteners to minimize the tendency of the joint to buckle.

(7) Insure that the fastening method exerts sufficient pressure to hold the surfaces in contact in the presence of deforming stresses, shock, and vibrations associated with the normal operation of the equipment in its expected environment.

(8) Use gasket or finger stock material where seam unevenness is encountered or where removable panels, drawers, etc., are used. The gasketing material should fill gaps and uneven places to provide continuous electrical contact between the mating surfaces.

(9) Attach removable covers and panels with closely spaced screws and apply conductive gasketing around the periphery.

(10) Choose gaskets with properties of high resilience and high conductivity.

(11) Provide the minimum gasket thickness which will allow for the expected surface discontinuities of the joint.

(12) Provide the height and pressure necessary to achieve an RF-tight seam.

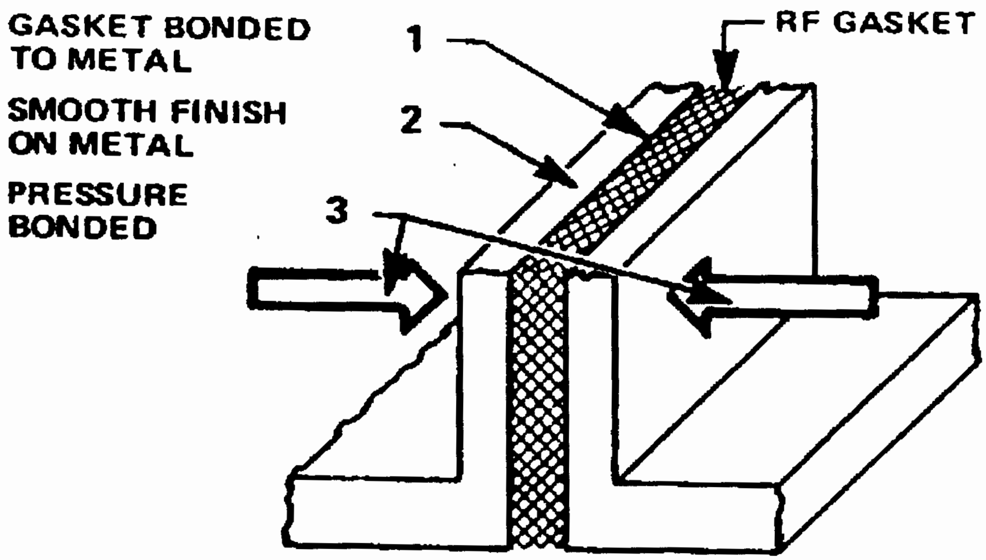
(13) Mount gaskets in permanent seams as shown in Figure 4-20. The features to be observed in this figure are:

(a) Gasket is bonded to one metallic surface of the seam with conductive adhesive; surfaces are cleansed of nonconductive material before application.

(b) Metallic surface is machined to smooth finish and all nonconductive materials are removed.

(c) Appropriate mechanical fasteners (i.e., clamps, bolts, etc.) are used to provide a high pressure on the RF gasket. The pressure should be reasonably uniform along the entire length of the seam.

FIGURE 4-20. METHODS OF MAKING PERMANENT SEAM USING A GASKET



(14) Insure that all RF gaskets are adequately compressed.

(15) On hinged side of doors or panels, mount gasket as shown in Figure 4-21 (item a). If the gasket is mounted in this manner, it receives little or no sliding motion as the door compresses it. If the gasket is mounted as shown in Figure 4-21 (item b), it will be more likely to wear out quickly because of the sliding motion of the door.

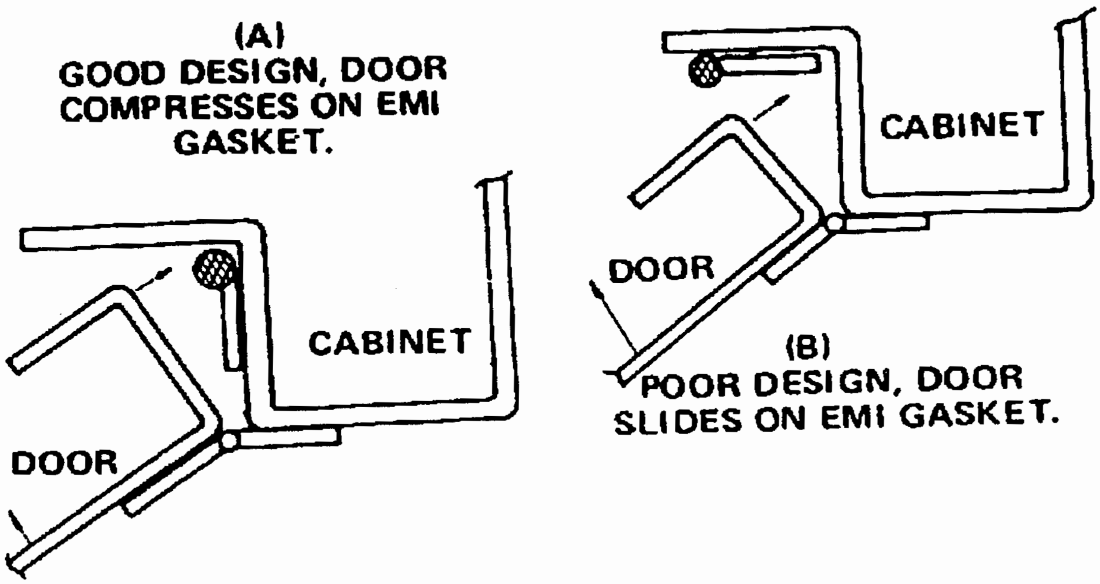
(16) Insure that the metal surfaces which mate with gaskets are free of oily film, corrosion, moisture, and paint.

(17) Handle finger stock with extreme care and install it in a recessed or inner lip to minimize the possibility of mechanical damage.

(18) Carefully maintain the pressure exerted by the spring fingers because this pressure is highly important to the shielding effectiveness of the seam.

b. Penetrations and Apertures. Mechanical and electrical interfaces require that openings exist in the equipment enclosure. Since each interface degrades the shielding effectiveness of the enclosure, the selection and implementation of techniques to provide continuity at these interfaces is important. Figure 4-22 illustrates both good and bad practices.

FIGURE 4-21. MOUNTING OF GASKET ON HINGED SIDE OF EQUIPMENT DOOR AND PANELS



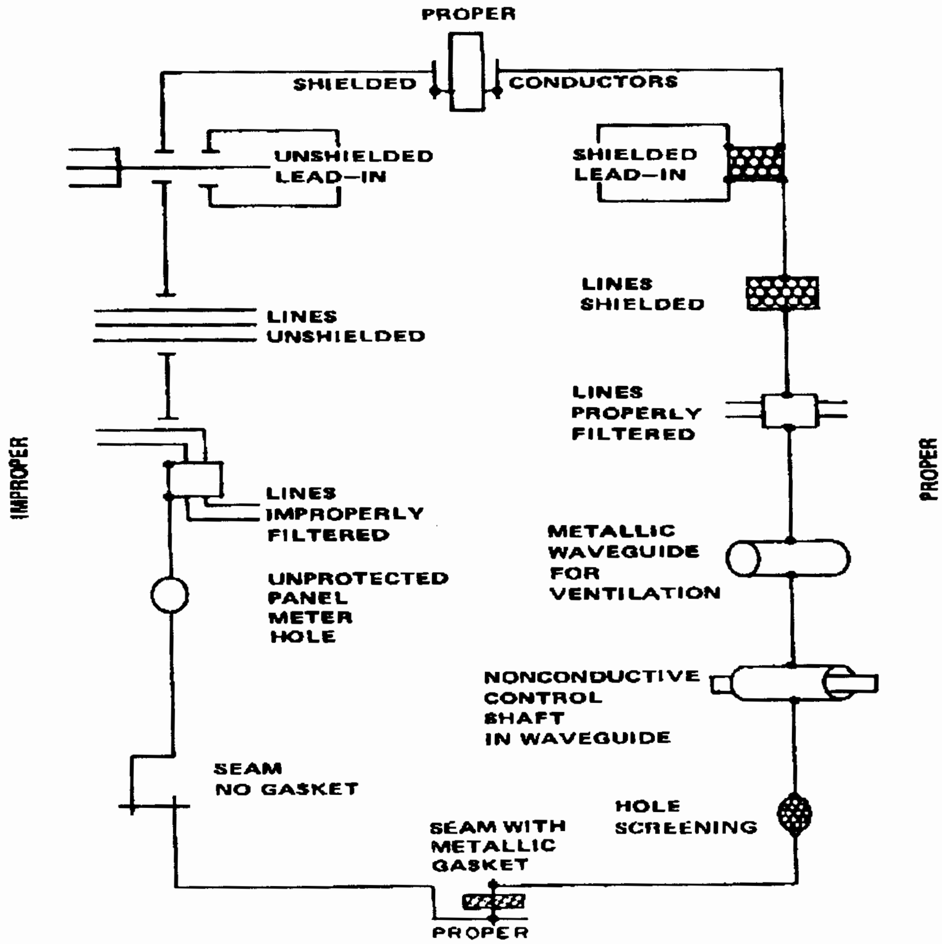
(1) Mount filters for power and control cables inside the shield and extend the filter input terminals through the shield.

(2) Metal control shafts extending through an enclosure should be grounded with metallic fingers, a grounding nut, or an RF gasket. An alternate to the grounded metal shaft is a nylon, teflon, or other dielectric shaft inserted in a waveguide below cutoff cylinder as illustrated in Figure 4-23.

(3) 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.

(4) Design equipment enclosures that require large inlet and/or outlet apertures to include suitable shielding such as honeycomb placed over the apertures. Table 4-1 lists typical cutoff and recommended usable frequencies for standard honeycomb cell sizes. Shielding may also be provided by layers of copper screening with an attendant lower shielding effectiveness and

FIGURE 4-22. ILLUSTRATIONS OF PROPER AND IMPROPER SHIELD PENETRATIONS



higher air resistance. The mesh size should offer 60 or more strands per unit wavelength at the highest frequency to be shielded.

(5) <u>Mount screens</u> over apertures in the manner shown in Figure 4-24.

(6) <u>Compare the attenuation</u> of various types of screen with the shielding effectiveness required before choosing the screen to be used.

(7) <u>Shield meters</u> with one of the techniques illustrated in Figure 4-25.

FIGURE 4-23. USE OF CYLINDRICAL WAVEGUIDE-BELOW-CUTOFF FOR CONTROL SHAFT SHIELD PENETRATION

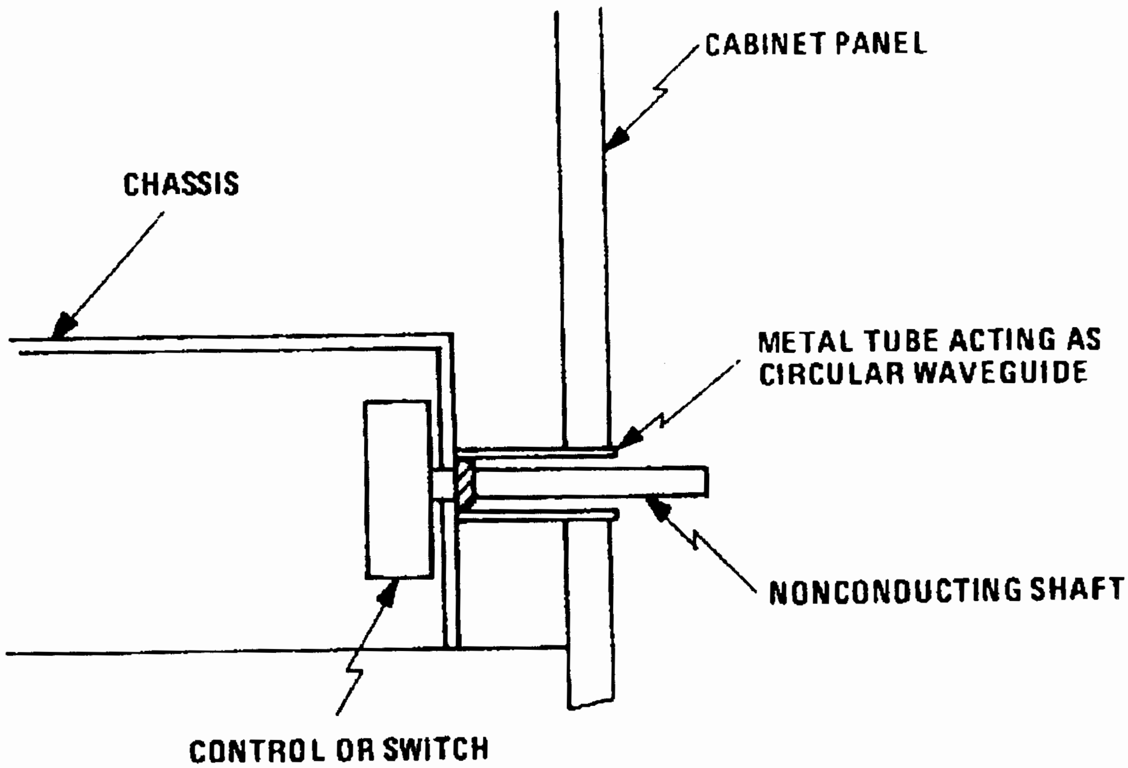


TABLE 4-1. LOW FREQUENCY PROPERTIES OF STANDARD SIDES OF HONEYCOMB

Cell Size (in.)	(mm)	Cutoff Frequency (GHz)	Upper Usable Frequency (GHz)
1/8	3.2	48	16
3/16	4.8	32	10.7
1/4	6.4	24	8.0
3/8	9.6	16	5.3

FIGURE 4-24. METHOD OF MOUNTING WIRE SCREEN OVER A LARGE APERTURE

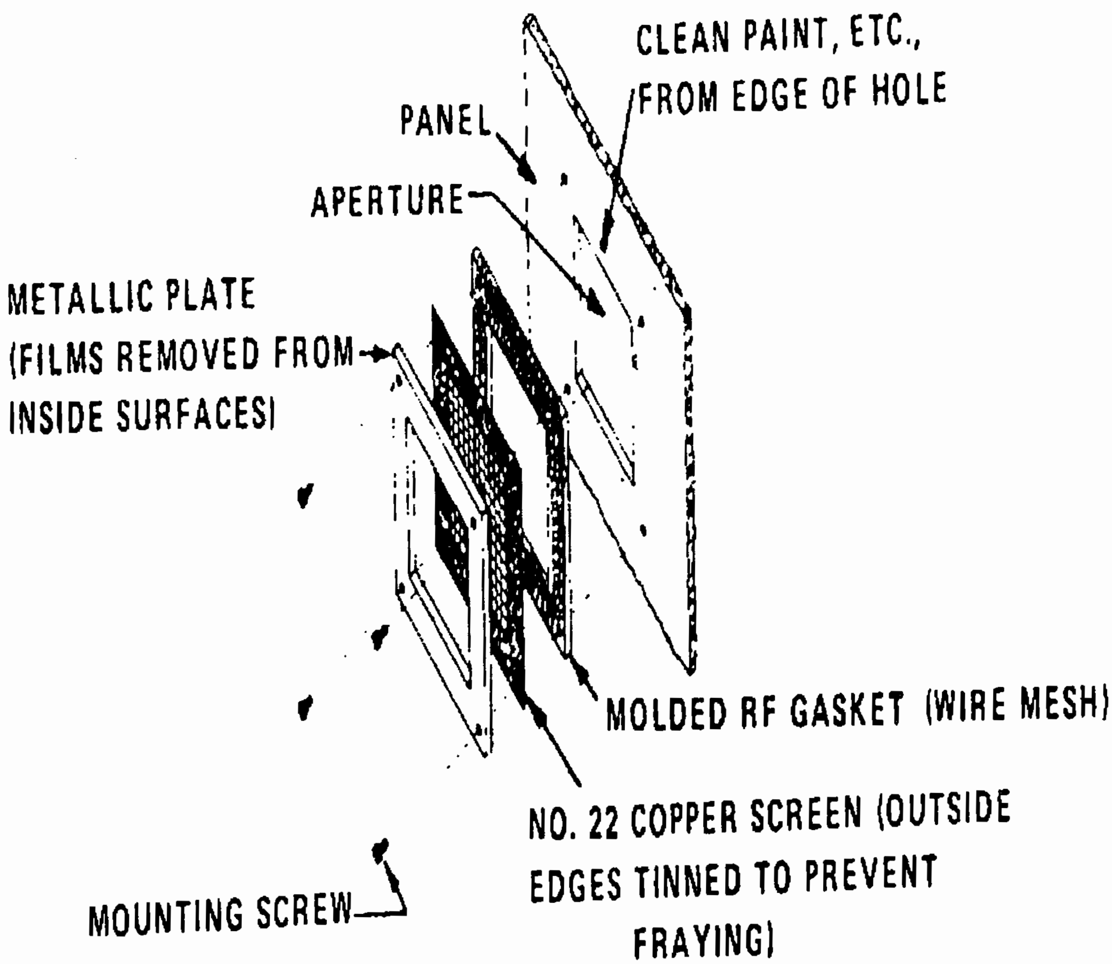
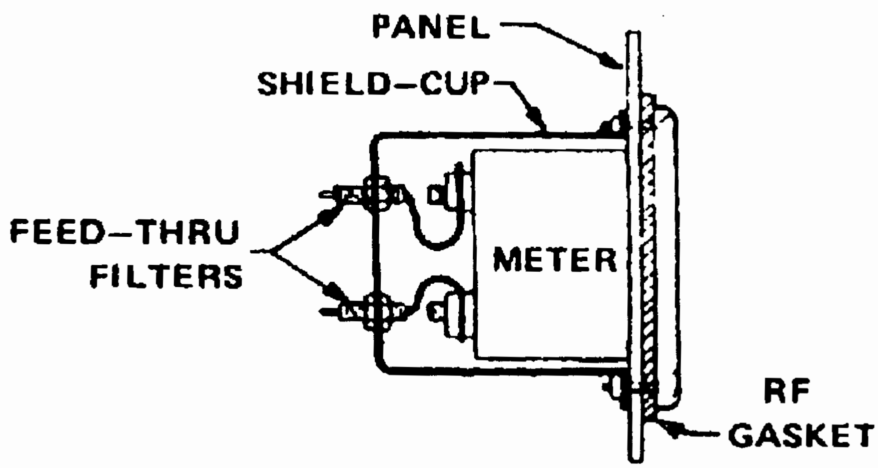
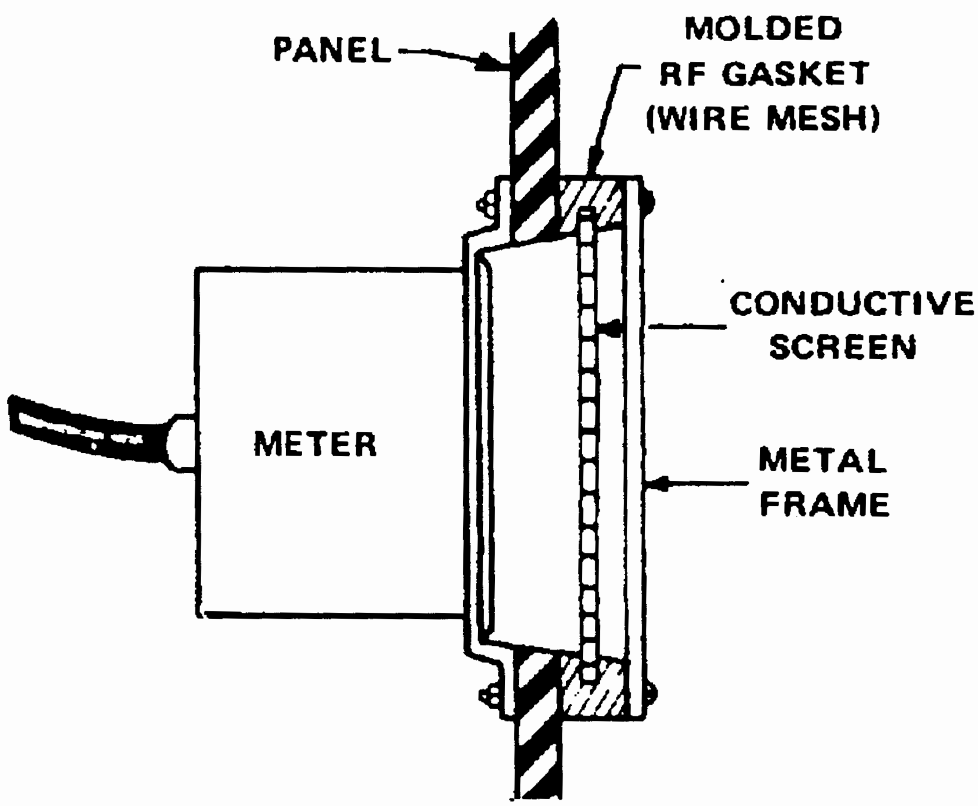


FIGURE 4-25. ACCEPTABLE METHODS OF SHIELDING PANEL-MOUNTED METERS





(8) Provide metal caps for fuse receptacles and for phone and meter jacks.

(9) Use fuses, jacks, and receptacles that have metallic bodies where possible.

(10) Shield either the front or rear of pilot and indicator lamps. Shielding of the front may be achieved through the use of wire screen or conductive glass.

(11) Use equipment enclosures and cabinets to attenuate unwanted signals.

(12) Employ internal modular shielding in specific applications where the enclosure shield is inadequate.

(13) Use internal walls and compartments to limit propagation of interference into and out of equipment subassemblies

(14) Separate high-level sources from sensitive receptors with internal shields such as panels or partitions.

244. - 249. RESERVED.

SECTION 4. COMMON-MODE NOISE CONTROL AND INSTRUMENTATION GROUNDING

250. GENERAL. Primarily, common-mode noise is reduced by either controlling its magnitude in the vicinity of the susceptible circuit, network, or device, or employing those practices which minimize the coupling to the existing voltages, currents, or fields. The first alternative is accomplished by physically separating the source from the susceptible circuits, shielding the source, reducing the current or voltage level at the source, and minimizing any impedance shared in common by the desired and undesired currents. The second alternative involves grounding only one side of a noise voltage source, balancing of signal lines, operating in a differential mode, striving for a zero-resistance reference plane, shielding of signal lines, using a less susceptible mode of signal transmission, minimizing signal loop pickup area, or combinations thereof. See Order 6950.20 for additional information on these minimization techniques.

a. Techniques. In some situations, one of these techniques may be sufficient, if properly implemented, to reduce the noise to an acceptable level. In general, however, combinations of elements of both alternatives will be necessary. To decide which combinations offer the greatest advantages for the least cost, the equipment or system must be carefully analyzed to determine its specific operational properties (or its requirements). The anticipated electromagnetic environment should be carefully examined in order to ascertain the specific type of protection that will probably be required. The two sets of factors must be compared with each other to determine the steps to be taken to achieve effective and reliable equipment or system operation.

b. Noise Control. Common-mode noise control is primarily the application of proper grounding, bonding, and shielding practices in combination with careful circuit and equipment functional design to maximize the signal-to-noise ratio within the overall system. In particular, the low-frequency practices recommended by this Order should be emphasized.

251. INSTRUMENTATION GROUNDING. While the following paragraphs refer specifically to instrumentation systems, the practices and techniques discussed are applicable to other low-frequency analog systems (e.g., voice communications). Many, if not most, data instrumentation systems are concerned with the measurement or detection of physical phenomena (or changes in them) that require periods of observation or measurement that range from a few milliseconds to several minutes or longer. Because of the relatively slow nature of the event, the fundamental frequency of

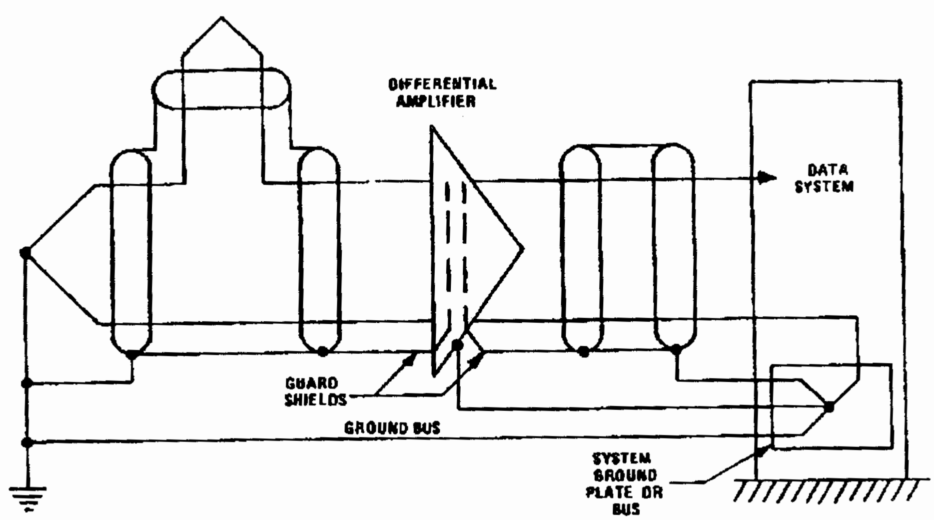
the transducer output may range from 0 (DC) to a few hundred Hertz.

Power distribution systems, electromechanical switches, and atmospheric noise produce extraneous voltages whose energy content is strongly concentrated within this low-frequency region. Because of this overlap of signals, special techniques are generally required to keep the voltages or currents produced by the extraneous sources from obscuring the transducer outputs. Data instrumentation systems may employ either analog or digital signals or a combination of both. The methods of grounding analog and digital systems are considered separately although the physical principles of noise reduction for both are basically the same.

a. Analog Systems. Since these analog signals are primarily low-frequency in nature, a basic single-point ground should be implemented. The signal return line should be grounded at one end only or not at all (i.e., it should be balanced). Similarly, shields around signal lines should be grounded at one end only.

(1) Grounded Transducers. The bonded (grounded) thermocouple, illustrated in Figure 4-26, is used with a single-ended data amplifier whose output drives recording devices such as oscillographs, strip-chart recorders, and magnetic tape recorders.

FIGURE 4-26. GROUNDING PRACTICES FOR SINGLE-ENDED AMPLIFIERS

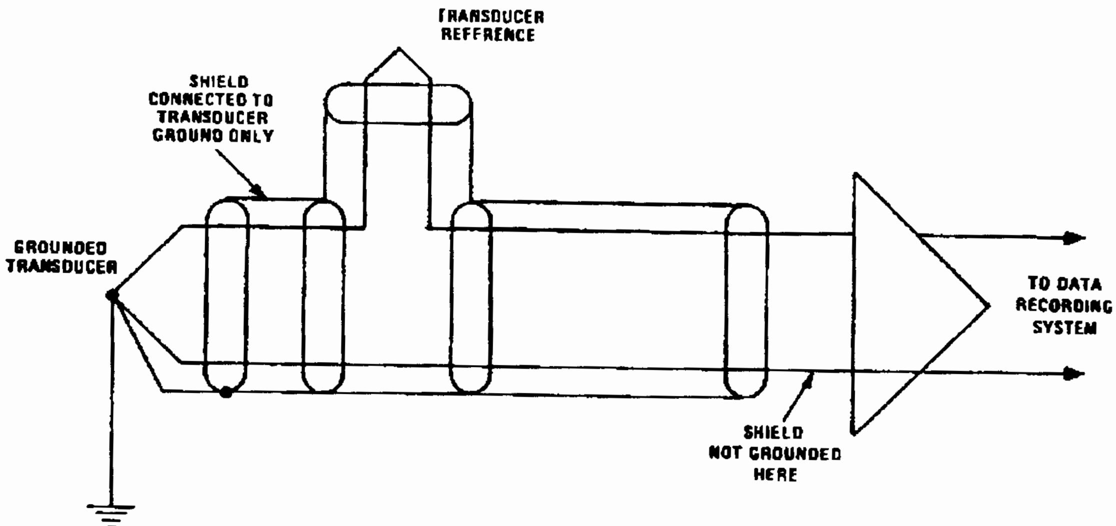


(a) The shield which surrounds the transducer signal leads should be grounded at the same point as the transducer to ensure that the shield and signal leads are at virtually the same potential.

(b) When single-ended amplifiers must be used, the recorder should be left ungrounded.

(c) When bonded thermocouple is connected to an isolated differential amplifier as shown in Figure 4-27, the

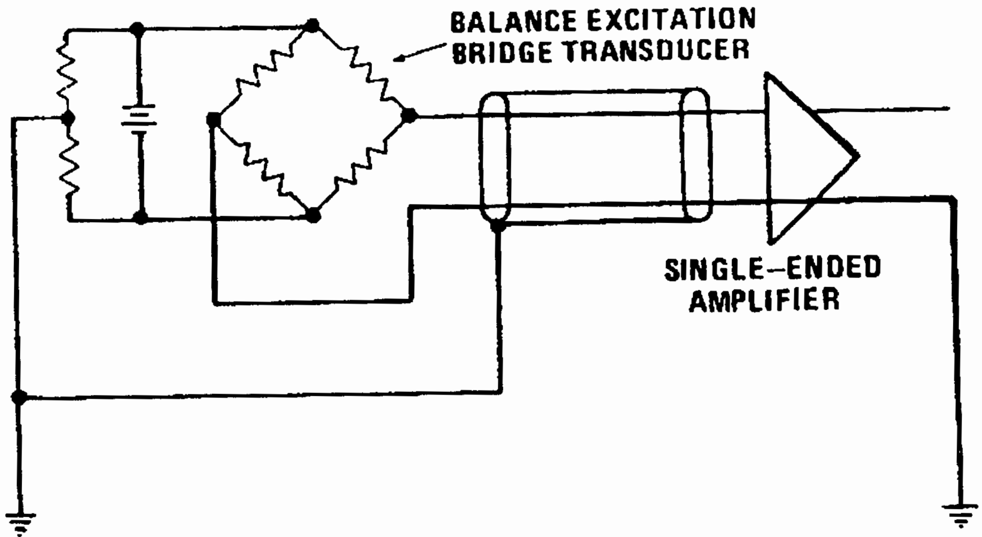
FIGURE 4-27. GROUNDING PRACTICES FOR DIFFERENTIAL AMPLIFIERS



shield of the input cable should be connected to the amplifier internal guard shield to continue the signal shield to within the amplifier. Notice that a grounding bus is shown connected between the data system signal reference and earth ground of the test area. This ground bus is necessary in any instrumentation system which uses isolated differential amplifiers in order to provide the earth reference for the signal circuitry within the recording system to reduce high voltage hazards, and to minimize the common-mode potentials that otherwise exist between the amplifier's input and output if the data recording system was grounded to a separate earth ground. Notice that the amplifier case and output shield are connected to the data system (or load end) ground.

(d) Grounded bridge transducers should be excited with a balanced DC source. By balancing the DC excitation supply relative to ground as shown in Figure 4-28, the entire bridge

FIGURE 4-28. METHOD OF GROUNDING BRIDGE TRANSDUCERS



will be balanced with respect to ground and the unbalanced impedance presented to the amplifier input will be due only to the leg resistances in the bridge. Although a ground loop still exists, its effect is greatly reduced by a balanced excitation supply.

(e) Wherever possible, use an isolated amplifier in the manner illustrated in Figure 4-29 with bridge transducers. With this configuration, both the transducer and the amplifier can be grounded without degrading system performance.

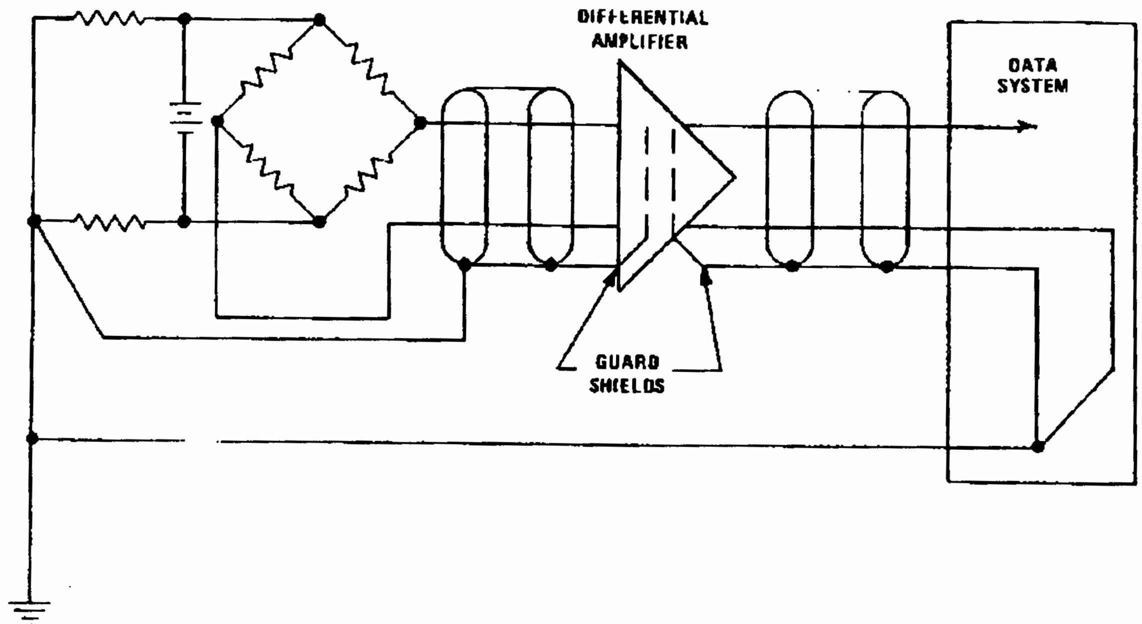
(f) Insure a low-resistance earth ground connection. See Chapter 2, Section 1.

(g) Provide a single, common signal reference point for all grounded transducers at the test area.

(h) Connect the instrumentation cable shield of each data channel as close to the transducer ground connection as possible.

(i) Use twisted shielded transducer extension wires.

FIGURE 4-29. USE OF ISOLATED DIFFERENTIAL AMPLIFIER WITH BALANCED BRIDGE TRANSDUCER



(j) Use a floating load on the output of single-ended data amplifiers when the amplifier input is a grounded transducer.

(k) Connect the guard shield of the data amplifier to the input cable shield.

(l) Always use insulated shielded cables. Uninsulated shields should never be used in data instrumentation systems.

(2) Ungrounded Transducers.

(a) Figure 4-30 illustrates the grounding techniques recommended for ungrounded transducers. The metallic enclosure of the transducer is connected to the cable shield and both the enclosure and the shield are grounded at the transducer. If the load on the cable signal line is a single-ended amplifier as shown in Figure 4-30a, the shield of the input cable should not be connected to the amplifier. The case of the amplifier should be grounded at the load.

(b) Figure 4-30b shows the recommended way of grounding the system when using an isolated amplifier. Certain types of non-isolated differential amplifiers require that a transducer ground path be provided for proper amplifier operation. The instructions supplied by the amplifier manufacturer should be consulted for correct procedures.

(c) Provide a single, common reference point for all cable shields.

(d) Ground all input cable shields at the transducer.

(e) Provide a continuous overall shield for signal wires from the transducer case to the input of the data amplifier.

(f) Connect the isolated amplifier guard shield to the input cable shield.

(g) Do not allow more than one ground connection in each input cable shield.

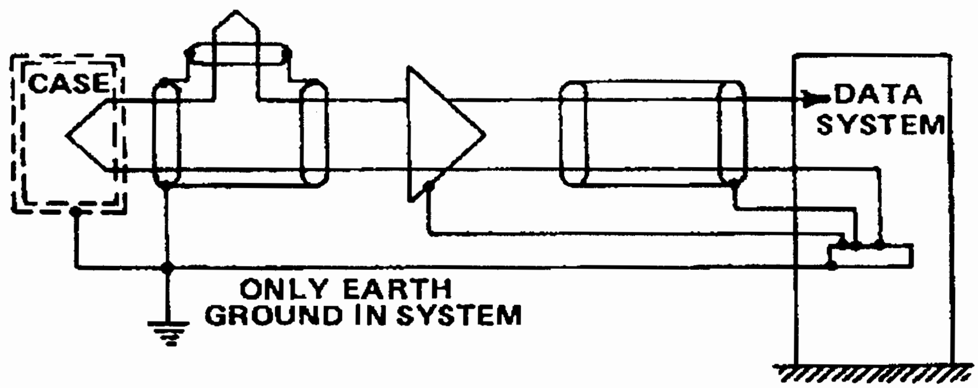
(3) Amplifiers.

(a) Single-ended amplifiers can be used in digital data acquisition systems if channel-to-channel isolation is provided (e.g., through the use of floating loads).

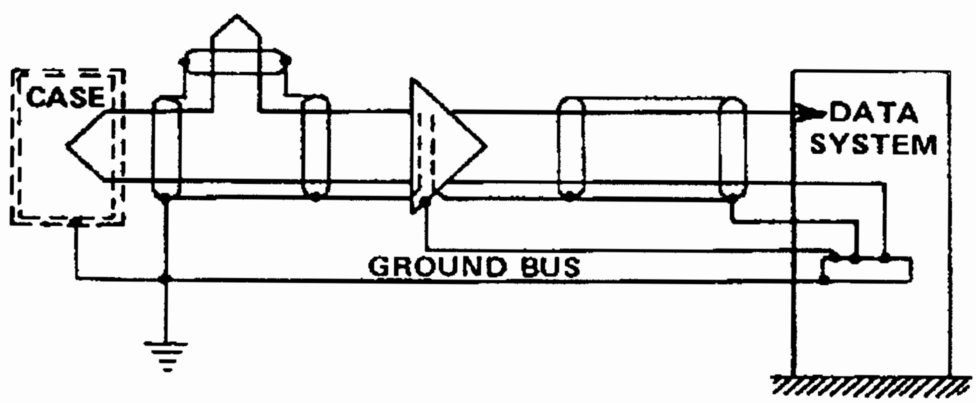
(b) Single-ended amplifiers should not be used with grounded (bonded) transducers in order to avoid channel-to-channel ground loops.

(c) Single-ended amplifiers should not be used with grounded bridges to avoid short circuiting one leg of the bridge.

FIGURE 4-30. RECOMMENDED GROUNDING PRACTICES FOR FLOATING TRANSDUCERS



a. SINGLE-ENDED AMPLIFIER



b. ISOLATED DIFFERENTIAL AMPLIFIER

(d) Connect amplifier output guard shield to data system ground bus.

(e) If a permanent unavoidable instrumentation ground exists at the test area as well as at the data system, use isolated differential amplifiers to break the ground loop.

b. Digital Data Systems. A digital circuit operates by recognizing the state of a two-level voltage or current signal. The speed of the system is determined by the speed at which the levels can be changed. Because of the capacitive and magnetic coupling effects resulting from the very fast rise and fall times of digital pulses, take every precaution to minimize the effects.

(1) Twist clock lines with their return leads to minimize the magnetic field near such lines.

(2) Use point-to-point wiring as much as possible to reduce capacitive coupling.

(3) Provide multiple paths in the ground wiring to distribute the ground current among several wires.

(4) Use electrostatic shielding with care to avoid excessive loading of data lines.

(5) Wire all digital circuits using shortest wire length possible.

(6) All ground wires must converge to a system common ground point.

(7) Maintain maximum distance between digital circuits and low level analog circuits.

(8) In a system where both analog and digital circuits must be housed in the same equipment cabinet, keep as much physical separation between them as possible, e.g., at opposite ends of the cabinet. A common ground plate for the system can be located in the center of the cabinet or two ground plates can be utilized, one for analog ground and one for digital ground. These two ground plates must be tied together with a low-inductance bus and then tied to the system ground bus line.

c. Recording Devices.

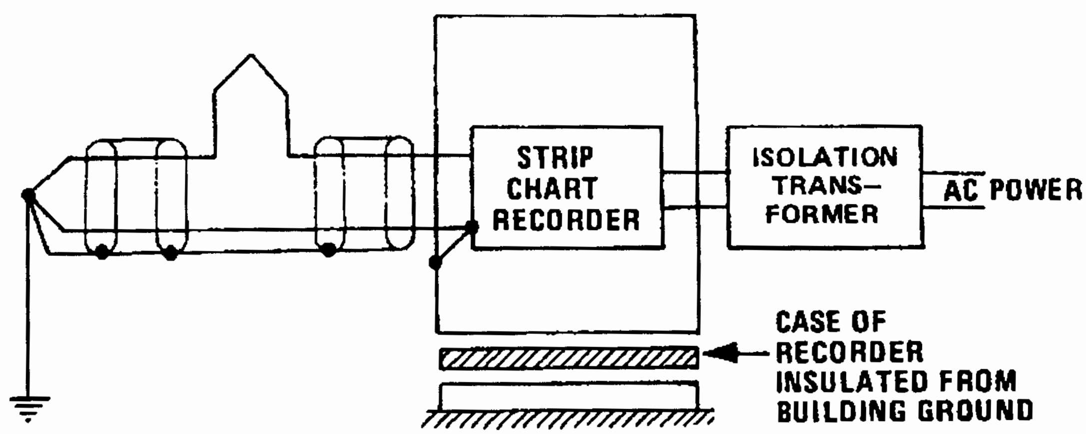
(1) Magnetic Tape Recorders.

(a) Magnetic tape recording systems are mostly single-ended and should therefore conform to much the same grounding practices as recommended for digital systems.

(b) Earth ground should be made at the test area with a single 4/0 AWG cable extending to an isolated grounding plate within the tape cabinet.

(c) When using only one recording device for a given channel, the channel may be connected directly to the recorder as shown in Figure 4-31.

FIGURE 4-31. GROUNDING FOR SINGLE CHANNEL STRIP CHART RECORDER



(d) Should the tape channels receive data in parallel with other single-ended channels, such as arise in analog-to-digital (A/D) systems, take special care to minimize the effects of inherent loops.

The optimum method of recording with two single-ended devices in parallel from the same data channel is to use an amplifier with isolated outputs. In this way, the inherent loop is broken and noise is minimized.

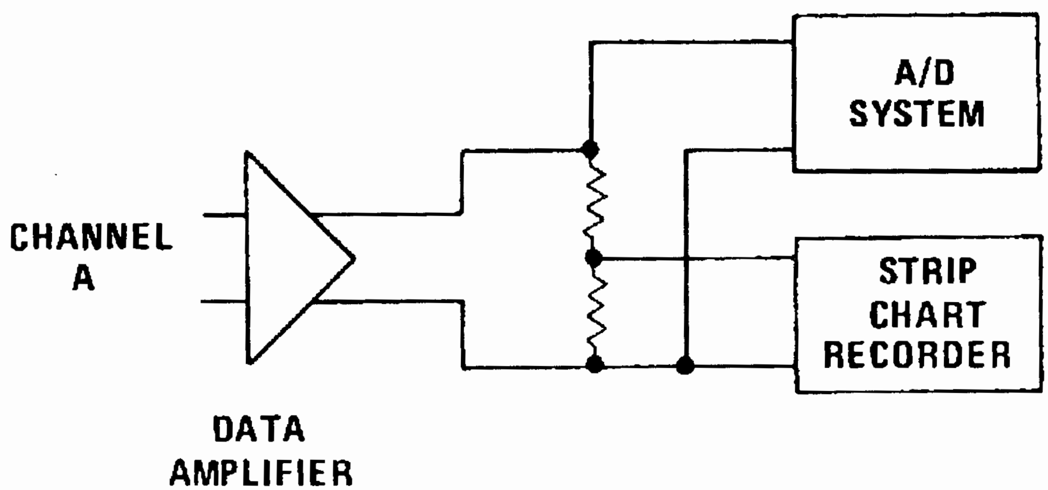
(2) Strip Chart Recorders.

(a) Strip chart recorders are mostly single-ended and should be grounded as described for magnetic tape devices.

(b) Since the strip chart recorder is a nulling device, its input impedance will change as it deflects from one position to another. This impedance change and the accompanying voltage feedback can be coupled directly from the strip chart input over to the input of a parallel device such as an A/D converter. Gross error can result in the A/D channel.

This difficulty can be resolved by using resistive isolation as shown in Figure 4-32 or by employing dual amplifier outputs, one for each channel, as described for analog tape systems.

FIGURE 4-32. RESISTIVE ISOLATION OF DATA CHANNELS



(3) X-Y Plotters. X-Y plotters are available in either digital or analog input configurations. The digital type plotters are usually connected as peripheral devices to computers or A/D systems and should be grounded in accordance with the recommended digital practices. Analog type X-Y plotters are normally single-ended and should be grounded and connected in the same manner as described for strip chart recorders.

252. - 259. RESERVED.

SECTION 5. EMP CONSIDERATIONS

260. GENERAL. Those general design practices which are effective for the control of electromagnetic interference generally are applicable to protection against EMP. The two factors of the EMP threat to be given particular emphasis are the strong magnetic field component, and the overall high level of the incident field.

a. Because of the magnetic field component, design practices which minimize magnetic pickup are most important. Practices such as minimizing loop pickup area by twisting signal conductors with their returns, twisting of power supply conductors, routing conductors close to ground planes, and utilizing minimum length conductors must be emphasized.

b. EMP shielding requires the use of high-permeability materials. Because of saturation effects, the thickness necessary for complete shielding can lead to rather heavy and bulky enclosures. Seams, joints, and apertures must be given the same careful attention and control required in the construction of shields for buildings and structures. For these reasons, it is generally more practical to shield the building or structure in which the equipment is located than it is to shield individual pieces of equipment.

c. In a shielded area or facility, critical equipment should be located as far from corners, discontinuities, openings, and penetrations as is practical. The most susceptible equipment should occupy the center locations with the least susceptible equipment closer to the shield.

d. Components exhibit different degrees of susceptibility to damage from EMP (see Order 6950.20). Electromechanical devices appear to be the least susceptible. Vacuum tube devices offer reasonable immunity, while solid-state devices such as diodes, transistors (field effect transistors in particular), silicon controlled rectifiers (SCR), and integrated circuits exhibit damage thresholds two to three orders of magnitude less than the threat posed by the EMP. These factors should be kept in mind during initial design and, wherever a circuit function can be accomplished with a less susceptible device, use the device with greater immunity. For example, an electromechanical relay will be less likely to suffer damage than will an SCR or transistor switch. A vacuum tube front end for a receiver will offer greater immunity than will the transistor version.

Where the more susceptible devices must be used, they should be adequately shielded (the compartmentalization of subassemblies is probably the most economical and practical approach) with appropriate surge protection applied to all incoming and outgoing leads.

e. Effective EMP design practices require careful tradeoff comparisons between functional requirements, device properties, physical constraints, and overall cost. Consult Order 6950.20 for additional design assistance.

261. - 269. RESERVED.

SECTION 6. TRANSIENT PROTECTION

270. GENERAL. Individual items of electrical and electronic equipment that directly interface any externally exposed equipment lines, including commercial AC power input lines, may require transient protection that is designed as an integral part of the electronic equipment. Whether or not protection is required is dependent on the damage susceptibility of the equipment of interest, the level of transient suppression provided on externally exposed lines at building penetration or external electronic equipment termination and the level of transient energy that is projected to be conducted to the electronic equipment. For use herein, externally exposed lines are defined as lines exposed to outside weather elements and environmental conditions. The lines may run overhead, run along grade surface, or be buried in earth. Included are AC power input lines and signal, control, status, and intrafacility power lines. The lines are commonly referred to as landlines. Transient protection is not required in electronic equipment when an interfaced landline is fiber optic in lieu of a metallic conductor. In order to provide effective transient protection, the damage (withstand) level for the electronic equipment must be determined, and the amplitude and number of transients that will be conducted to the electronic equipment must be known. This information is provided in this section. Three areas of equipment circuitry normally require transient protection, and are listed below:

a. The AC power input to electronic equipment.

b. Where other externally exposed lines interface the electronic equipment.

c. Rectifier outputs of 5 to 48 V DC power supplies that operate from commercial AC power and supply operating power for solid-state equipment.

271. TRANSIENT DEFINITION. The waveform and amplitude of transients that may appear on commercial AC input lines and other landlines connected to electronic equipment are provided in this paragraph.

a. AC Powerline Transients. The number and amplitude of lightning-induced transients projected to occur on AC power inputs to electronic equipment over a 10-year period are listed in Tables 4-2 and 4-3. The waveform for the transients is 10-by-20 microseconds where 10 microseconds is the risetime from 0 to peak amplitude, and 20 microseconds is the time from the start of the transient until exponential decay to 50% of peak value. The transients listed are based on the data in Section 6 of Chapter 2. The transients listed in the two tables represent clamp voltages that will be reflected across electronic equipment by the facility secondary AC arrester installed at the service disconnecting means (See Section 6, Chapter 2), when discharging surges. Voltages and currents actually reflected across protected electronic equipment will be related to the amounts and type of equipment operating from power supplied through the service disconnecting means.

b. Landline Transients. The number and amplitude of transients projected to be conducted to each landline equipment interface are listed in Table 4-4. The waveform for the transients is 10-by-1000 microseconds where 10 microseconds is the risetime from 0 to peak amplitude for the transient, and 1,000 microseconds is the time from the start of the transient until exponential decay to 50% of peak amplitude. The information presented in Table 4-4 is based on data contained in Section 6, Chapter 2. Since an equipment designer will not normally know whether external lines will be enclosed in ferrous metal conduits, different transient amplitudes are not provided for in Table 4-4.

272. DETERMINATION OF EQUIPMENT DAMAGE (WITHSTAND) LEVELS. Manufacturers do not normally specify withstand levels for components. Therefore, an analysis should be performed to determine the withstand level for each item of electronic equipment that directly interfaces any externally exposed lines including AC input lines. Transients that are projected to be conducted to electronic equipment are provided in Tables 4-2, 4-3, and 4-4. The analysis must be based either on results of laboratory tests or conservative engineering evaluations.

Also the analysis must include all electronic equipment circuitry that will be exposed to transients. Three factors determine the withstand level for the electronic equipment as follows:

a. Component Destruction Level. The component destruction level is the transient energy level that either causes immediate component destruction or degrades component operation to a point so that useful operation cannot be achieved.

b. Shortened Component Operating Life. Useful component operating life can be appreciably shortened by repeated overstressing of components. The over-stressing occurs as a result of repeated application of some level of transient energy. This energy level may be difficult in some cases to determine, but is certainly meaningful when designing protection against transients.

TABLE 4-2. TRANSIENT SURGES, LINE-TO-GROUND, PROJECTED TO BE REFLECTED ACROSS ELECTRONIC EQUIPMENT BY SECONDARY AC SURGE SUPPRESSOR OVER A 10-YEAR PERIOD

Surge Current Amplitude(10-by-20 μS)	Number of Surges
1.5 kV, 100 A	1,500
2 kV, 200 A	700
2.5 kV, 300 A	375
3 kV, 500 A	50
3.5 kV, 1 kA	5
4 kV, 1.5 kA	2
4.5 kV, 2 kA	1

TABLE 4-3. TRANSIENT SURGES, LINE-TO-LINE, PROJECTED TO BE REFLECTED ACROSS ELECTRONIC EQUIPMENT BY SECONDARY AC SURGE SUPPRESSOR OVER A 10-YEAR PERIOD (UNGROUNDED SERVICE ONLY)

Surge Amplitude (10-by-20 μS)	Number of Surges
500 V, 50 A	1,000
750 V, 100 A	100
1 kV, 200 A	50
1.5 kV, 300 A	10

TABLE 4-4. TRANSIENTS PROJECTED TO OCCUR IN 10-YEAR PERIOD ON EXTERNALLY-EXPOSED LANDLINES

Number of Surges (10-by-1000μs)	Peak Amplitude (Voltage and Current)
1,000	100 V, 50 A
500	500 V, 100 A
50	750 V, 375 A
5	1,000 V, 1,000 A

c. Operational Upset Level. The operational upset level is the transient energy level that causes a change in the electronic equipment operating state. Since a change in the electronic equipment operating state will normally create an intolerable change in associated system operation, transient protection must ensure that transient energy levels reflected to protected electronic equipment do not cause operational upset.

d. Establishing Withstand Level. To establish the electronic equipment withstand level, compare the transient energy levels that cause immediate component destruction, component overstressing, or equipment operational upset. Select the lower of the three transient energy levels, and establish the withstand level at 10% below the lowest transient energy level.

273. DETERMINATION OF NEED FOR TRANSIENT PROTECTION. Power supplies (5 to 48 V) operating from AC inputs and supplying operating power for solid-state equipment always require internal transient protection. Other electronic equipment that directly interfaces externally exposed lines, including commercial AC inputs, may or may not require transient protection designed as an integral part of the equipment. To determine whether transient protection is required, compare the electronic equipment withstand level with the transients of Table 4-2, 4-3, or 4-4, as applicable. If the equipment withstand level is above the transient amplitudes provided in the tables, equipment-level transient protection is not required. When the transient amplitudes are above the equipment withstand level, equipment-level transient protection is required, either at the AC input, other externally exposed line-equipment interfaces, or both.

274. MINIMIZING TRANSIENT DAMAGE. When electronic equipment requires protection against lightning-induced transient damage, transient suppression design must ensure that transients are attenuated to the electronic equipment withstand level prior to entering any electronic equipment component. Therefore, the transient suppression must be effective at the external line-equipment interface.

a. New Electronic Equipment.

(1) AC Inputs. The most feasible method for providing transient suppression is to design the suppression as an integral part of the electronic equipment.

(2) Other External Line Interfaces (DC to 3 MHz). The most effective method for providing transient suppression is to design low-energy level transient suppression as an integral part of the electronic equipment and specify that high-energy level

transient suppression, of a design provided by the manufacturer, be installed on applicable lines in cable demarcation junction boxes at building penetration or exterior electronic equipment termination. Total transient suppression may be designed as an integral part of the electronic equipment but caution must be exercised to ensure that a separate, dedicated path to earth ground be provided for the high-energy level dissipation section of the transient suppression.

(3) External Line Interfaces (RF Frequencies). All transient suppression must be designed as an integral part of the applicable electronic equipment. Effective transient protection can be realized by terminating all RF axial cables on a grounded metal bulkhead connector plate, except when the shield is isolated for proper electronic equipment operation. This will route transient current from the cable shields to earth ground instead of through terminating equipment to ground. (See Chapter 2, Section 6).

Transient protection components for the axial cables shall be contained in a sealed metal enclosure for each individual line. These enclosures shall have appropriate connectors at each end, permitting an in-line installation. These devices shall be as described in Chapter 2, Section 6. The protective devices shall utilize the latest state-of-the-art components having minimum effect on the signals being transmitted.

Particular attention shall be given to the impedance, insertion losses and voltage standing wave ratio for the RF signals. When installed end-to-end in ferrous metal conduits, transient protection is required only at electronic equipment entrances. When not run in ferrous metal conduits, transient protection is required at the facility entrance and electronic equipment. When this is the case, the high energy device shall be on the applicable lines, at the metal bulkhead plate at the building penetration and the low-energy transient suppression shall be installed as a part of the electronic equipment.

b. Existing Equipment. The most effective transient protection can be provided as described in Paragraphs 274a(1), (2), and (3) above. When room is not available in the existing electronic equipment to add required transient suppression components, the components can be installed in a small enclosure affixed to the chassis or cabinet rack.

275. AC POWER INPUT TO ELECTRONIC EQUIPMENT. The clamp voltage, reflected across protected electronic equipment by the secondary AC surge arrester installed at the facility service disconnecting means, when dissipating a surge, may be higher than the withstand

level for the electronic equipment. Therefore, effective transient suppression must be designed as an integral part of the electronic equipment.

a. Transient Suppression Design. To provide effective protection, equal suppression must be installed line to ground on each "hot" conductor input and the neutral input. For floating (ungrounded) line-to-line power inputs, line-to-ground and line-to-line suppression must be installed.

Suppressors installed at the electronic equipment power input should have a slightly lower turnon voltage and a slightly faster response time than suppressors of the secondary AC surge arrester at the service disconnecting means. This permits the suppressors integral to the electronic equipment to clamp short-duration overshoot voltage that occurs before the secondary AC surge arrester can turn on and clamp in response to a transient. Also, with a lower turnon voltage, the suppressors at the electronic equipment will have a lower clamp voltage for a given transient surge than the secondary arrester and thus provides optimum equipment protection.

Given these specified characteristics, the surge suppressors at the electronic equipment will tend to dissipate the occurring transient before the secondary arrester turns on. Therefore, it is imperative that an inductor be added in series with the input line. The secondary surge arrester will then turn on very rapidly after the electronic equipment suppressor(s) turn on because of the voltage increase across the inductor. The voltage increase is caused by current drain through the electronic equipment suppressors to ground.

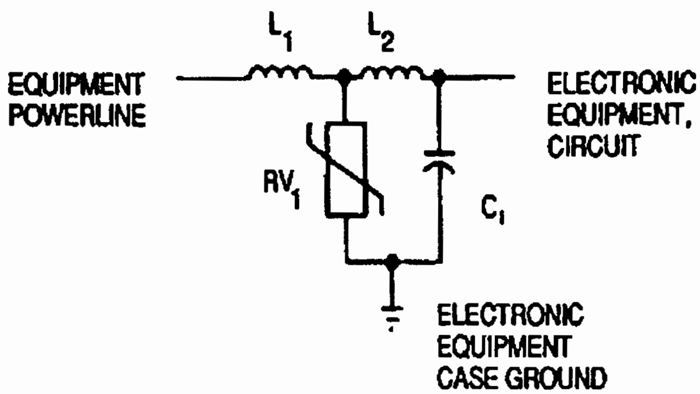
Figure 4-33 depicts a typical suppression circuit for use at the electronic equipment level on AC inputs with a neutral.

Figure 4-34 depicts a typical suppression circuit for use on ungrounded (line-to-line) inputs.

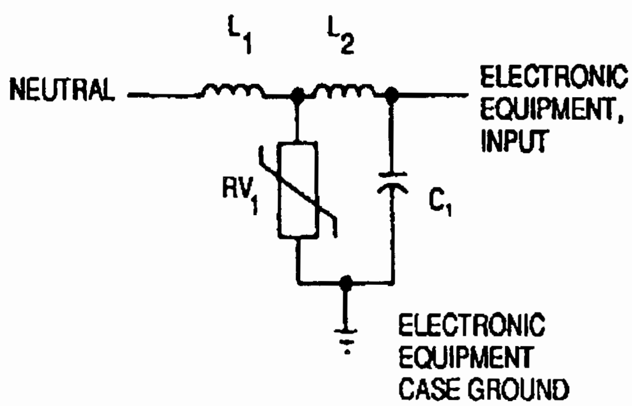
b. Components.

(1) Inductor L1. The inductor L1, shown in Figures 4-33 and 4-34, is necessary to provide a voltage increase to cause the secondary AC surge arrester at the service disconnecting means to turn on very rapidly when suppressor RV1 turns on and conducts transient current to ground. The inductor must be capable of safety passing normal operating voltages and current, and current resulting from 130% overvoltage for a period

<u>FIGURE 4-33. TYPICAL CONFIGURATION FOR PROTECTION OF ELECTRONIC EQUIPMENT FROM CONDUCTED POWERLINE SURGES & TRANSIENTS (NEUTRAL GROUNDED)</u>

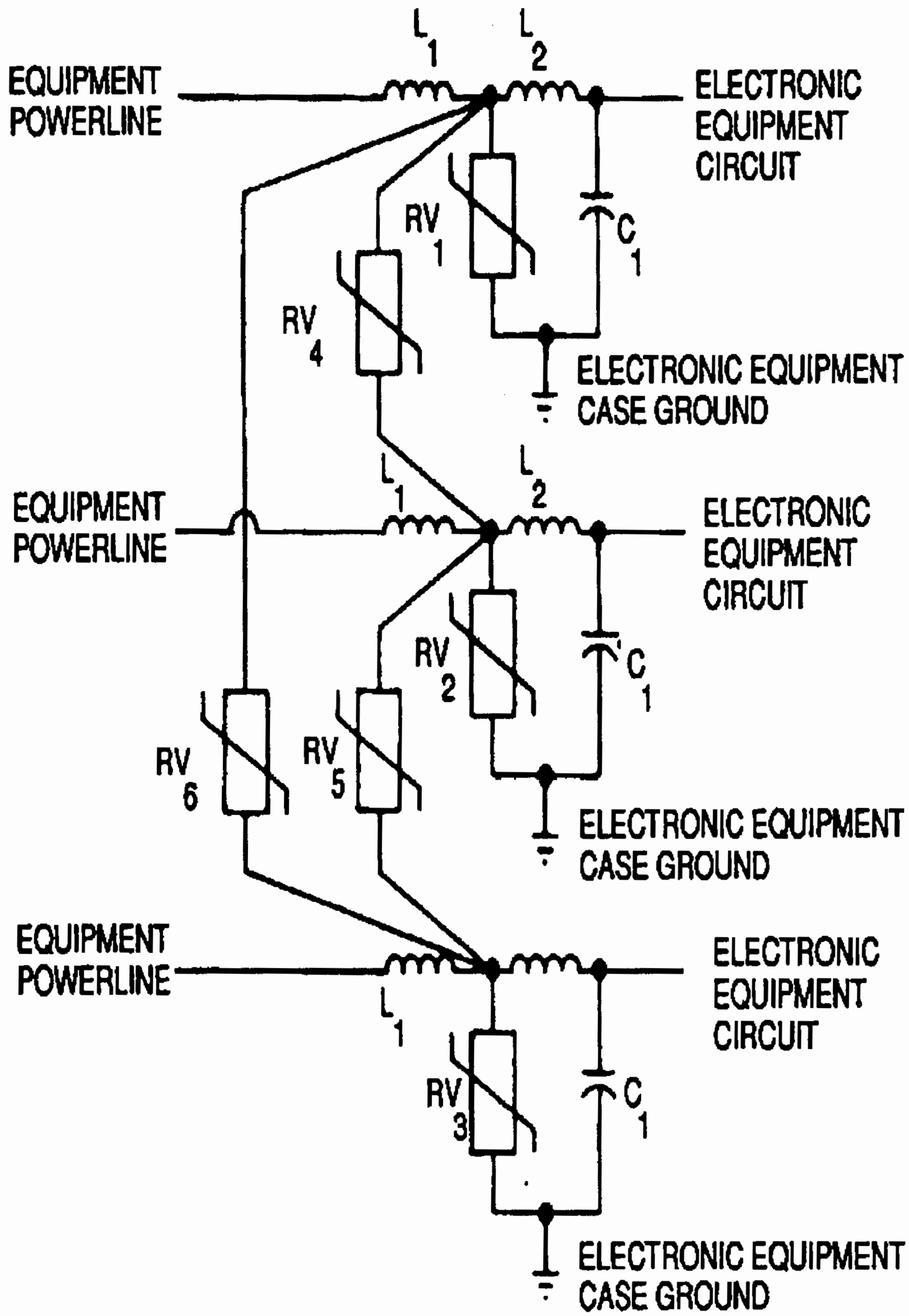


A. TYPICAL TRANSIENT SUPPRESSION FOR HOT AC INPUT TO ELECTRONIC EQUIPMENT



B. TYPICAL TRANSIENT SUPPRESSION FOR NEUTRAL AC INPUT TO ELECTRONIC EQUIPMENT

FIGURE 4-34. TYPICAL CONFIGURATION FOR PROTECTION OF ELECTRONIC EQUIPMENT FROM CONDUCTED POWERLINE SURGES AND TRANSIENTS (UNGROUNDED SERVICE)



of 50 milliseconds (ms). Also, the inductor must:

(a) Have a very low DC resistance.

(b) Present a high impedance to transient surges.

(c) Present a very low impedance to 60 Hz line voltage.

(d) Be capable of safely passing the transient current listed in Table 4-2.

(2) Suppressor RV1. Figure 4-33 shows RV1 as a metal oxide varistor (MOV) because the zinc oxide nonlinear resistor type of MOV is especially well suited for this particular application. Other types of MOV are constantly being upgraded and are now possibly suitable for use. Other devices are also suitable for use, and, in some cases will be required. Silicone avalanche diodes are effective for use in protecting very susceptible equipment. Data for different type suppressors are provided in Chapter 2, Section 6. Use of a gas-filled spark gap for use at the location of RV1 is not recommended for two reasons.

(a) Available gas-filled spark gaps with the required current handling capability have a relatively high sparkover (turnon) voltage and relatively slow turnon times. Therefore, if spark gaps are used for transient suppression at AC inputs, additional suppression including inductors, MOV and/or silicon avalanche diode suppressors must be added to provide required protection.

(b) Arc voltage for spark gaps is a nominal 20 to 30 volts. Therefore, when the spark gap turns on when a transient occurs, normal line voltage is interrupted which will usually cause operational upset of the affected electronic equipment. Also, since the arc voltage is only 20 volts and is across a 120-volt supply, the spark gap will likely remain in the arc mode of operation and draw current until the supply voltage waveform crosses 0 or until the supply circuit breaker opens. It is likely that the spark gap will be destroyed before the supply circuit breaker opens. Either condition is very undesirable.

(3) Inductor L2 and Capacitor C1. These two components form an LC network to filter out high frequency components of transient surges and are required only for electronic equipment susceptible to high frequency, very short duration (less than 1 nanosecond) transient pulses that might pass across RV1.

c. Transient Suppression Grounding. When at all feasible, transient suppressor grounds should be directly bonded to the electronic equipment case (multipoint) ground. When the direct bond is not feasible, the suppressor grounds must be connected with as short and direct a conductor as possible to the electronic equipment case (multipoint) ground, and the case must have a low bond resistance to earth ground. Otherwise, the suppressors cannot operate properly.

d. Functional Characteristics. Functional characteristics for transient suppression at the AC input-electronic equipment interface must be as follows for effective transient suppression.

(1) Voltage Characteristics. The operating (reverse standoff) voltage must be 125 +5% of normal line voltage. Turnon voltage, discharge (clamp) voltage and the amplitude and time duration of any overshoot voltage must be sufficiently low to preclude electronic equipment damage or operational upset.

(2) Leakage Current. Leakage current for each suppression component at reverse standoff voltage must not exceed 100 microamperes.

(3) Self-Restoring Capability. The transient suppressors must automatically restore to an off state when transient voltage falls below turnon voltage for the suppressor.

(4) Operating Lifetime. Electronic equipment transient suppression must be capable of safely dissipating the number and amplitude of surges specified in Tables 4-2 or 4-3 as applicable. Clamp voltage shall not change more than 10 percent over the operating lifetime.

(5) In-line Devices. Only inductors designed to have low DC resistance shall be used as in-line devices for suppression of conducted power line transients. In-line inductors shall safely pass equipment operating voltages and line current with 130 percent overvoltage conditions for a period of 50 ms.

e. Housing. Suppression components should be housed in a separate, shielded, compartmentalized enclosure as an integral part of electronic equipment design. Bulkhead-mounted, feedthrough capacitors should be used as necessary to prevent high-frequency transient energy from coupling to electronic equipment circuits. Suppression components should be directly bonded to electronic equipment case ground when at all feasible. Suppressor connections to ground must be short, straight, and direct.

276. ELECTRONIC EQUIPMENT POWER SUPPLY TRANSIENT SUPPRESSION. Power supplies (5 to 48 V dc) that operate from the facility AC power inputs and furnish operating voltage to solid-state equipment will frequently require a transient suppressor installed between the rectifier output and electronic equipment case ground. This protection (in addition to the AC surge arrester at the service disconnecting means and powerline suppression at electronic equipment entrances) is required because of the adverse electromagnetic environmental operating conditions for much FAA equipment.

A silicon avalanche diode suppressor will provide the best protection for this particular application. The silicon avalanche diode suppressor is recommended because of the very fast response time of the device, since the primary purpose is to clamp very fast risetime and very short duration transients. The silicon avalanche diode suppressor provides the lowest clamping voltage available. When this device is used, the clamped output of the transient suppression at the AC input-electronic equipment interface will be clamped to a lower level by the avalanche diode at the rectifier. This, in turn, provides optimum protection for solid-state voltage regulators and other solid-state components receiving operating voltage from the power supply. Operating characteristics for the suppressor installed at the rectifier output must be as follows if the suppressor is to provide the desired function:

a. Operating (Reverse Standoff) Voltage. Reverse standoff voltage must be 5 percent above maximum rectifier output voltage.

b. Leakage Current. Leakage current to ground should not exceed 100 microamperes at standoff voltage.

c. Turnon Voltage. Turnon voltage must be as near standoff voltage as possible using state-of-the-art suppressors, and shall not exceed 125 percent of reverse standoff voltage.

d. Discharge (Clamp) Voltage. Clamp voltage must be the lowest possible value that can be obtained using state-of-the-art suppressors not to exceed 160 percent of turnon voltage.

e. Overshoot Voltage. Overshoot voltage must be sufficiently low to preclude electronic equipment damage or operational upset. Time duration of overshoot voltage shall be limited to the shortest possible time not exceeding 2 nanoseconds.

f. Self-restoring Capability. Transient suppressors installed in power supplies must automatically restore to an off state when line transient falls below rated turnon voltage for the suppressor.

g. Operating Lifetime. The transient suppressors must safely dissipate 1000 surges with an amplitude of 200 volts above rectifier output voltage and a waveform of 10-by-20 microseconds. Ten microseconds defines the time from the start of the transient to peak voltage, and 20 microseconds is the time from the start of the transient until the transient exponentially decays to 50 percent of peak value.

277. LANDLINE TRANSIENT SUPPRESSION. When the electronic equipment withstand level is below the transient energy level projected to occur at direct landline-electronic equipment interfaces, transient suppression must be provided by electronic equipment design. Generally, all direct landline-electronic equipment interfaces will require transient suppression. However, when the landlines are totally enclosed end-to-end in ferrous metal conduits, a much lesser degree of suppression is required than when the landlines are direct earth-buried or overhead cable runs. At the time of new electronic equipment design, when provisions for transient protection must be included, the manufacturer may not know whether externally exposed landlines will be totally enclosed in ferrous metal conduits.

When the manufacturer is not conclusively certain that external landlines will be enclosed in metal conduits, designed transient protection must ensure that the electronic equipment will be adequately protected against the transient levels of Table 4-4. Subsequent paragraphs provide design guidelines for transient suppression for all types of landlines. Coaxial and twinaxial lines are treated separately. Also, externally-exposed landlines that carry signals of 3 MHz to 400 MHz are treated separately.

a. Control, Status, Intrafacility Power, and Audio Landlines. Control, status, intrafacility power, and audio lines, other than coaxial or twinaxial lines, are most effectively protected by transient suppression designed as an integral part of the electronic equipment, and specified transient suppression installed at building penetration or exterior electronic equipment termination. Effective design is shown in Figure 4-35.

(1) Suppression Design and Component Selection. Transient suppression will effectively protect electronic equipment only when proper components are selected so that the components operate in conjunction to provide the desired function. This is necessary so that the clamped output of

the suppression components/circuits can provide optimum electronic equipment protection. Actual suppression components are shown in Figure 4-35 as GT1, RV1 and RV2, and TS1. The suppression component at the electronic equipment entrance should be chosen so that it has a lower turnon and clamping voltage than the suppression component at the facility entrance. Therefore, resistor R1 must provide a voltage to turn on the suppression component at the facility entrance and limit current flow through the suppressor at equipment entrance. Otherwise, the suppression component at the facility entrance may not turn on when a transient occurs. The component will not normally turn on when a transient of less than 400 volts peak amplitude occurs and the component is a gas-filled spark gap (GT1). However, when a transient of greater amplitude occurs, the suppression component at the facility entrance must turn on. Otherwise, the suppression component at the electronic equipment entrance will attempt to dissipate the entire transient to ground. As a result, the suppression component at the electronic equipment entrance will attain a higher clamp voltage as it dissipates additional transient current. The higher clamp voltage is reflected across protected electronic equipment. In addition, the suppression component is likely to fail.

(a) Gas-Filled Spark Gap GT1. A gas-filled spark gap is suitable for use as a transient suppressor at building/facility entrance in some cases. The device has a relatively high sparkover (turnon) voltage and a relatively slow turnon time when compared with a metal oxide varistor (MOV) or silicon avalanche diode suppressor (SAS).

For typical lightning induced transients on landlines, turnon voltage is a nominal 500 volts with an associated turnon time of 5 microseconds. These characteristics are satisfactory as long as the value of resistor R1 is 10 ohms or more, and the peak pulse current rating for the suppression component at the electronic equipment entrance is not exceeded. When R1 is 10 ohms, a peak current of 50 amperes is required to provide a voltage of 500 volts across R1 which is the nominal turnon voltage for GT1. Since GT1 turns on after a nominal 5 microseconds, the peak pulse current rating for most MOV and SAS devices will not be exceeded. After the spark gap turns on, arc voltage across the device is a nominal 20 volts. This may be sufficiently below the normal line voltage to create operational upset of the protected electronic equipment, which in some cases cannot be tolerated. If normal line voltage is greater than 20 volts, difficulty may be encountered in turning off the device, depending on available current. The arc mode of operation may be sustained by current greater than 1 ampere for some devices. When the value of R1 is less than 10 ohms, an MOV or other equivalent suppressor must be used at the facility entrance because a spark gap will not turn on before the suppressor at the electronic equipment entrance is damaged by overcurrent, particularly when the suppressor at the electronic equipment entrance is a SAS.

(b) <u>Metal Oxide Varistor (MOV) RV1, RV2</u>. As shown in Figure 4-35, MOV can be used in various configurations to provide effective transient suppression. Turnon time for the MOV is less than 50 nanoseconds, and turnon voltage ranges from 22 to 1800 volts. Clamp voltage is not as low as for SAS devices and turnon time is not as fast. The turnon time for SAS devices is typically less than 10 nanoseconds, and less than 1 nanosecond in some configurations. The configuration shown in Figure 4-35c is especially effective for protecting highly susceptible electronic equipment. The configurations shown by Figures 4-35a and 4-35b provide adequate protection when the protected electronic equipment can safely withstand the rated clamping voltage for the MOV at the electronic equipment entrance. An MOV with a 20 mm element diameter will normally provide required protection at facility entrance, and a 10 mm element diameter MOV will normally provide required protection at the electronic equipment entrance. To enable desirable functioning, the turnon voltage of the MOV suppressor at the facility entrance should exceed that of the MOV at the electronic equipment entrance by approximately 10 percent. This is desirable to permit the MOV at the electronic equipment entrance to turn on and dissipate low-amplitude transients while reflecting a low clamp voltage to protected electronic equipment. When a high-amplitude transient occurs, the voltage increase across R1 will cause the MOV at the facility entrance to turn on. When the MOV at the facility entrance turns on, it dissipates most of the remaining transient energy, and the MOV at the electronic equipment entrance conducts current only as required in response to the clamp voltage reflected by the MOV at the facility entrance. Thus, the MOV at the electronic equipment will conduct only a small amount of current and maintain a low clamp voltage that is reflected across the protected electronic equipment. The MOV operating characteristics are similar to those for a pair of back-to-back zener diodes. Therefore, the device responds the same to a negative or positive transient voltage.

(c) <u>Silicon Avalanche Diode Suppressor (SAS) TS1</u>. The SAS device has the fastest turnon time of any of the three suppressor devices shown in Figure 4-35. Turnon time is typically less than 10 nanoseconds and can be less than 1 nanosecond in some configurations depending on lead length and the path to ground for the device. Turnon voltage ranges from 6.8 volts to 200 volts. Devices may be connected in series to obtain higher turnon voltages and to improve power handling capability. For example, two devices connected in series can dissipate approximately 1.8 times the power dissipated by a single device. The clamping voltage for the device is also lower than for MOV devices. The maximum clamping voltage for the SAS devices is approximately 1.6 times the turnon voltage at peak pulse current. Peak pulse current ranges from 139 amperes for a 6.8-volt device to 55 amperes for a 200 volt device over a period of 1 millisecond.

Devices recommended for use at the electronic equipment entrance have a peak pulse power dissipation rating of 1500 watts over a period of 1 millisecond. Devices are available in both unipolar and bipolar configurations. Operation of a unipolar device is very similar to that of a zener diode, and operation of a bipolar device is very similar to that for a pair of back-to-back zener diodes. For the most effective protection, unipolar devices should be used on lines that carry unipolar voltage provided the AC noise level on the applicable line is less than 0.5 volt. Use bipolar devices on lines that carry bipolar (ac) voltage and on lines with an AC noise level greater than 0.5 volt. Select SAS devices based on the reverse standoff voltage rating. The reverse standoff voltage must be greater than maximum line operating voltage, and should exceed normal line voltage by 20% when possible.

(d) <u>Resistor R1</u>. The function of resistor R1 is to provide current limiting for the suppression device at the electronic equipment entrance and to provide a turnon voltage for the suppressor at the facility entrance. Empirical evidence has shown that the power rating for the resistor should be 5 watts. The resistance value should be as high as the electronic equipment operation will permit. Typical values are 10 to 50 ohms. Values as low as 2 ohms have been successfully used. However, when the value is less than 10 ohms, the suppressor at the facility entrance must be an MOV or equivalent type suppressor.

(e) <u>Resistor R2 and Capacitor C1</u>. Resistor R2 attenuates current flow to protected electronic equipment resulting from clamp voltage of the transient suppressor at the electronic equipment entrance. The resistor also speeds up, and in some cases, generates turnon of the transient suppressor at the electronic equipment entrance. In addition, the resistor limits current drain from protected electronic equipment when a transient with polarity opposite that of the electronic equipment power supply occurs. A power rating of 1 watt is sufficient for the resistor. The resistance value should be as high as can be tolerated by applicable equipment, taking into consideration the value of resistor R1 and the impedance of the associated landline. The purpose of capacitor C1 is to filter out some high-frequency transient components, and the value of C1 should section of the equipment. This is necessary to preclude cross-coupling of transient energy to other electronic equipment circuits. The suppression components must be located so that transients are attenuated prior to entering any electronic equipment component susceptible to damage, including emi filters. Packaging design for transient suppression specified for installation at facility entrance is not critical. However, the design should provide for short, direct connection of transient suppressors between line termination and its related ground.

b. Coaxial and Twinaxial Lines. The same transients are projected to occur on externally exposed coaxial and twinaxial lines as on the control and status lines discussed in paragraph 277a. In general, the same transient protection described in paragraph 277a will provide effective transient protection for electronic equipment that directly interfaces the coaxial and twinaxial lines. That is, the most effective transient protection is provided by installing a high-energy transient suppressor and resistor at the facility entrance or exterior electronic equipment termination, with low-energy transient suppression included as an integral part of the electronic equipment as shown in Figure 4-35. Where cables are protected externally by ferrous metal conduits, protection is required only at the electronic equipment entrances. Transient suppression shall be provided equally for each conductor and shield that is not directly grounded to the electronic equipment case.

Special attention shall be given to the design of transient protection for axial lines. The design may be particularly critical at RF frequencies. Suppression circuits shall be designed using components which have minimum effect upon the signals being transmitted. In many cases, end electronic equipment connected to coaxial lines cannot tolerate added capacitance imposed by capacitor C1. Also, in most cases, the added resistance of resistor R2 cannot be tolerated. Because most end electronic equipment connected to coaxial and twinaxial lines has a relatively low withstand level, the configuration shown in Figure 4-35c, without resistor R2 and capacitor C1, should be used for transient suppression. The silicon avalanche diode suppressor TS1 should always be bipolar. The configuration shown by Figure 4-35c should be used for protection of electronic equipment that directly interfaces externally exposed twinaxial lines. In most cases, it is necessary to use a bipolar SAS since the twinaxial lines normally conduct both DC and low-level audio signals. Specific design criteria is provided in paragraphs 277b(1) and (2).

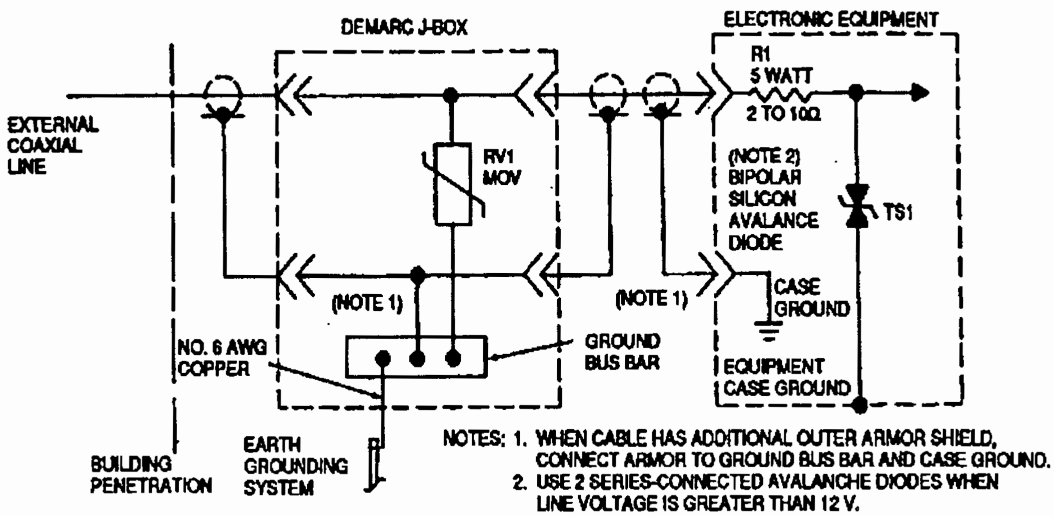
(1) Facility Entrance Suppression. The high-energy transient suppression specified for location at facility entrance

or exterior electronic equipment termination should be designed for in-line installation on applicable lines. The lines should be terminated at a metal connector plate located in a junction box at the facility entrance or exterior electronic equipment termination. Transient suppression components should be enclosed in a sealed, metal enclosure with appropriate connectors to facilitate in-line installation. The ground side of suppressor(s) in the sealed package must be connected as directly as possible with No. 12 AWG copper wire (minimum) to a ground point located on the exterior of the sealed package to facilitate connection to a ground bus or tie point in the junction box. The ground point on the exterior of the sealed package must be electrically isolated from the enclosure and the cable shield. The package for a twinaxial line must include two suppression circuits, one for each of the two center conductors. Also, when a coaxial cable shield is not directly grounded at interfaced equipment, the enclosure for in-line installation must also contain two transient suppression circuits, one for the cable center conductor and one for the cable shield. Circuit configurations for each type of line are depicted in Figures 4-36 and 4-37. Primarily because of the grounding configuration, MOV or equivalent devices should be used at facility entrance.

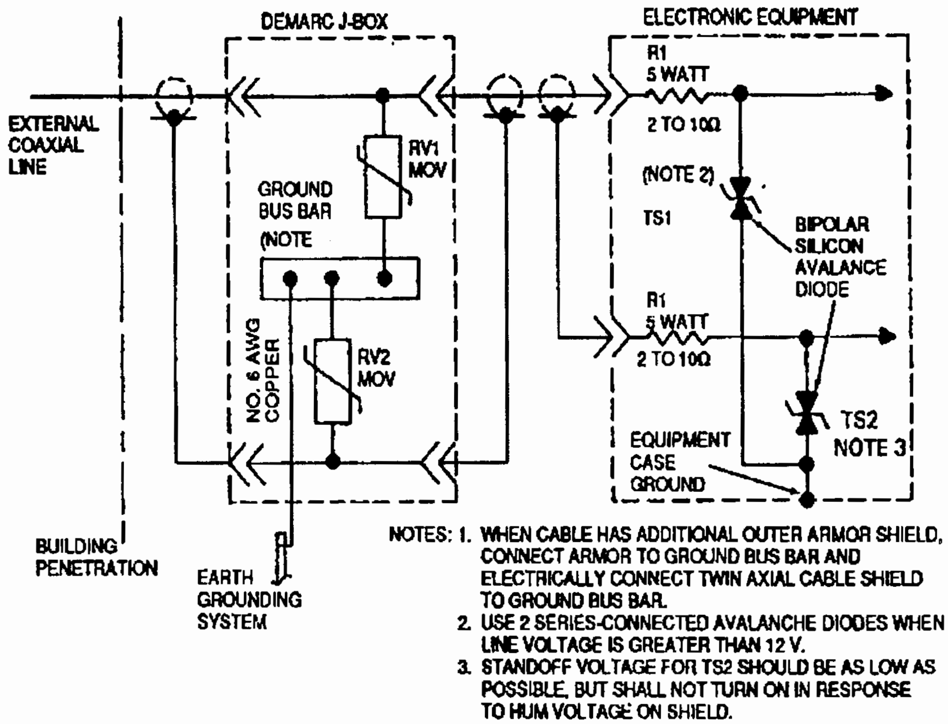
(2) Electronic Equipment Entrance Suppression. Electronic equipment entrance suppression is shown in Figure 4-36 for coaxial line-equipment interfaces. The transient suppression should be enclosed in shielded, compartmentalized areas to prevent cross-coupling of transient energy to other electronic equipment circuitry. The transient suppression must be located so that transients are attenuated prior to entering any susceptible electronic equipment components, including EMI filters. Because of the normally low withstand levels for end equipment, only bipolar avalanche diode suppressors should be used at electronic equipment entrance. However, MOV suppressors may be used when the protected electronic equipment can safely withstand the clamp voltages that will be reflected across protected electronic equipment. For the most effective protection, the ground side of transient suppressors should be bonded directly to the electronic equipment case (multipoint ground). When direct bonding is not possible, short, direct connections to the electronic equipment case must be used.

c. Transient Suppression for Lines in Metal Conduits. When externally exposed lines are enclosed end-to-end in ferrous metal conduits, the amplitude of transients projected to be conducted to electronic equipment will be attenuated a minimum of 90%. The number of transients that occur will not change. Therefore, the number of transients listed in Table 4-4 will still occur, but amplitudes will be only 10% of the amplitudes listed in Table 4-4. When the electronic equipment manufacturer is

FIGURE 4-36. TRANSIENT SUPPRESSION FOR COAXIAL LINE (DC TO 3 MHZ)

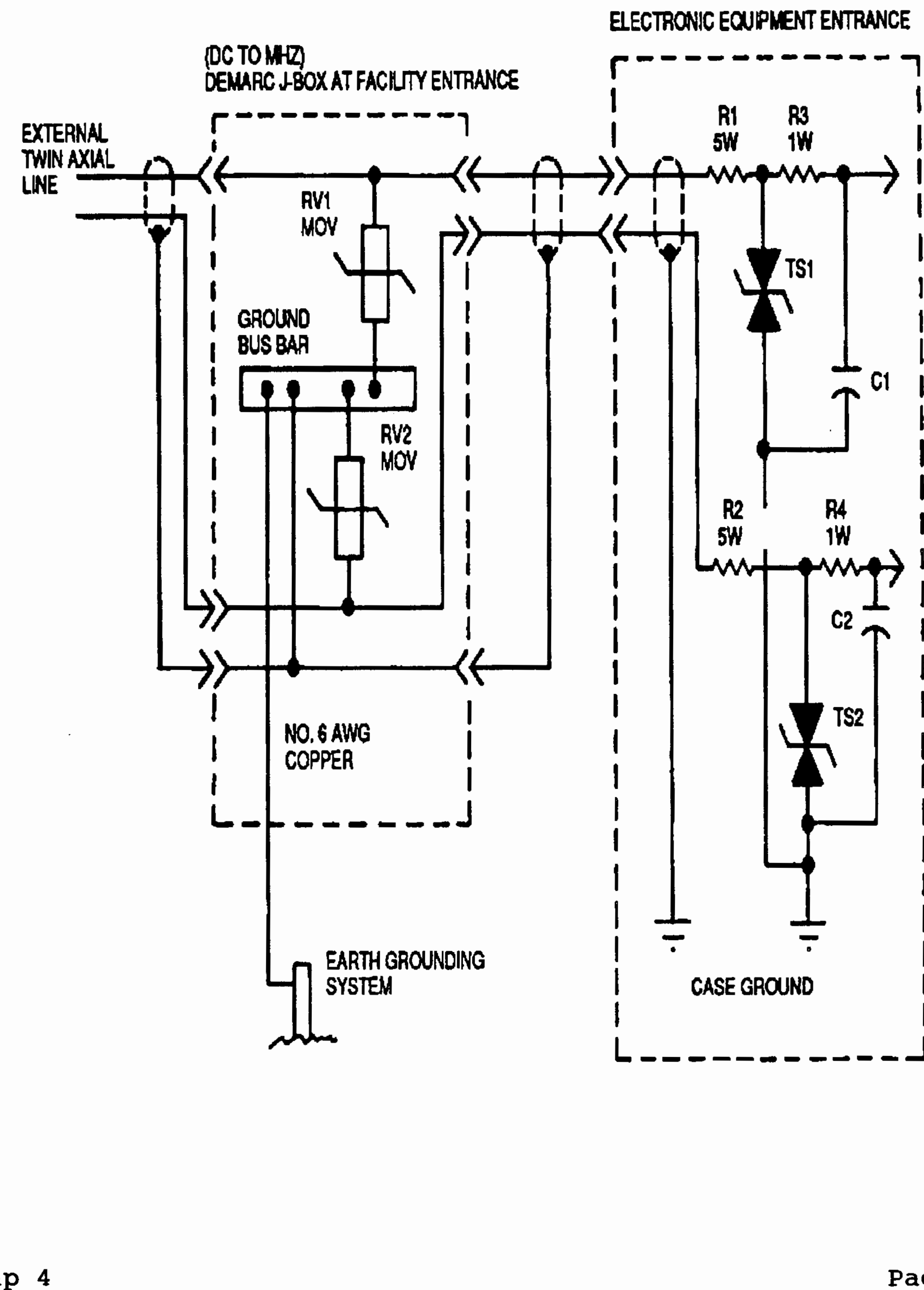


A. TYPICAL TRANSIENT SUPPRESSION FOR COAXIAL LINE
(SHIELD NOT ISOLATED FROM GROUND)



B. TYPICAL TRANSIENT SUPPRESSION FOR COAXIAL CABLES
(COAXIAL SHIELD ISOLATED FROM GROUND)

FIGURE 4-37. TRANSIENT SUPPRESSION FOR TWINAXIAL LINES (DC TO 3 MHZ)



absolutely certain that all externally exposed electronic equipment lines will be enclosed in ferrous metal conduit, total transient suppression should be designed as a integral part of the electronic equipment. The total transient suppression should consist of a 5 watt resistor in series with the landline input, and an MOV or SAS connected line-to-ground on the electronic equipment side of the 5 watt resistor.

d. Functional Characteristics. For effective transient suppression, the suppression components must have certain minimum operating or functional characteristics. These characteristics are defined in Paragraphs 277d(1) and (2) for high-and low-energy transient suppressors respectively.

(1) High-Energy Transient Suppression Characteristics.

(a) Reverse Standoff Voltage. Operating or reverse standoff voltage rating of suppressing components should not exceed 20 percent of above normal line voltage.

(b) Leakage Current. Leakage current to ground should not exceed 100 microamperes at reverse standoff voltage.

(c) Turnon Voltage. Turnon voltage should not exceed 125 percent of reverse standoff voltage.

(d) Overshoot Voltage. Overshoot voltage should be the lowest voltage that can be obtained, for the shortest time possible, using the best state-of-the-art suppressors available.

(e) Clamp (Discharge) Voltage. Clamp voltage of the transient suppressors should be as low as possible without affecting normal operation and shall be below the electronic equipment susceptibility levels when discharging a transient with a peak amplitude up to 1000 amperes.

(f) Operating Life. Transient suppressor must be capable of discharging the number of transients listed in Table 4-4 with peak amplitudes that are 90% of those listed in Table 4-4. Clamp voltage must not change more than 10% over the operating lifetime.

(g) Self-Restoring Capability. The transient suppressor must automatically restore to the off state when the transient voltage level falls below turnon voltage.

(2) Low-Energy Transient Suppressor Characteristics.

(a) Reverse Standoff Voltage. The reverse standoff voltage rating of the transient suppressor should be

20 ± 5 percent above nominal line voltage.

(b) Turnon Voltage. Turnon voltage of the suppression component at the equipment must be as close to reverse standoff voltage as possible using state-of-the-art devices, and shall not exceed 125 percent of reverse standoff voltage.

(c) Overshoot Voltage. Overshoot voltage must be the lowest value that can be obtained, for the shortest time possible, using state-of-the-art suppressors. Overshoot voltage shall be low enough to prelude electronic equipment damage or operational upset. The requirement will apply for transients with rise times as fast as 5,000v/microsecond.

(d) Leakage Current. Leakage current to ground should not exceed 100 microamperes at reverse standoff voltage.

(e) Clamp Voltage. Clamp voltage must remain below the electronic equipment withstand level while dissipating transient currents with peak amplitudes that are 10% of those listed in Table 4-4. The clamp voltage must not change more than 10% over the operating lifetime.

(f) Operating Life. The transient suppressor must be capable of safely dissipating the number of transients listed in Table 4-4, with current amplitudes that are 10% of those listed in Table 4-4.

278. - 279. RESERVED.

SECTION 7. ELECTRONIC EQUIPMENT INSPECTION AND TEST PROCEDURES

280. GENERAL. Before installing, or accepting for installation, any piece or item of electronic equipment in a facility designed or modified to meet the recommendations represented herein, the electronic equipment should be evaluated for conformance with the practices set forth in this volume. Appendix 2, although for design, may be used for guidance in accomplishing the inspection evaluation.

a. Before beginning the evaluation, determine whether the electronic equipment is designed to operate at frequencies below 100 kHz (low frequencies) or above (high frequency). In making this determination, the primary signals to consider are those which interface or communicate with other electronic equipment or systems. For example, the frequencies of control and monitor signals, communication signals, data links, and input and output RF signals should be noted. Those signals arising from internal sources and utilized only internally to a unit or piece of electronic equipment are primarily the designer's responsibility.

b. After establishing the frequency classification of the electronic equipment, inspect the low-frequency types and the high-frequency types for conformance with the recommendations contained in Section 1. Some electronic equipment will necessarily utilize both low-and high-frequency signals for interfacing purposes. For example, wideband data links frequently extend from low audio frequencies to frequencies well above 10 MHz. Such hybrid systems should also be inspected for conformance to the recommendations set forth in Section 1. Specific inspection steps and procedures for all three types of electronic equipment are contained in the following sections.

281. LOW-FREQUENCY ELECTRONIC EQUIPMENT.

a. Examine the drawings and schematics and visually inspect to see if an isolated single-point ground system as described in Section 1 is provided. Provide a brief description of the single point ground system on the inspection form or attach copies of the schematics of drawings. Verify that the internal signal reference network is a single point ground system and is terminated to an insulated signal ground terminal of a type described in Section 1 or as otherwise specified. If a wire is used, verify that the size conforms to the 500 cmil per foot criteria (or as specified). Enter the information requested on the inspection form.

b. Verify that the single point ground terminal is correctly identified (labeled or color coded green with bright yellow tracer).

c. With all cables (signal cables, control lines, power cables, etc.) disconnected, measure the resistance between the single point ground terminal and the electronic equipment case with an ohmmeter. See Figures 4-38 and 4-39. The resistance should be greater than 10 megohms. Also measure the resistance between each AC input terminal (ground wire excluded) and the case. A resistance of 10 megohms or greater should be measured.

d. Record both readings on the inspection form. If the measured resistance is less than 10 megohms, proceed as follows:

(1) First check to see that all cables, lines, cords, etc., are disconnected from the electronic equipment or that the far end of any such cables are insulated from other equipment and the structure. Disconnect all cables found still connected.

(2) If no connected cables are found or the low-resistance reading still exists after disconnecting all cables, visually inspect the mounting of the single point ground terminal to see that it is properly insulated from the case or cabinet (disassemble, if necessary). Alternately, disconnect the single point ground connection inside the electronic equipment and then measure the resistance between just the terminal and the case. If the terminal is not insulated from the case or cabinet, it must be redone so as to be insulated from the case.

(3) If the preceding two steps fail to identify the reason for the lack of isolation, the electronic equipment. schematics and mechanical layout should be analyzed and inspected to locate the compromise in the single point ground isolation. Be particularly alert for sneak paths through components (transformers, switches, relays, etc.), readout devices (meters, lights), physical contact between the case or cabinet and the single point ground, and wiring errors.

e. Measure the resistance between the equipment grounding conductor and the case. The resistance reading should be 0.1 ohm or less. If a higher resistance reading is obtained, inspect the electronic equipment to see if the equipment grounding conductor in the power cord has been connected to the case or cabinet.

If the connection is there physically, was the paint removed from the area of attachment? Are screws or nuts fastened securely? If any of these deficiencies exist, they must be corrected before installing or energizing the electronic equipment.

FIGURE 4-38. SIGNAL GROUND TERMINAL ISOLATION TEST FOR AN INDIVIDUAL ITEM OF ELECTRONIC EQUIPMENT

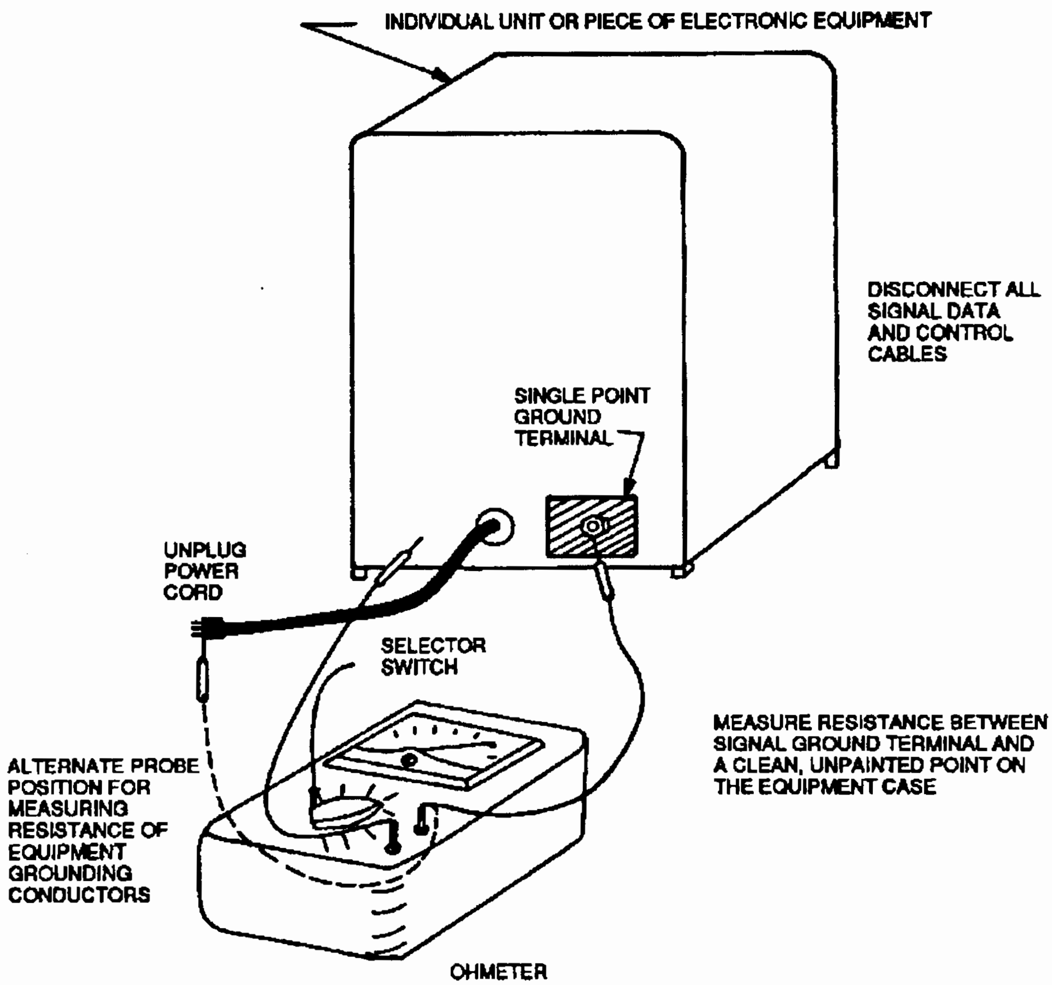
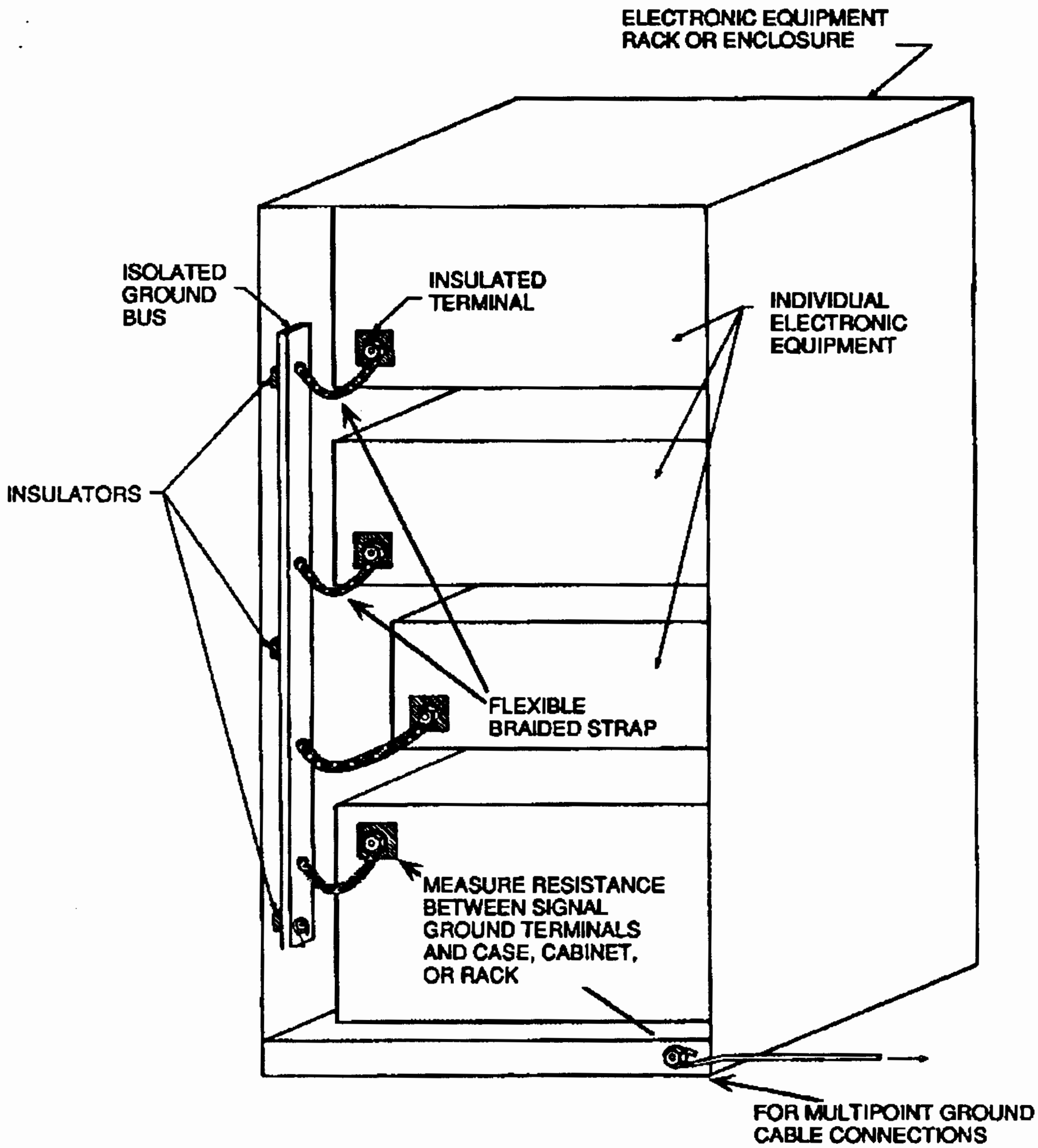


FIGURE 4-39. SIGNAL GROUND TERMINAL ISOLATION RESISTANCE TEST FOR AN ELECTRONIC EQUIPMENT ASSEMBLY



NOTE: PRIOR TO PERFORMING RESISTANCE TESTING, DISCONNECT OR UNPLUG ALL CABLES (SIGNAL, POWER, DATA, CONTROL, ETC.)

f. Inspect all cabling and connectors to see that balanced signal lines are used for low-frequency interfacing lines and that cable shields are grounded only at one end. The shields of individual cable pairs must be isolated from each other except at the common ground points. Check overall shields for grounding and accordance with Section 1. Record any specifically noted deficiencies on the Inspection Form.

g. If the electronic equipment is already installed, verify that the single point ground terminal is connected to the nearest feeder ground plate of the low-frequency single point ground system for the facility. Check the size of the cable to see that it conforms to the 500 cmil per foot criteria of Section 1 or as otherwise specified.

282. HIGH-FREQUENCY EQUIPMENT.

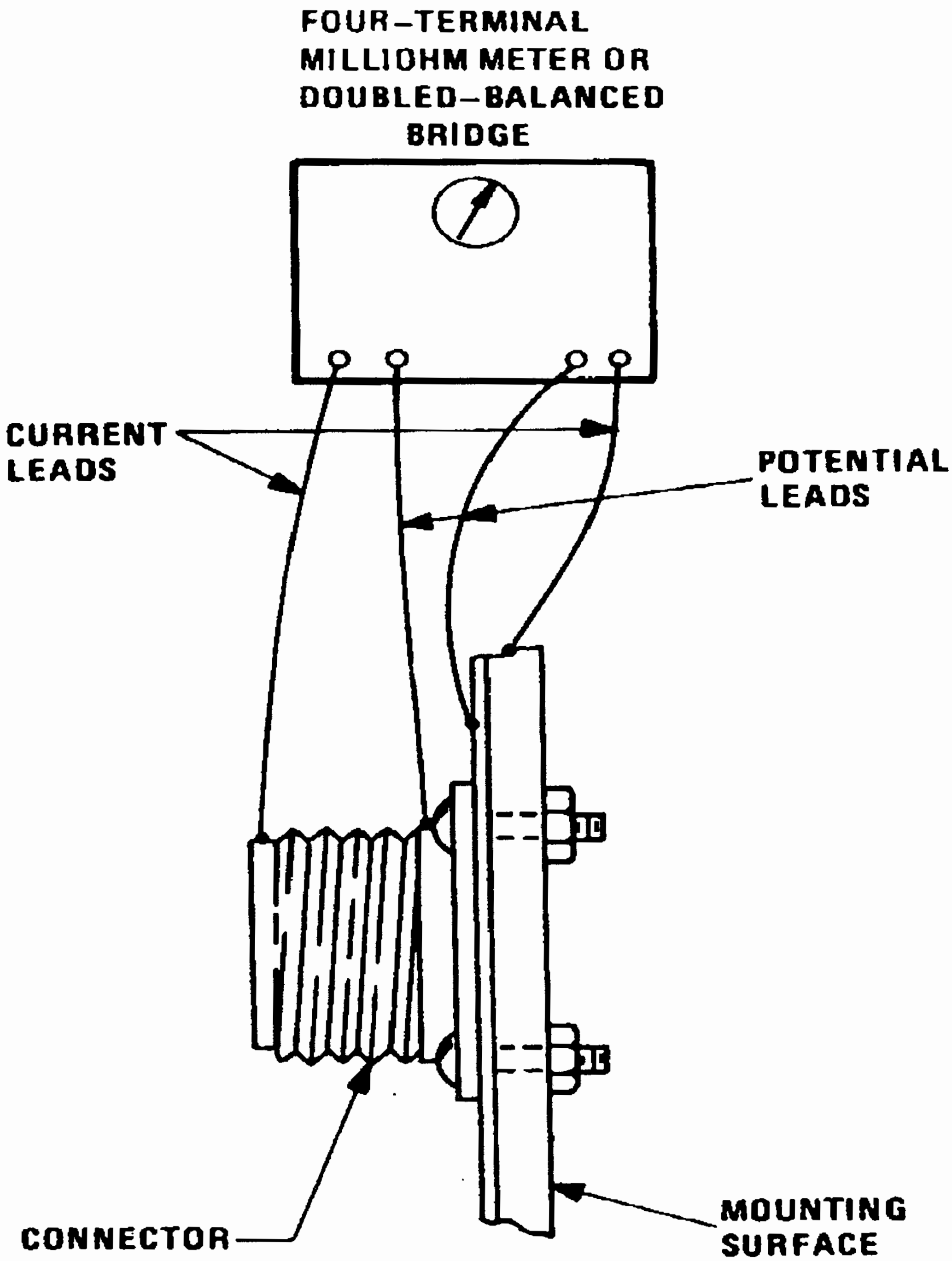
a. Verify that high-frequency (greater than 100 kHz) multipoint ground points and planes are directly grounded to the chassis and the electronic equipment case to the extent permitted by circuit design requirements and unless specified otherwise. If necessary, review Section 1 before inspecting the high-frequency multipoint grounds in the electronic equipment.

b. Check to see that proper impedance cables are used for interfacing purposes. Verify that all connectors are of a type and design that provides a low-impedance path from the signal line shield to the electronic equipment case. Do not permit the use of pigtails for the termination of high-frequency line shields outside the electronic equipment case.

c. Check connectors for tightness, cleanliness, and for proper mounting. Measure the resistance between the connector shell or body and its mounting surface with a double-balanced DC bridge as illustrated in Figure 4-40. Alternately, a four-terminal milliohmmeter may be used. The resistance should not exceed 1 milliohm. If the resistance exceeds 1 milliohm, the mounting surfaces should be recleaned to remove all paint, nonconductive coatings, or dirt, and all screws for fasteners should be retightened to achieve a close mechanical fit.

d. Measure the point-to-point resistance between selected points on the case or cabinet with the double balanced bridge. The maximum resistance between any two points on the case or cabinet should be 1 milliohm or as specified. If the resistance is greater than 1 milliohm, check to see that all bonding surfaces are properly cleaned and that all connections are securely fastened. Larger sized grounding cables may have to be added to reduce the resistance to 1 milliohm or less.

FIGURE 4-40. MEASUREMENT OF CONNECTOR BONDING RESISTANCE



e. The inspection on the Inspection and Checklist, Appendix 1, is furnished for guidance in accomplishing the above.

283. HYBRID EQUIPMENT. Before inspecting equipment utilizing both low and high-frequency interfacing signals, review Section 1. If the low-frequency (single point ground) and high-frequency (multipoint ground) signal reference networks are separate, inspect each in accordance with the preceding respective instructions. If the networks involve both low-and high-frequency signals, inspect for conformance with the high-frequency requirements. Record the results of the inspection on the inspection form.

284. INSTALLED EQUIPMENT. Check to see that installed electronic equipment, in addition, have their cases or cabinets grounded to the multipoint ground system of the facility with a cable providing at least 2000 cmil per running foot (or as specified) as described in Section 1. Part II of the Design Checklist - New Electronic Equipment, Appendix 2, is furnished for guidance in accomplishing the above.

285. EQUIPMENT GROUNDING. Verify that all exposed metal parts of the electronic equipment are properly grounded with an equipment grounding conductor as prescribed by the NEC. The size of this wire must conform to the requirements of the NEC. Convenience outlets should be grounded in the manner described in Section 1 and isolated ground pin receptacles shall not be used as convenience outlets.

286. BONDING. Refer to Section 2 as required when performing the bonding inspection.

a. Inspect all joints, seams, and connections to see that the mating surfaces were cleaned of corrosion, nonconductive finishes, and dirt prior to joining. Check fasteners for tightness. Check for combinations of dissimilar metals which create corrosion cells.

b. Do not permit sheet metal screws or Tinnerman nuts to be used for electrical bonding.

c. Where used, do bonding jumpers conform to the recommendations contained in Section 1?

d. Generally check all bonds between subassemblies, equipment, and racks for conformance with Section 2.

e. Inspect overall shield terminations for tight peripheral bonding to the connector shell. Such connections should be firm, offer maximized contact between the shield and the shell, and should be formed in a way that restricts the entrance of moisture and foreign matter into the bond area. Preferably, bonds should be protected with an adequate weather seal.

f. Inspect pigtail terminations for tightness and for excessive length. The pigtail should only be long enough to permit the connection to be made. Ensure that pigtails are not used to terminate high-frequency line shields outside the electronic equipment case.

g. Part V of the Design Checklist, Appendix 1, may be used for guidance in accomplishing the above inspection.

287. SHIELDING.

a. Examine the construction and layout of the electronic equipment carefully to see if the design guidelines contained in Section 3 have been conscientiously considered. Be particularly alert for obvious shielding deficiencies such as poorly bonded seams; very high-level (or very low-level) circuits or devices with no shielding applied; use of unshielded wire extending into or out of shielded areas; unprotected meters, jacks and other openings; unnecessarily large or unshielded ventilation ports; and the absence of gaskets or those which have been poorly installed.

b. Inspect gaskets for correct cleaning and preparation of the mounting and contacting surfaces. Check the gasket for firm and continuous contact with the mating surface upon closure. Does the gasket appear to offer sufficient resilience to withstand the repeated compression and release expected to be associated with the point where applied? Is the gasket and mating surface adequately protected against corrosion?

c. Part V of the Design Checklist - New Electronic Equipment, Appendix 2, may be used for guidance in accomplishing the above inspections.

288. INSTRUMENTATION SYSTEMS.

a. Inspect analog systems for conformance with the recommendations presented in Section 4.

b. Inspect the grounding networks of digital data systems for conformance with the recommendations of Section 4.

289. LIGHTNING-INDUCED TRANSIENT PROTECTION. Refer to Section 6 as required when performing this part of the inspection.

a. Check that adequate transient protection has been installed in electronic equipment on each conductor at AC power inputs when required to protect the electronic equipment.

b. Check that an adequate transient suppressor is installed on the rectifier output of each 5 to 48 V DC power supply that operates from commercial AC and supplies operating power to solid-state equipment.

c. Check that transient suppression is installed on externally exposed electronic equipment lines (not enclosed end-to-end in ferrous metal conduits) at the first termination after building penetration or exterior electronic equipment termination when the end using equipment is susceptible to damage from lightning-induced transients.

d. Check that all electronic equipment that directly interfaces externally exposed lines and is susceptible to damage from lightning-induced transients has adequate transient suppression installed at the line-electronic equipment interface.

e. Check that high-energy transient suppressors have short, direct paths to earth ground, and are isolated and separate from other equipment grounds.

290. EMP DESIGN.

a. Has the potential threat of an EMP event been considered in the design of the equipment? Most of the measures for EMP protection are also effective against lightning. Have measures been taken to reduce magnetic pickup? (See Order 6950.20).

b. Has extra emphasis been devoted to providing effective magnetic shields over potentially susceptible devices and components?

c. Are components and devices having high degrees of immunity of EMP (and lightning surges) used where possible?

d. Are all incoming and outgoing conductors adequately protected with fast-acting surge arresters?

291. OTHER OBSERVATIONS. As appropriate, note the existence of any personnel hazards due to deficiencies of grounding, bonding, or shielding under Part IV of the Inspection Form. Determine what type of lightning surge protection, if any, is provided on signal, control, or power lines associated with the equipment. Record all observations. Appropriate parts of the Design checklists may be used during these inspections.

APPENDIX 1. DESIGN CHECKLIST - NEW FACILITY

Facility______________________________ Date___________________________

Location______________________________ Designer_______________________

PART I - EARTH ELECTRODE SYSTEM

A. Soil Resistivity ____________(ohm-cm).

B. Calculated Resistance of designed earth electrode system: ________________ohms.

C. Design of Earth Electrode System shown on drawings:

Dimensions of Earth Electrode System indicated
Locations of other buried objects indicated _______

Risers indicated for:

Lightning Down Conductors _______

Grounding Electrode Conductor _______

Electronic System (Main Ground Plate) _______

High Energy ("A" Bus) Transient Ground _______

Building Structural Steel Columns _______

D. Design Check List (Note:- Information may be in the specifications in lieu of being indicated on the contract drawings.)

Ground rod size noted on drawings _______

No. 4/0 bare copper counterpoise cable noted on drawings _______

All connections to buried metal objects shown on drawings _______

All inaccessible joints and connections noted to be exothermic welded _______

Access (Ground) wells, if provided, shown on drawings _______

PART II - LIGHTNING PROTECTION NETWORK

A. Zone of Protection:

Profile views of facility with Zone of Protection (See Section 2.) shown in the Design Analysis.

B. UL Approved Air Terminals Noted on Drawings or Specified

Yes ________ No ________

C. UL Approved Conductors for Lightning Protection Systems Noted on Drawings or Specified Yes ________ No ________

D. Design Checklist:

	Specified or Shown on Drawings	Comments
Air Terminals		
Materials	________	________
Height	________	________
Diameter	________	________
Placement	________	________
Roof Conductors		
Size	________	________
Materials	________	________
Routing	________	________
Down Conductors		
Size	________	________
Materials	________	________
Routing	________	________
Fasteners & Hardware		
Materials	________	________
Mounting	________	________
Guards	________	________

PART III - SINGLE POINT GROUND SYSTEM

A. Configurations: Contract drawings of facility have final layout of single point grounding system indicated. ________________

B. Isolation: Specified or noted on drawings to be at least 10 megohms and that isolation test is to be made prior to final connection to the Main Ground Plate. ____

C. Design Checklist:

	Specified or Shown on Drawings	Comments
Main Ground Plates:		
Location	____________	____________
Size	____________	____________
Mounting	____________	____________
Branch Ground Plates:		
Locations	____________	____________
Size	____________	____________
Mounting	____________	____________
Feeder Ground Plates:		
Locations	____________	____________
Size	____________	____________
Mounting	____________	____________
Trunk Cable:		
Size	____________	____________
Routing	____________	____________
Length	____________	____________

	Specified or Shown on Drawings	Comments
Branch Cable:		
Size	________	________
Routing	________	________
Length	________	________
Electronic Equipment Ground Cable:		
Size	________	________
Routing	________	________
Length	________	________
Labels and Covers - Color coded green with bright yellow tracer		
Cables	________	________
Plate Covers	________	________
(Slashes in lieu of tracer)		

PART IV - MULTIPOINT GROUND SYSTEM

A. Steel Frame Buildings:

Structural joints - Correct bonding indicated on drawings or specified - See Part V below.

B. Non-steel Frame Buildings:

Supplemental Grounding Network:

	Specified or Shown on Drawings	Comments
Cable Sizes	____________	____________
Color coded	____________	____________

(Green with bright orange tracer)

Facility Ground Plates:

Size	____________	____________
Location	____________	____________

Low Resistance Paths Indicated on Drawings or Specified Between:

Equipments	____________	____________
Structural Steel	____________	____________
Raceways	____________	____________

PART V - BONDING

A. Procedures:

	Specified or Shown on Drawings	Comments
Cleaning	________________	__________________
Fastening	________________	__________________
Protection	________________	__________________

B. Torque Values:

Information from Table 2-3	________________	__________________

C. Resistance Tests of Bonds to be Made and limits:

(The following test requirements are shown on the drawings or are specified.)

Structural Steel	____________	__________________
Ground Plates	____________	__________________
Equipment	____________	__________________

PART VI - LIGHTNING-INDUCED TRANSIENT PROTECTION

A. Average Number of Thunderstorm Days Per Year: ________

B. Incoming AC Service Conductors:

	Specified or Shown on Drawings	Not Applicable
Buried lines enclosed end-to-end in watertight, rigid galvanized steel electrically continuous conduit.	________	________
Conduit connected to earth electrode system each end.	________	________
Overhead conductors have guard wire installed that provides zone of protection.	________	________
Overhead guard wire extends from service transformer secondary to service entrance fitting.	________	________
Overhead guard wire connected to ground rod each end.	________	________
Adequate secondary surge suppressor installed on incoming ac power lines at service disconnecting means, on line side.	________	________
Interconnecting cables between service disconnecting means and surge arrester short and direct with no loops, sharp bends or kinks; No. 4 AWG copper or as otherwise specified by the manufacturer of arrester).	________	________
Surge arrester ground has short, direct path to earth ground with no loops, sharp bends or kinks.	________	________

C. Externally-exposed lines with direct equipment interfaces.

Applicable	Specified or Shown on Drawings	Not
Buried cable runs of 300 feet or less enclosed end-to-end in rigid galvanized steel, watertight, electrically continuous conduit.	____	____
Conduit effectively connected to earth ground at each end.		
Buried cable runs not enclosed in metal conduit have No. 6 AWG solid copper guard wire installed a minimum of 10 in. above cable run.	____	____
Guard wire effectively connected to earth ground at each end and when over 300 feet in length, every 300 feet or portion thereof.	____	____
Buried cables enter facility in rigid steel conduit extending 5 feet past counterpoise with end of conduit bonded to earth electrode system.	____	____
High-energy transient suppressors installed line-to-ground at building penetration or exterior equipment termination.	____	____
High-energy transient suppressor components and Ground Bus for these components isolated from junction box, equipment, and electronic equipment ground system.	____	____
High-energy transient device ground bus connected to the earth electrode system with No. 4 AWG insulated copper conductor color coded green with a bright red tracer.	____	____
When total transient suppression is included at building penetration, high and low-energy level suppressors have separate paths to earth ground.	____	____

	Specified or Shown on Drawings	Not
Low-energy transient protection devices located at electronic equipment.	____________	_______
Low-energy transient protection devices ground connected to electronic equipment case (multipoint ground system).	____________	_______
Ground leads from transient protection devices as short as practical with no loops, sharp bends or kinks.	____________	_______
All axial lines terminated at effectively grounded metal bulkhead connector plate at building penetration.	____________	_______

APPENDIX 2. DESIGN CHECKLIST - NEW ELECTRONIC EQUIPMENT

Equipment
Type____

Manufacturer____________________________________

(Fill out the above items if the information is available.)

Date____________________________

PART I - ELECTRONIC EQUIPMENT GROUND SYSTEM

A. Following items of electronic equipment are connected to the single point ground system.

Equipment	Location

B. Schematic Diagram or Word Description of Electronic Equipment Ground System should be shown on the contract drawings.

(Single point or multipoint ground system and type of equipment, manufacturers' recommendations should also be noted, in justifying the type or types of electronic grounding systems of the design.)

C. Single Point Ground Terminal

Type ______________________________

Size ______________________________

Location ______________________________

D. Isolation Resistance Requirements:

Single Point Ground Terminal ______________

AC Input Terminals ______________________

E. Cables and Connectors (Justify type, isolated or case-grounded, and size of conductor).

Location	Type and Size

PART II - EQUIPMENT TO BE INSTALLED

A. Single Point Ground System conductor sizes indicated

____

B. Multipoint Ground System conductor sizes indicated

____

C. Resistance between case and facility ground system or structure specified or noted on drawings - 5 milliohms maximum __________________

PART III - ELECTRONIC EQUIPMENT GROUNDING

A. Separate Equipment Grounding Conductor Conforming to Article 250 of NEC specified and shown on drawings

____

B. Resistance Between the Power Plug Ground Terminal and the Case or Cabinet is specified or is noted on the contract drawings to be a maximum of 0.1 ohm

____

PART IV - BONDS

A. Resistance Measurements noted to be made at bonds - Maximum of 1 milliohm resistance:

Location	Specified or Noted on Drawings
______________________________	____________
______________________________	____________
______________________________	____________
______________________________	____________
______________________________	____________

PART V - SHIELDING

A. Shielding has been designed into system.

Location

- Electronic cables installed 6 Feet or more from Lightning Cables:

____

- Electronic cables separated from power cables by space in air or by installation in rigid steel conduit:

____

- Shields of low frequency signal lines specified as noted in Chapter 4:

____

- Shields on lines from high impedance DC sources specified as noted in Chapter 4:

____

- Individual shields of low frequency signal lines within a cable bundle insulated from each other:

____

- Overall shields of multiconductor cable grounded at both ends:

____

- Outer shield of multiple conductor cable grounded to the electronic equipment case:

____

PART VI - TRANSIENT PROTECTION

A. Transient suppression specified or indicated on drawings to be installed on electronic equipment ac power inputs. If none installed, note why not:

____

B. Transient suppression specified or indicated on contract drawings to be installed on rectifier output of 5 to 48 V dc power supplies:

Yes____ No____ (If No, why not?)

____

C. Transient suppression specified or noted on drawings to be installed immediately after building penetration or exterior electronic equipment termination on externally exposed electronic equipment lines (dc to 3 MHz). If none installed, note why not:

____

D. Grounding for all transient suppression devices specified or shown on the drawings.

Yes____ No____ (If No, why not?)

____

PART VII - OTHER OBSERVATIONS

A. Personnel Hazards: Any hazards to personnel that may occur while installing or maintaining equipments are indicated on the drawings.

____

B. Surge Protection: The A.C. Surge Protection device, newly furnished or existing, is indicated on the drawings (type, voltage, location (must be on line side and within 12 inches of the service disconnecting means.)

____

APPENDIX 3. INSPECTION CHECKLIST

The purpose of this Appendix is to provide an Inspection Checklist to:

a. Provide the necessary background and information to design engineers and the responsible field personnel performing the Joint Acceptance Inspection (JAI) of new facilities for Earth Electrode Systems, Lightning Protection Systems, connections and grounding of A.C. Power Surge Arresters and Electronic Landline Transient Protection Devices, and Power and Electronic Grounding Systems in the Facility.

b. Assist field personnel in the determination of adequacy for grounding of power and electronic grounding systems at an existing facility.

c. Provide pertinent information to personnel at existing facilities in trouble shooting area where "grounding problems" are suspect.

THIS CHECK LIST IS NOT INTENDED TO BE USED AS DESIGN CRITERIA. THE DESIGN GUIDANCE CHECKLIST MAY BE FOUND IN OTHER APPENDICES OF THIS DOCUMENT. ADDITIONAL GUIDANCE AND INFORMATION ON THE SUBJECT MATTER INDICATED IN PARAGRAPH a, ABOVE CAN BE FOUND IN THE RELATED CHAPTERS IN THE BODY OF THIS DOCUMENT.

The following standards, orders, specifications and codes establish the requirements for the Inspection Checklists presented in Sections 1 through 6 of this Appendix.

<u>FAA ORDER 6950.19; Practices and Procedures for Lightning Protection, Grounding, Bonding and Shielding Implementation</u>.

This order provides procedures and recommendations for use in the design of effective grounding, bonding, shielding and lightning protection of FAA electronic equipment and facilities that make up the National Airspace System. It also provides procedures for protection against damage and outages due to lightning induced surges and transients, provisions for ensuring compliance with the National Electrical Code and guidance in checking the design of the FAA installations as well as guidance in the inspection of new and existing facilities.

FAA ORDER 6950.20; Fundamental Considerations of Lightning Protection, Grounding, Bonding and Shielding.

This order provides the basic background of theory and principals associated with effective lightning protection, grounding, bonding and shielding for new and existing electronic equipments and facilities housing this equipment that make up the National Airspace System. In addition, guidelines and recommendations are provided for personnel protection, fault protection, interference reduction and electromagnetic pulse (EMP) protection.

FAA-STD-019; Lightning Protection, Grounding, Bonding and Shielding Requirements for Facilities.

The requirements specified in this standard are applicable to new construction or modifications made to existing facilities required for the installation of electronic equipment. This standard establishes the standard configuration for lightning protection, surge and transient protection, grounding, bonding and shielding for FAA air traffic control, communication, navigation and surveillance facilities. The requirements of this standard are intended to minimize electrical hazards to personnel and damage to facilities and electronic equipment due to lightning and power faults, and to minimize electromagnetic interference levels.

FAA-STD-020; Transient Protection, Grounding, Bonding and Shielding Requirements for Equipment.

This standard establishes the minimum requirements for transient protection, grounding, bonding, shielding and personnel protection at radar, navigation, communication, data processing and other electronic equipments used in the support of air traffic control and its associated functions. The intent of this standard is to minimize electrical hazards to personnel, minimize damage to equipment due to lightning transients and power faults, and to minimize electromagnetic interference levels. This standard applies to new electronic equipment or as modifications are made to existing electronic equipment

FAA-G-2100; Electronic Equipment, General Requirements.

This specification covers the general requirements for the design and construction of ground electronic equipment. It establishes the ambient conditions within which the must operate satisfactorily and reliably. The general material, process for selection, application of parts and tests required for ground electronic equipment are all covered within this specification.

FAA-C-1217; Electrical Work, Interior.

This specifications covers the minimum requirements for the interior electrical installation at FAA facilitates. Among the items related to this inspection list are grounding of the service disconnect means, facility neutral conductor, raceway grounding, equipment grounding conductors, grounding electrode conductors, connections for below grade wiring and methods, raceway support systems and color coding at FAA facilities.

FAA-C-1391; Installation and Splicing of Underground Cables.

This specification covers the minimum requirements for the installation of electrical cables buried directly in the earth or installed in an underground duct or conduit. It includes trenching, installation and splicing or joining of cables, and testing of cables for acceptability.

NFPA 70; National Electrical Code.

The National Electrical Code (NEC) sets forth requirements that constitute a standard for the practical safeguarding of personnel and property from hazards arising from the use of electricity. The NEC is not intended as a design specification. It is, however, to be used as a minimum by competent personnel in the basic design and/or installation of electrical equipment. The FAA standards, specifications and orders DO NOT violate the code, but have requirements that exceed the code due to FAA operational requirements. The code contains provisions considered necessary for safety and applies to ALL electrical work, both indoors and outdoors. Compliance with the provisions of the National Electrical Code can effectively minimize fire and accident hazards in any electrical installation, but is not necessarily efficient or adequate for good service or future expansion of electrical use. Consideration should always be given to over sizing feeders, panelboards, etc. to allow for future growth or expansion of the electrical or electronic systems.

NFPA 780; Lightning Protection Code.

The lightning Protection Code sets forth the requirements for practical safeguarding of persons and property from hazards arising from exposure to lightning. This code covers lightning protection requirements for ordinary buildings, miscellaneous structures and special occupancies, heavy duty stacks, and structures containing flammable liquids and gases. It does not cover lightning protection requirements for explosive manufacturing facilities and magazines or electrical generating, transmission or distribution systems.

UL 96A; Installation Requirements for Lightning Protection Systems.

This standard contains the basic requirements of the Underwriters laboratories, Inc. (UL) for the installation of lightning protection systems. These requirements cover the installation of lightning protection components on all types of structures with the exception of structures used for production of, handling, or storage of ammunition, explosives, flammable liquids or gases, and explosive ingredients. Electrical transmission lines and equipment are not within the scope of this standard.

SECTION 1. EARTH ELECTRODE SYSTEM

	Para.	Yes	No	?
1. Has an earth electrode system been installed at this facility?	1.1	_____	_____	_____
2. Is original site grounding survey data available at the facility?	1.2	_____	_____	_____
3. Is the present earth electrode system properly interconnected with the proper sizes and types of ground rods and conductors?	1.3	_____	_____	_____
4. Are all connections to ground rods made by exothermic welds or other FAA approved methods?	1.4	_____	_____	_____
5. Is there a bond resistance of one (1) milliohm or less?	1.4	_____	_____	_____
6. If an access well has been provided at this facility, is it properly installed and marked?	1.5	_____	_____	_____
7. Using the 62% "Fall of Potential" method does the earth electrode system measure 10 ohms or as required in the specifications?	1.6	_____	_____	_____
8. With the test probe in the same location and using the 62% Fall of Potential method above, do other connected grounds to the earth electrode system have the same resistance as measured in No. 7?	1.6	_____	_____	_____

SECTION 2. SERVICE ENTRANCE GROUNDING

	Para.	Yes	No	?
1. Is the incoming power system neutral (identified) conductor grounded at the transformer and at the service disconnecting means?	2.1	_____	_____	_____
2. Are the transformer enclosure and the service disconnecting means housing properly grounded?	2.1	_____	_____	_____
3. Is the service entrance conduit grounded at both ends?	2.2	_____	_____	_____
4. Is the grounding electrode conductor properly installed and terminated at a ground rod in the earth electrode system?	2.3	_____	_____	_____
5. Is the grounding electrode conductor properly terminated at the service disconnecting means neutral bar?	2.3	_____	_____	_____
6. Is the grounding electrode conductor properly sized?	2.4	_____	_____	_____
7. Is the ground bus properly bonded to the neutral bar and to the SDM housing in the service disconnecting means?	2.5	_____	_____	_____
8. Are all load side neutral conductors grounded only at the service disconnecting means or at the source of a separately derived system? (Neutral must not be grounded at any electrical or electronic equipments, raceways, switches, panelboards, receptacles, etc.	2.6	_____	_____	_____

4

SECTION 3. SURGE AND TRANSIENT PROTECTION EQUIPMENT GROUNDING

	Para.	Yes	No	?
1. Verify that the proper A.C. surge protection device is installed at the facility.	3.1	_____	_____	_____
2. Is the A.C. power surge protector installed as close as practical to (within 12") and on the line side of the service disconnecting means?	3.2	_____	_____	_____
3. Is the A.C. power surge arrester installed with the shortest lead lengths possible, keeping the number of bends to a minimum and without any loops, sharp bends or kinks?	3.3	_____	_____	_____
4. Verify that phase, neutral and equipment grounding conductor of the A.C. surge protector are properly installed.	3.3	_____	_____	_____
5. Is the connection from the A.C. surge protector to the earth electrode system sized No. 4 Awg and installed as direct and short as possible without any loops, sharp bends or kinks (or to the neutral bus in the service disconnecting means where the neutral bus is properly connected to the earth electrode system)?	3.3	_____	_____	_____
6. Is the ground bus (A Bus) of the high-energy lightning transient suppression device connected directly to the earth electrode system with a No. 4 Awg conductor, color coded green with a red tracer and installed without any loops, sharp bends or kinks?	3.4	_____	_____	_____
7. Is the ground bus of the low energy lightning transient suppression device connected directly to the electronic equipment multipoint ground system?	3.4	_____	_____	_____

SECTION 4. ELECTRICAL GROUNDING

	Para.	Yes	No	?
1. Are all equipments grounded with equipment grounding conductors that are color coded green?	4.1	_____	_____	_____
2. Are the equipment grounding conductors run in the same raceway with and sized properly for the related phase and neutral conductors?	4.2	_____	_____	_____
3. Are all metallic raceways electrically continuous from end to end?	4.2	_____	_____	_____
4. Are all equipment grounding conductors properly terminated?	4.3	_____	_____	_____
5. Are all wiring troughs and electrical enclosures properly grounded?	4.2	_____	_____	_____
	4.3	_____	_____	_____
6. Where isolated ground receptacles are utilized for the reduction of electrical noise, are they identified with an orange color located on the face of the receptacle?	4.4	_____	_____	_____
7. Where used, are the isolated ground receptacles (No. 6 above) installed in accordance with the requirements of the National Electrical Code and as noted in this Order?	4.4	_____	_____	_____

SECTION 5. ELECTRONIC GROUNDING SYSTEMS

	Para.	Yes	No	?
1. Is the Main Ground Plate connected to the earth electrode system with the shortest conductors possible?	5.2	_____	_____	_____
2. Is the Main Ground Conductor properly terminated at both ends?	4.3	_____	_____	_____
3. Does the low-frequency electronic equipment designated as single point grounding have an isolated ground terminal?	5.2	_____	_____	_____
4. Is the Feeder Ground Plate of the single point grounding system properly installed and marked?	5.2	_____	_____	_____
5. Is the Branch Ground Plate of the single point grounding system properly installed and marked?	5.2	_____	_____	_____
6. Is the single point ground cable properly terminated at single point grounding system plates (Branch and Equipment Ground Plates)?	5.2	_____	_____	_____
7. Is the single point ground cable properly color coded?	5.2	_____	_____	_____
8. Is the multipoint ground cable properly color coded?	5.3	_____	_____	_____
9. Is the multipoint ground cable properly terminated at the equipment?	5.3	_____	_____	_____
10. Is a supplementary ground plate installed on the opposite side of the building from the Main Ground Plate and adequately connected to the Earth Electrode System?	5.4	_____	_____	_____
11. Is the TELCO ground properly terminated to the facility ground system?	5.5	_____	_____	_____

SECTION 6. LIGHTNING PROTECTION

		Para.	Yes	No	?
1.	Are all air terminals UL approved for lightning protection?	6.1	______	______	______
2.	Are all air terminals properly supported?	6.2	______	______	______
3.	Are all air terminals at the proper elevation?	6.3	______	______	______
4.	Are air terminals properly spaced for their height above the object to be protected?	6.3	______	______	______
5.	Are all air terminals properly interconnected?	6.4	______	______	______
6.	Are all exterior metal objects subject to flashover (within 6 feet of a down conductor) properly bonded to the roof or down conductors?	6.9	______	______	______
7.	Are the exterior metal objects subject to a direct lightning strike properly bonded to the roof conductor? If the metal thickness of these metal objects is less than 3/16 thick, do they have air terminals mounted on it and are they properly bonded to the structure lightning protection conductors?	6.8	______	______	______
8.	Does each air terminal have a minimum of two paths to the earth electrode system?	6.5	______	______	______
9.	Are all the down conductors installed properly and are they external to the facility building?	6.6	______	______	______
		6.7	______	______	______
10.	Are all down conductor properly bonded to the ground rods in the earth electrode system?	6.10	______	______	______

	Para.	Yes	No	?
11. Are all conductors compatible with the materials on which they are installed?	6.11	_____	_____	_____

NOTE: The following are brief synopses of the subjects that can be found in ORDER 6950.19A. Additional information can be found regarding each item in its related Chapter and Section of the text.

1. EARTH ELECTRODE SYSTEM

1.1 An earth electrode system shall be installed capable of dissipating the energy of direct lightning strikes, dissipating DC, AC, and RF currents, and conducting power system fault currents, to earth.

1.2 A site survey may be made for existing facilities if data is not otherwise available. The four-probe method using a Biddle earth tester should be used. Measurements should be made at distances of 10, 20, 30 and 40 feet. All survey data should be made a permanent record of the facility and kept with the drawings pertinent to the facility.

1.3 The Earth Electrode System shall consist of ground rods, a counterpoise cable forming an enclosed loop on the ground rods, and approved connections. The ground rods shall be 3/4 inch diameter x 10 feet in length, copper clad steel installed with the top of the ground rod at least 12 inches below the finished grade. The ground rods shall be interconnected by the counterpoise cable which shall be a bare No. 4/0 Awg. copper conductor buried at least two feet below the grade. The ground rods shall be located outside of the dripline of the building.

1.4 Connections to the ground rods shall be by exothermic welds or by use of FAA approved pressure connectors (Burndy Hyground or equivalent below grade except for lightning protection system connections). The structural steel of the building shall be connected to the earth electrode system at every other column around the building at intervals averaging not more than 60 feet, with bare No. 4/0 Awg. copper conductors. All underground metallic pipes and tanks and telephone grounds shall be connected to the earth electrode system by means of a bare copper conductor sized not smaller than No. 2 Awg. All bonding resistances measured using a Biddle digital low resistance ohmmeter (or equivalent) shall be one (1) milliohm or less for each bond.

1.5 An access well may be provided for large facilities. The access well shall have a removable cover which can be locked. The access well shall be located at a ground rod (not having a lightning protection system down conductor connected to the ground rod) as near the central location of the facility as possible. This access well may be used for the connecting the electronic grounding systems to the Earth Electrode System and for the connection of future grounding (excluding lightning protection) systems to the Earth Electrode System.

1.6 Using the Fall of Potential Method, use the tester to establish the resistance plot indicating how the earth electrode system is performing. During the tests, lead C2 should remain stationary and P2 moved to make new measurements.

2. SERVICE ENTRANCE

2.1 The incoming A.C. power system neutral conductor must be grounded at the service disconnecting means using a grounding electrode conductor (See 2.3 below) This same neutral conductor must also be bonded to the transformer case and connected to a ground rod installed at the transformer location.

2.2 The underground service entrance conduit shall contain only the service conductors including the neutral conductor. Rigid galvanized (heavywall) steel conduit shall be grounded at both ends in accordance with the NEC.

2.3 A grounding electrode conductor shall be used to connect the neutral conductor in the service disconnecting means to a ground rod in the earth electrode system. This grounding electrode conductor shall be installed in one continuous length, without splice or joint. Metal enclosures for the grounding electrode conductor shall be made electrically continuous by bonding each end of the enclosure to the grounding electrode conductor in accordance with the requirements of the NEC.

2.4 The grounding electrode conductor shall be sized in accordance with the NEC except that in no case shall it be smaller than No. 4 Awg.

2.5 The ground bus in the service disconnecting means shall be bonded to the neutral bar in the service disconnecting means using a bonding jumper sized no smaller than the grounding electrode conductor.

2.6 The neutral conductor shall not be connected to ground other than in the service disconnecting means.

3. SURGE AND TRANSIENT PROTECTION DEVICES

3.1 Refer to the contract drawings pertaining to A.C. surge protection equipment for the proper type and installation procedures.

3.2 The A.C. surge protection device shall be installed as close as practical (not more than 12 inches away) and shall be connected to the line side of the service disconnecting means.

3.3 The leads from the A.C. surge protection device shall terminate on their respective phase buses and the neutral bar in the service disconnect means. The connection from the element output terminal in the A.C. surge arrester shall be connected direct to the grounded neutral bus in the service disconnecting means. The case of the surge protector and the conduit nipple between the surge protection unit and the service disconnecting means shall be bonded to ground in the service disconnecting means via a No. 6 AWG green insulated equipment grounding conductor. All leads shall be as short as practicable and shall not have any loops, sharp bends or kinks.

3.4 Where the transient protection devices for electronic equipment landlines are both located in a junction box installed at the landline entrance to the facility specifically for the protection against lightning induced transients, there is an "A" bus on the high energy input side and a "B" bus on the low energy output side of the transient protection devices. The "A" bus shall be isolated and shall be connected directly to the earth electrode system with an insulated conductor color coded green with a red tracer and the "B" bus shall be terminated on the multipoint ground system at the electronic equipment case with an insulated conductor color coded green with a bright orange tracer. Where the high energy device and the low energy devices are separate components, the high energy devices shall be located where the landlines enter the building and the low energy devices shall be located at the electronic equipment. The high energy device ground connections shall be isolated from all grounds except the earth electrode system to which it will be connected with an insulated conductor color coded green with a bright red tracer. The low energy device grounds shall be mounted directly on the electronic equipment case (multipoint ground system).

4. ELECTRICAL GROUNDING

4.1 All equipment having an A.C. power feeder shall be grounded with an equipment grounding conductor run with the related phase and neutral conductors. (Reference the National Electrical Code, ARTICLE 250, for equipment that must be grounded.) The equipment grounding conductor shall be color coded green.

Conductors larger than No. 6 Awg. other than white or natural gray, may be permanently reidentified as an equipment grounding conductor by the installation of a green tape or green paint at each end and wherever visible throughout the run.

4.2 The path to ground shall be permanent and continuous. It shall have the capacity to safely conduct any fault current likely to be impressed on it and shall have low impedance to limit the voltage to ground and to facilitate the operation of the protection device in the circuit. The equipment grounding conductor shall be run in the same raceway as its related phase and neutral conductors. All power raceways shall be electrically continuous and shall be solidly connected to the equipments at both ends of the raceway with UL approved fittings.

4.3 Grounding conductors shall be connected by pressure UL approved connectors, clamps or other FAA approved means. Connection devices or fittings that depend on solder shall not be used. A connection shall be made between the one or more equipment grounding conductors and a metal box by means of an approved grounding device.

4.4 Isolated Ground Pin Receptacles installed in accordance with ARTICLE 250-74, exception 4, shall only be permitted where approved for the purpose. This type of receptacle requires two (2) equipment grounding conductors, both run in the same raceway as its related phase and neutral conductors. The first equipment grounding conductor shall be connected to the isolated ground pin of the receptacle and this equipment grounding conductor shall be permitted to pass through one or more panelboards without connection to the panelboard grounding terminals, so as to terminate directly at an equipment grounding conductor terminal of the applicable derived system or service. This equipment grounding conductor shall be color coded green with yellow and red bands at each end and wherever it passes through a box. The second equipment grounding conductor shall ground the outlet box housing and shall be run and this equipment grounding conductor shall terminate on the ground bus in the panelboard housing the circuit protection device for the receptacle. This equipment grounding conductor shall be color coded green.

5. ELECTRONIC EQUIPMENT GROUNDING SYSTEMS

5.1 The Main Ground Plate is the connection point in the facility for the connection of the electronic equipment grounding systems to the Earth Electrode System of the facility. This grounding conductor shall be installed so as to have the most direct and shortest path to the earth electrode system. There are two types of electronic equipment grounding systems that are connected to the Main Ground Plate. One is designed for low frequency electronic equipment and the other is for high frequency electronic equipment. The type of electronic equipment ground system is determined by the manufacturer of the equipment. Either or both types of electronic grounding systems may be found in a facility.

5.2 The low frequency ground system is known as the single point ground system and is totally isolated from all other grounds, power and electronic, except at the Main Ground Plate. The single point ground system and multipoint ground systems are interconnected only at the Main Ground Plate for the connection to the earth electrode system. Separate single point ground systems shall also be kept isolated from each other except at their individual connections to the Main Ground Plate. Each low frequency electronic equipment unit shall have an isolated single point ground conductor originating at an isolated terminal in or in the equipment and terminating on an isolated ground plate located near and convenient to the equipment noted as the Feeder Ground Plate. Where there are numerous electronic equipment units or lengthy conductor runs, several Feeder Ground Plates may be connected via insulated conductors to individual terminations on an isolated ground plate noted as the Branch Ground Plate. There may be more than one Branch Ground Plate, each serving Feeder Ground Plates. When this occurs, the Branch Ground Plates are tied directly to each other (See Figure 2-23, Chapter 2 of this Order) with the last in line from the equipments tied directly to the Main Ground Plate. All of the conductors noted herein are insulated conductors, installed so as to be completely isolated from any other equipments, grounding systems, building structure, etc. These conductors for the Single Point Ground System shall be color coded-green with a bright yellow tracer from the Main Ground Plate to their terminations on single point equipments. The conductor from the Main Ground Plate to the Earth Electrode System shall be an insulated 500 MCM conductor, properly bonded at both ends.

5.3 The high frequency ground system is known as the Multipoint ground System. This ground system includes the electronic equipment cases, frames, etc., conduits containing the conductors to the high frequency equipments, high frequency electronic equipment ground plates (Not Single Point System Ground Plates), and building structural steel. It is also interconnected to the electrical equipment grounding conductor at the electronic equipment housing. This multipoint grounding conductor CAN NOT be used in place of or as a substitute for the electrical equipment grounding conductor. It is isolated from the single point ground system except at the Main Ground Plate. The

Multipoint Ground System conductor shall be color coded green with a bright orange tracer.

5.4 A supplementary ground plate shall be provided on the opposite side of the building from the main ground plate. This supplementary ground plate is connected to the earth electrode system with a 500MCM or equivalent copper conductor, not exceeding 50 feet in length, that provides a second path to the earth electrode system from the multipoint ground system. This conductor is exothermically welded to the earth electrode system and bolted to the supplementary ground plate with an UL approved connector. Connections are made between the supplementary ground plate and the electronic equipment, the electronic equipment ground plates and the structural steel of the building so that there is a minimum of two paths to ground throughout the multipoint ground system.

5.5 Telco ground must be connected to the facility ground system.

6. LIGHTNING PROTECTION

6.1 A lightning protection system consists of air terminals, roof and down conductors, bonding conductors, fittings, connectors, ground rods, and all connections required throughout the system. All materials shall be in accordance with the requirements of the Underwriters Laboratories (UL) for lightning protection components and shall be marked in accordance with the requirements of the UL.

6.2 Standard Drawing D-6075-107, Air Terminal Assembly, shows an excellent method of supporting an air terminal. The air terminal is well braced and it has the down conductor from the base of the air terminal properly attached to the air terminal support. The elevation of the air terminal can be easily varied by utilizing the proper length of pipe. Use only heavy wall, rigid metal pipe for this application.

6.3 The tip of the air terminal shall be at least 10 inches above the object to be protected. Spacing of air terminals less than 24 inches high is not more than 20 feet and spacing of air terminals 24 inches or higher is not more than 25 feet on ridges of pitched roofs and around the perimeter of flat or gently sloping roofs.. Each air terminal that is more than 24 inches in height shall be supported at a point not less than one-half (1/2) its height.

6.4 All air terminals shall be interconnected as required by the Lightning Protection Code, NFPA 780, to insure that each air terminal has at least two paths to ground (except where one path is permitted by the code).

6.5 Not less than two down conductors shall be provided for buildings or structures (except for pole type structures where only one down conductor is required). The down conductors will be as widely separated as practicable.

6.6 A lightning protection conductor that is run through ferrous material (conduit, tubing, or molding) shall be bonded to each end of the ferrous material.

6.7 Conductors shall be securely attached to the object upon which they are placed. Fasteners shall be spaced not more than three (3) feet apart on all conductors and they shall be compatible with the structure material. Conductors shall maintain a horizontal or downward course. No bend in a conductor shall form an included angle of less than 90 degrees nor have a radius of less than 8 inches.

6.8 Metal objects subject to direct lightning strikes shall be bonded to the lightning protection system. Where the metal object has a thickness of 3/16 of an inch or greater, the metal object need only be bonded to the lightning protection system utilizing main size conductors and bonding plates having a minimum of three square inches of contact. Such connections shall provide a two way path to ground as is required for air terminals. Where the metal thickness of the object is less than 3/16 inch thick, air terminals shall be provided so that no outside corner of the object being protected is less than two (2) feet from an air terminal. The air terminals shall be connected to the structure lightning protection system utilizing main size cable in such manner that a two way path to earth is provided from each air terminal on the metal object.

6.9 Metal objects within 6 feet of a main conductor and subject to a buildup of potential (sideflash or flashover) shall be bonded to the closest point of the lightning protection system using UL approved fittings and secondary bonding conductors.

6.10 Approved method of below grade connection is that the down conductor must be terminated on a ground rod in the earth electrode system utilizing exothermic welds. (Pressure type connectors are not acceptable for bonding of underground connections for lightning protection.)

6.11 Copper lightning protection materials shall not be installed on aluminum roofing, siding or other aluminum surfaces. Aluminum lightning protection materials shall not be installed on copper surfaces. Aluminum materials shall also not be in contact with earth, a surface coated with alkaline-based paint, embedded in concrete or masonry, or installed in a location subject to excessive moisture.

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