

METRIC

MIL-STD-1542B (USAF)

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SUPERSEDING

MIL-STD-1542A (USAF)

Dated 01 MAR 88

**MILITARY STANDARD**

**ELECTROMAGNETIC COMPATIBILITY  
AND  
GROUNDING REQUIREMENTS  
FOR  
SPACE SYSTEM FACILITIES**



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FOREWORD

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## SECTION 1

### SCOPE

#### 1.1 PURPOSE

The purpose of this standard is to specify the design, performance, and verification requirements for electrical subsystems for space system facilities, including electromagnetic compatibility (EMC), electrical power, grounding, bonding, shielding, lightning protection, and TEMPEST security. These requirements are interrelated and interdependent, and therefore require an integrated approach in the design.

#### 1.2 APPLICATION

This standard is intended primarily for use in design and construction contracts for space system facilities. The requirements are applicable to all related facilities including, but not limited to, launch complexes, tracking stations, data processing rooms, satellite control centers, checkout stations, spacecraft or booster assembly buildings, and any associated stationary or mobile structures that house electrical and electronic equipment. The requirements are not intended to be applicable to Long Hall/Tactical Communication System Facilities (see MIL-STD-188-124A). The technical requirements for Ground Support Equipment (AGE) used in direct support of space vehicles are contained in MIL-STD-1541. The technical requirements for equipments installed in ground facilities (not a part of the facility) are contained in MIL-STD-461.

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SECTION 2

REFERENCED DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this standard to the extent specified herein:

MILITARY SPECIFICATIONS:

MIL-E-4158	Electronic Equipment Ground: General Specification For
MIL-F-15733	Filter, Radio Interference, General Specification for

MILITARY STANDARDS:

MIL-STD-188-124	Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communications Systems
MIL-STD-220	Method of Insertion-Loss Measurements
MIL-STD-285	Attenuation Measurement for Enclosures, Electromagnetic Test Purposes, Method of
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-463	Definitions and Systems of Units, Electromagnetic Compatibility Technology
MIL-STD-889	Dissimilar Metals
MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Systems

MILITARY HANDBOOKS:

MIL-HDBK-419	Grounding, Bonding and Shielding for Electronic Equipments and Facilities
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OTHER GOVERNMENT DOCUMENTS:

AFM 88-4	Facility Design & Construction (AIR FORCE MANUAL 88-4)
AFP 91-38	Maintenance of Electrical Grounding Systems (AIR FORCE PUBLICATION 91-38)
FIPS PUB 94	Guidelines on Electrical Power for ADP Applications (Federal Information Processing Standard Publication 94)
NACSIM 5203 (C)	Guidelines for Facility Design and Red/Black Installation (U)
NACSEM 5204 (C)	Shielded Enclosures (U)

(Copies of specifications, standards, handbooks, drawings, and publications required by contractors in connection with specified acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 NONGOVERNMENT DOCUMENTS

The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or request for proposal shall apply.

**American National Standards Institute:**

ANSI C 84.1-1982	Power Systems - Voltage Ratings for Electric Power Systems and Equipment (60 Hz)
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Application for copies should be addressed to:

American National Standards Institute,  
1430 Broadway,  
New York, N.Y. 10018

**National Association of Corrosion Engineers:**

NACE Std. RP-01-69	Recommended Practice - Control of External Corrosion on Underground or Submerged Metallic Piping Systems.
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Application for copies should be addressed to:

National Association of Corrosion Engineers,  
P.O. Box 218340,  
Houston, TX 77218.

National Fire Protection Association:

NFPA No. 70                      National Electrical Code  
NFPA No. 78                      Lightning Protection Code

Application for copies should be addressed to:

National Fire Protection Association,  
Batterymarch Park,  
Quincy, MA 02269

(Nongovernment standards and other publications are normally available from the organizations which prepare or which distribute the documents. These documents also may be available in or through libraries or other informational services.)

### 2.3 ORDER OF PRECEDENCE

In the event of a conflict between the text of this standard and the references cited herein, the text of this standard shall take precedence. However, nothing in this standard shall supersede applicable laws and regulations unless a specific exemption has been obtained.

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SECTION 3  
DEFINITIONS

Electromagnetic compatibility (EMC) terms are as defined in MIL-STD-463. Other terms are in accordance with the following definitions:

3.1 FACILITY.

A facility is a building or other structure, either fixed or transportable in nature, with its utilities, ground networks, and electrical supporting structures. All wiring and cabling that is provided under terms of the facility contract are considered to be part of the facility. Any electrical and electronic equipments required to be supplied and installed by the facility contractor are also part of the facility.

3.2 SPACE SYSTEM FACILITY.

A space system facility is an earth-based facility that houses technical equipment for the operational support of a military space system. The technical equipment may be electrical, electronic, mechanical, optical, or any combination.

3.3 FACILITY GROUND NETWORK.

The facility ground network is a network of conductors that form direct low impedance paths between earth and various power, communications, and other equipments to effectively extend an approximation of ground reference throughout the facility. The facility ground network is comprised of four subsystems as follows:

- a. Earth Electrode Subsystem. The earth electrode subsystem is a network of electrically interconnected rods, mats, or grids installed in the earth for the purpose of establishing a low impedance contact with the earth.
- b. Lightning Protection Subsystem. The lightning protection subsystem is a low impedance path for lightning energy to the earth electrode subsystem. Air terminals must be provided to intentionally attract the leader lightning strike. Roof and down conductors carry the high currents away from susceptible elements in the facility and limit voltage gradients developed by the high currents to safe levels.

- c. Equipment Fault Protection Subsystem. (Facility Ground). The equipment fault protection subsystem is a set of ground return conductors (green wires) that provide a current path to structure and the earth electrode subsystem of sufficient capacity so that protective devices (fuses and circuit breakers) can operate properly to protect personnel from shock hazard and equipment from damage. It also encompasses all earth referencing of all noncurrent-carrying metallic objects such as piping, ducts, conveyances, structural steel, air conditioning equipment, electric motor frames, electronic enclosures, etc.
  
- d. Signal Reference Subsystem (Technical Ground). The signal reference subsystem, or technical ground, is a network of conductors that provide the ground reference for all technical equipment used for operational support. It provides the ground reference for the signal circuits for the technical equipment that is related directly to the military space system. It may consist of a low frequency grounding network (single point grounding), or high frequency grounding network (multipoint grounding) or a combination thereof. The signal reference system shall not be used in lieu of safety ground conductors (green wires) as a path for fault currents.

### 3.4 LOW FREQUENCY CIRCUITS.

For the purposes of this standard, low frequency electrical and electronic circuits are those that operate in the frequency range from dc to 30 kilohertz.

### 3.5 HIGH FREQUENCY CIRCUITS.

In this standard, high frequency electrical or electronic circuits are those that operate above 30 kilohertz.

### 3.6 SINGLE POINT GROUNDING.

Single point grounding is a method of circuit and shield grounding in which each circuit of the system or subsystem has only one physical connection to a ground reference subsystem, ideally at the same point for a given system or subsystem. Single point grounding is effective only for low frequency circuits where it is applied to prevent return currents from flowing in structural elements resulting in ground loops and ground reference potential differences. Power distribution circuits utilize single point grounding. (See Figure 1)



### 3.7 MULTIPOINT GROUNDING.

Multipoint grounding is a method of circuit and shield grounding which provides multiple low impedance paths for high frequency signals to an equipotential plane constituting the ground reference for high frequency signals and signal transmission circuits. Multipoint grounding requires the existence of an equipotential ground plane (See 3.8). Multiple connections are made to the equipotential plane for high frequency circuits by the shortest, lowest impedance method. High frequency circuits utilize multipoint grounding to the earth electrode subsystem.

### 3.8 EQUIPOTENTIAL PLANE.

An equipotential plane is a mass or surface of metal (solid or grid) that offers a negligible impedance to current flow so that differences in electrical voltage are minimized across the plane (see Figures 2 and 3). An equipotential plane is considered an earth ground for a signal reference subsystem (technical ground) regardless of its elevation from physical earth. The equipotential plane has multiple connections to structural steel and to the earth electrode subsystem.

### 3.9 TECHNICAL POWER.

Technical power is the electrical power supplied to power circuits of technical equipment used for the operational support of a military space system, such as: checkout equipment, test equipment, communications equipment, and data processing equipment. Surge loads and electromagnetic interference are limited to prevent damage or malfunction of electrical or electronic equipment. Large motors required to operate technical equipment are not connected to technical power circuits.

### 3.10 FACILITY POWER.

Facility power is the electrical power supplied to a facility for lighting, heating, air conditioning, large surge loads, large electric motors, and other station-keeping functions.

### 3.11 CATHODIC PROTECTION.

A technique to prevent corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

3.12 PRIMARY POWER.

Primary power is the electrical power supplied to a facility from a utility or generation source.

3.13 SECONDARY POWER.

Secondary power is electrical power that has passed through a conditioning device such as a transformer or converter.

3.14 UNINTERRUPTIBLE POWER SYSTEMS (UPS)

An uninterruptible power system is a back-up electrical power system to provide continuous electrical power for a period of time in the event of the failure the main power source.

3.15 LOW LEVEL SIGNAL LINES

Low level signal lines are those that have maximum voltages of less than one volt.

SECTION 4

GENERAL REQUIREMENTS

4.1 ELECTRICAL POWER CHARACTERISTICS.

When commercial electrical power quality or reliability is not sufficient to meet the program requirements, alternate methods such as dedicated power generation, power conditioning, motor generators, or uninterruptible power systems (UPS) shall be evaluated and utilized as required to meet the program needs.

4.2 ELECTROMAGNETIC COMPATIBILITY.

Facility electrical and electronic subsystems and equipment shall be compatible with each other as well as with the technical equipment installed in the facility for support of space system operations. To achieve this goal with a high probability of success the imposition of conducted and radiated EMI limits on the facility equipment is required.

4.3 SHIELDING.

Shielding shall be provided for the protection of circuits, equipment, and groups of equipment; for electromagnetic compatibility within the system; and to comply with security (TEMPEST) requirements.

4.4 FACILITY GROUND NETWORK.

All space system facilities containing electrical or electronic technical equipment shall have an earth-referenced facility ground network. The facility ground network shall consist of the following electrically interconnected subsystems:

- a. The earth electrode subsystem.
- b. The lightning protection subsystem.
- c. The equipment fault protection subsystem.
- d. The signal reference (technical ground) subsystem.

These items together constitute the total grounding network for the facility. The grounding of either fixed or mobile facilities shall comply with the criteria of MIL-HDBK-419.

#### 4.5 ELECTRICAL BONDING.

Electrical bonding is the procedure by which the conductive surface of a component or subassembly is electrically connected to another in a manner which provides a low impedance path between them. This reduces the development of electrical potentials between the interfacing surfaces for frequencies capable of causing interference. Low impedance bonding shall be provided as required for safety, for electromagnetic compatibility within the system, and to comply with security (TEMPEST) requirements.

#### 4.6 FILTERING.

Filtering shall be provided for the purpose of establishing electromagnetic compatibility, TEMPEST, or shielded enclosure integrity. The design, performance, and testing of EMI filters shall be in accordance with the requirements specified herein.

SECTION 5  
DETAILED REQUIREMENTS

5.1 ELECTRICAL POWER.

5.1.1 Electrical Power Characteristics. Power quality requirements cannot be imposed on commercial power sources when these are utilized for space system facilities. If commercial power quality is not sufficient to meet program requirements, power conditioning equipment shall be provided. Unless otherwise specified, power conditioning equipment including motor generators, uninterruptible power subsystems (UPS), and dc power supplies shall comply with Part 9 of MIL-STD-461 and operate successfully to provide the following power source environment:

- a. Voltage Regulation       $\pm 5$  percent no-load to full-load with power factor ranging from 1.0 to 0.8 lagging
- b. Frequency Regulation    $\pm 1$  Hertz for 60 to 400 Hz
- c. Harmonic Distortion    5 percent total
- d. Transients              MIL-STD-461 Part 3, Paragraph 5.2
- e. Distribution Voltage    Standard commercial voltages in accordance with ANSI C 84.1 shall be utilized, but not less than 480 volts.
- f. Transformer            Unless otherwise specified, the electrical power transformer shall be a DELTA-WYE configuration.

5.1.2 Electrical Power Distribution

5.1.2.1 Technical Power. The technical power feeders from the main power distribution panel shall be isolated by separate transformers from facility power feeders. Multiple technical power transformers shall be used to isolate power circuits between users and subsystems to provide electromagnetic compatibility. User transformers shall be the isolation type. Technical power characteristics shall comply with MIL-E-4158.

Guidelines for technical power for computer facilities are contained in AFM 88-4 and FIPS PUB 94.

5.1.2.2 Facility Power. Facility power feeders from the facility main power distribution panel shall be in separate conduits from technical power feeders and serve separate distribution buses.

5.1.3 Power Grounding.

5.1.3.1 Primary Utility Power. Primary power neutrals shall be grounded to the equipment fault protection subsystem only at the service disconnect means, as shown in Figure 1 and Figure 8. Transformers supplying technical equipment shall be of the isolation type (i.e., primary windings mechanically and electrically isolated from the secondary winding), with electrostatic shielding incorporated. Transformers shall be DELTA-WYE. Neutral/return side power switching shall not be used. Further guidance for power grounding is provided in AFP 91-38.

5.1.3.2 Secondary Power. Secondary power that is converted from primary utility power shall have dc resistance isolation of 1 megohm or greater between the secondary and primary power measured at the transformer terminals. The various secondary power subsystems shall have dc resistance isolation of 1 megohm or greater between each other. Secondary power neutrals shall be single-point grounded to the equipment fault protection subsystem at the transformer or at the load as system requirements dictate. Sensitive electronic equipment shall be powered through a shielded isolation transformer to a technical equipment bus.

5.1.3.3 Ground Fault Circuit Interrupters. Receptacle outlets for 120-volt single phase (15- and 20-ampere) shall have ground fault circuit interrupters (GFCIs) where required for personnel protection by the National Electrical Code, Articles 210 and 215, (NFPA No. 70).

5.1.3.4 Power Sources. Rotary or other power sources shall have their frames and cases bonded to the equipment fault protection subsystem. Load current and voltage unbalance among phases shall be limited as indicated in FIPS PUB 94.

5.1.3.5 Thermostats and Heaters. The control of primary power by a thermostat is permitted only through a relay; the relay shall be EMI suppressed and shielded. The relay and thermostat case shall be referenced to the equipment fault protection subsystem. The metal case of the associated step-down transformers shall also be referenced to the equipment fault protection subsystem. Connections between a

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thermostat and the control relay shall utilize a shielded twisted pair of wires, with the shield grounded at both ends. The shield shall not be used to carry current intentionally.

5.1.3.6 Small Power Tools. Small power tools shall have a case ground connection provided from the tool chassis to the wall receptacle or shall be double insulated.

5.1.3.7 Shop Equipment. All items such as motor case equipment frames shall be bonded to the equipment fault protection subsystem in accordance with requirements stipulated in MIL-HDBK-419.

5.1.3.8 Voltage Regulators and Transformers. Voltage regulators and transformers used for voltage regulating shall have their frames and cases bonded to the equipment fault protection subsystem.

5.1.3.9 Power Control and Switching Equipment. All power circuits, switch gear, motor control, and control center distribution panels shall be bonded, shielded, and grounded to provide for the attenuation of radiated interference. All metal parts shall be bonded to the equipment fault protection subsystem.

## 5.2 ELECTROMAGNETIC COMPATIBILITY.

5.2.1 Facility Interference Limits. Unless otherwise specified, the conducted and radiated requirements of MIL-STD-461 shall apply as follows to facilities electrical equipment:

- a. Parts 1 and 3 for Fixed and Mobile Ground Facilities Equipment (Class A3). See Table 4-1 of MIL-STD-1541 for Types of Equipment.
- b. Parts 1 and 7 for Noncritical Ground Areas (Class B - Shop Equipment)
- c. Parts 1, 9, and 10 for Electrical Power Equipment (Such as generators and UPS)

Commercial off-the-shelf (COTS) equipment that is installed as a part of a facility shall meet the requirements specified in Part I of MIL-STD-461.

5.2.2 EMC Testing. Compliance with Paragraph 5.2.1 requirements shall be determined by tests performed in accordance with MIL-STD-462 or contracting officer approved test plans.

### 5.3 SHIELDING.

5.3.1 General. Shielding shall be utilized along with other basic interference control measures such as filtering, wire separation, wire twisting, circuit layout, spectrum control, and frequency assignment to achieve electromagnetic compatibility within and between systems. The degree of shielding shall be determined by the systems engineering analysis process to meet the requirements of this standard and of the system.

#### 5.3.1.1 Wire Shielding.

5.3.1.1.1 General. A double, triple, or solid conduit shield shall be used where a single overall shield is not adequate. Shields shall not be used as intentional current-carrying conductors, except for high frequency transmission lines.

5.3.1.1.2 Grounding. High frequency shields (coax, twinax, shielded twisted pairs, and multiconductor cable shields) shall be grounded at both ends and at every point where a discontinuity exists at metal enclosures. Low frequency circuit shields shall be grounded at one end only; at the source end for interference-generating circuits and at the load end for interference-sensitive circuits. The shield shall maintain continuity through metallic enclosures and panels. High frequency shields shall be grounded circumferentially to or inside connectors or equipment enclosures with no discontinuities in the external shield.

5.3.1.1.3 Isolation. Except for solid conduit shields, shields shall be isolated from each other and from any metallic component by at least 1 megohm (dc) when shield grounds are lifted. Except as may be specified in the contract, solid conduit shields shall not be isolated from each other or from structure.

5.3.1.1.4 Wire and Cable Routing. The routing and layout of wires and cables shall be performed in a manner that does not jeopardize the integrity of the equipment shield. Cables or wires carrying high level signals shall be routed a minimum of 0.1 meters (4 inches) from level power signal lines. Power lines shall be separated from sensitive digital or other susceptible circuits. Power distribution wiring shall be in steel conduit, cable trays, or raceways.

#### 5.3.1.2 Shielded Equipment Enclosures.



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5.3.1.2.1 Materials and Workmanship. Equipment shields shall be constructed of materials that provide the required attenuation of electromagnetic interference. Materials shall be corrosion resistant and compatible as defined by MIL-STD-889. Materials and workmanship shall be in accordance with MIL-HDBK-419.

5.3.1.2.2 Gaskets. Conductive gaskets, finger stock, or other sealing devices shall be installed on all doors, covers, joints, seams, or other closures that require frequent opening to the extent necessary to provide electromagnetic compatibility in their intended environment. Door sealing devices shall withstand 10,000 open-close cycles without maintenance and retain the required attenuation. Beyond 10,000 cycles, maintenance procedures and periodic testing to retain the required attenuation shall be developed and documented.

5.3.1.2.3 Filters. Filters shall be installed where required for interference control on power, control, and signal lines in a manner that maintains the integrity of the shield. Filters shall comply with the requirements of MIL-F-15733 and Paragraph 5.5 of this Standard.

5.3.1.2.4 Access or Ventilation Openings. All access or ventilation openings shall be covered in accordance with the criteria of MIL-HDBK-419.

### 5.3.1.3 Shielded Rooms.

5.3.1.3.1 General. Shielded rooms shall be provided when required for the control of National Security Information (Red/Black Criteria) signals or to provide a quiet electromagnetic environment for operation or testing of electrical and electronic devices. Shielded rooms shall meet the requirements of this standard as well as the requirements of Appendix B of NACSEM 5204 and Appendix O of NACSIM 5203. The attenuation requirements of the shield room walls, doors, and penetrations shall be as specified in the above referenced documents or as specified in the contract. Welded rooms shall be welded by means of the Metal Inert Gas (MIG) arc welding process. Welders shall be certified for the MIG welding process.

5.3.1.3.2 Doors. Doors that utilize finger stock shall be of the recessed contact design. The recessed contact shall provide protection and wiping action shall be provided to maintain a low impedance contact. The cycling and maintenance requirements of Paragraph 5.3.1.2.2 shall apply.

5.3.1.3.3 Grounding. Internal and external grounding of the circuits and the shielded room shall be in accordance with Figure 4 and MIL-HDBK-419. High frequency grounding inside the shielded room shall be by welding to the inside of the shielded room wall. If low frequency (single point) grounding is required inside shielded areas, it shall be provided by the user, and the ground shall be at a single point as shown in Figure 4. The exterior of the room shall be grounded to the earth electrode subsystem and structure at multiple points. Cable size shall be in accordance with Paragraph 5.4.1.6.

5.3.1.3.4 Transformers and Filters. Transformers and filters may be located on either the outside or inside wall of the shielded room. The external enclosures of these units shall be bonded to the shield wall in either case.

5.3.1.3.5 Penetrations. Penetrations shall be made in a manner which meets the operational function while maintaining the integrity of the RF shield. All shielded room penetrations shall meet the requirements of Appendix B of NACSEM 5204 and Appendix O of NACSIM 5203. Warranty requirements of these documents shall apply.

5.3.1.3.6 Quality Assurance. All seams and penetrations shall be tested during construction to validate seam welding quality by means of "sniffer" type EMI test equipment that has been approved by the contracting officer.

5.3.1.3.7 Testing. The shield attenuation testing shall be performed in accordance with MIL-STD-285, MIL-STD-220 and Appendix B of NACSEM 5204. Test frequencies and test point locations shall be as specified in the contract, or in a test plan approved by the contracting officer. The receiving antennas shall be positioned and oriented for maximum signal pickup.

#### 5.4 FACILITY GROUND NETWORK.

##### 5.4.1 Earth Electrode Subsystem.

5.4.1.1 General. An earth electrode subsystem shall be installed at each space system facility to provide a low impedance path to earth for lightning and power fault currents, and to ensure that hazardous voltages do not occur within the facility. This subsystem shall be capable of dissipating to earth the energy of direct lightning strikes with no ensuing damage to itself. This subsystem shall also interconnect all driven electrodes and underground metal objects of the facility. The earth electrode subsystem for either fixed or mobile facilities shall be designed in accordance with MIL-HDBK-419.

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5.4.1.2 Earth Resistivity Survey. The design of the earth electrode subsystem shall be based on an earth resistivity survey conducted at the site prior to the detailed design. The magnitude of earth resistivities shall be measured and recorded. Natural features such as rock formations and underground streams, as well as man-made features that have an effect on earth resistivity, shall be recorded. This data shall be documented as a part of the facility design data.

5.4.1.3 Resistance to Earth. The dc resistance to earth of the earth electrode subsystem shall be 10 ohms or less. Lower earth electrode subsystem resistance shall be considered for areas that have high lightning incidence to lower the probability of equipment damage. Where 10 ohms or less cannot be obtained with the basic electrode configuration due to high soil resistivity, rock formations, or other terrain features, alternate methods for reducing the resistance to earth shall be considered. These considerations include, but are not limited to, the following:

- a. Increasing the number of ground rods.
- b. Use of longer rods.
- c. Use of horizontal wires or grids instead of vertical rods.
- d. Lowering of the soil resistivity through chemical enhancement. (See AFP 91-38)

This Standard, MIL-HDBK-419, and MIL-STD-188-124 do not recommend the use of deep wells for the achievement of lower impedance to earth. Deep wells do achieve low dc resistance, but have very small benefit in reducing ac impedance. The objective of the earth electrode subsystem is to reduce ac and dc potentials between and within equipments. If deep wells are utilized as a part of the earth electrode subsystem grounding net, the other portions of the facility ground network shall be connected to them.

If a separate power source (substation) earth electrode subsystem is utilized, the resistance to earth shall not exceed 10 ohms. MIL-HDBK-419 provides further information on earth electrode subsystems design and the reasons therefore.

5.4.1.4 Earth Electrode Subsystem Configuration. The basic earth electrode subsystem shall consist of driven ground rods uniformly spaced around the facility and placed 0.6 to 1.8 meters (2 to 6 feet) outside the drip line of structures. The rods shall be interconnected with number 4/0 AWG (American Wire Gage) bare copper cable buried at least 0.6 meters (2 feet)

below grade (see Figure 5 and 6). The interconnecting cable shall be welded to each ground rod and close on itself to form a complete loop. MIL-HDBK-419 provides additional guidance for the design of earth electrode subsystems. All structural steel columns shall be connected to the earth electrode subsystem by number 4/0 AWG bare copper cable and all connections shall be welded.

**5.4.1.5 Ground Rods.** Ground rods shall be copper clad steel, a minimum of 3 meters (10 feet) in length, spaced apart not more than twice the rod length, and shall not be less than 19.0 millimeters (0.75 inches) in diameter. Difficult installation conditions may require shorter rod lengths. The thickness of the copper jacket shall not be less than 0.3 millimeters (0.012 inches). If deeper rods are required to meet the earth resistivity requirements of Paragraph 5.4.1.3, threaded rod extensions of the same specifications may be used. Extension joints shall be welded.

**5.4.1.6 Ground Conductors.** The lightning down conductors, the signal reference conductor, and the equipment fault protection conductors shall be welded to the earth electrode subsystem. The cross sectional area of the ground conductors shall be 2,000 circular mils per running foot (3.32 square millimeters per meter) and shall not be smaller than number 4/0 AWG.

**5.4.1.7 Power Transformer Grounding.** Utility power shall be grounded to the earth electrode subsystem only at the neutral of the secondary of the subsystem transformer or service disconnect as required by NFPA 70.

**5.4.1.8 Ground Isolation.** Low frequency signal reference subsystems (technical ground) shall be isolated from other ground subsystems except at connection to the earth electrode subsystem.

**5.4.1.9 Service Structures.** Metallic structures, such as service towers, umbilical towers, and cherry pickers, shall be connected to the nearest earth electrode subsystem ground plate by number 4/0 AWG bare copper cable or tubing. The grounding cable shall be as short as possible and not exceed 30 meters (100 feet).

**5.4.1.10 Service Structure Tracks.** The roll-back tracks shall be grounded by connecting a number 4/0 AWG bare copper cable or equivalent tubing to the nearest earth electrode subsystem ground rod, cable, or plate. The grounding conductors shall be as short as possible and not exceed 30 meters (100 feet), and must meet the criteria of paragraph 5.4.1.6.

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5.4.1.11 Launch Pad Structure. The launch pad structure shall be electrically bonded in accordance with Paragraph 5.6 and shall be grounded to the earth electrode ground subsystem by number 4/0 AWG (minimum) bare copper cables. The grounding cables shall be as short as possible and shall must meet 30 meters (100 feet).

5.4.1.12 Passageways. The homogeneous bonding of the metal network of the interconnecting passageways shall be grounded by connecting the network of passageways to the building structure by number 4/0 AWG bare copper cable. The grounding cable shall be as short as possible and shall meet the criteria of paragraph 5.4.1.6.

5.4.1.13 Security and Perimeter Fences. All security and perimeter fences shall be grounded according to procedures outlined in MIL-HDBK-419.

5.4.1.14 Cathodic Protection. Cathodic protection of underground pipes or structures shall be designed and installed in accordance with the guidance provided in MIL-HDBK-419 and NACE Standard RP-01-69. Cathodic protection subsystems shall be isolated from the earth electrode subsystem.

5.4.1.15 Testing.

5.4.1.15.1 Resistance Measurements. The resistance to earth of the earth electrode subsystem shall be measured by the fall of potential method (see MIL-HDBK-419) during dry surface soil conditions prior to completion of construction of structures, in order to comply with the requirements of Paragraph 5.4.1.3. Dry surface soil is defined as no rainfall during the previous three-day period. Under dry surface soil conditions, it is recommended that resistance to earth measurements be made at least at three month intervals for the first year and at 21 month intervals thereafter. For additional test information, see MIL-HDBK-419.

5.4.1.15.2 Cathodic Protection. Cathodic protection subsystems shall be tested for compliance, and maintained, using the criteria and methods established by NACE Standard RP-01-69.

5.4.2 Lightning Protection Subsystem.

5.4.2.1 Buildings and Structures. Lightning protection shall be provided for all space system facilities and structures including, but not limited to, substations, technical equipment buildings, towers, antennas, and masts.

**5.4.2.2 Air Terminals (Lightning Rods).** Air terminals shall be designed and installed in accordance with NFPA No. 78, MIL-HDBK-419, and Figure 7 of this Standard. Refer to MIL-HDBK-419 and NFPA No. 78 for air terminal placement on nonflat-roof configurations and to Figure 7 for air terminal placement on flat-roofed structures.

**5.4.2.3 Roof and Down Conductors.** The roof and down conductors shall be number 4/0 AWG minimum bare copper cables and shall comply with requirements of paragraph 5.4.1.6 and shall be spaced not more than 15 meters (50 feet) apart (see Figure 7). Roof and down conductor spacings of Figure 7 also apply to nonflat-roof configurations. Down conductor bends shall have a radius greater than 200 millimeters (8.0 inches). Down conductors shall be located external to structures. Each down conductor shall be connected only to the structural steel only at the base of the building by welding, that conductor in turn is connected to the earth electrode subsystem by welding. A minimum of two conductive paths shall exist between air terminals and the earth electrode subsystem. All down conductors shall have a ground rod at the base of each down conductor (Fig. 6). All buried cables shall be connected to ground rods at 15 meter (50 foot) intervals.

**5.4.2.4 Structural Steel.** Substantial metal structural elements of buildings and towers shall be acceptable substitutes for lightning down conductors provided they are bonded in accordance with Paragraph 5.6.5 and the buildings do not contain sensitive electronic equipment. The air terminal cables shall be welded or brazed to the peripheral steel columns of the building. The bases of the steel columns shall be connected to the earth electrode subsystem by number 4/0 AWG bare copper cables. Multiple structure lightning ground systems shall be connected together by a minimum of two conductors conforming to paragraph 5.4.1.6.

**5.4.2.5 Waveguide Grounding.** As a minimum, all waveguides located external to buildings shall be grounded as follows:

- a. Waveguide to antennas shall be grounded as a minimum to the earth electrode subsystem at three points: at the antenna, at the base of the tower, and at the waveguide entry port using number 6 AWG bare copper wire (as a minimum).
- b. Metallic supporting structures for waveguide shall be electrically continuous and grounded to the earth electrode subsystem at all supporting columns using number 6 AWG as a minimum.

5.4.2.6 Exterior Wires and Cables. Corrosion-protected steel conduit shall be used to enclose all external power or signal lines above or below ground to shield against lightning or lightning-induced currents and voltages. Junction boxes shall be electrically bonded to the conduit. The conduit shall be connected to the earth electrode subsystem at each end, and have ground rods at 15 meter (50 foot) intervals. The use of fiber optic cables to guard against lightning induced voltage is recommended for external signal circuits. If fiber optic cables are not used, the circuit protective devices of Paragraph 5.4.2.8 are required.

5.4.2.7 Bonds. All bonds between elements of the lightning protection subsystem shall be welded or brazed. All structural steel members shall be bonded to each other by welding.

5.4.2.8 Lightning Transient Protection. All power and signal circuits that may be damaged or malfunction as a result of lightning-conducted or induced transients shall be protected against pulses that have the characteristics as specified in MIL-E-4158. Information on voltage limitations and surge protecting devices is contained in MIL-HDBK-419. Power and signal lightning arrestors shall be installed in accordance with the National Electrical Code and MIL-HDBK-419.

#### 5.4.3 Equipment Fault Protection Subsystem.

5.4.3.1 General. The equipment fault protection subsystem grounding conductor (green wire) protects personnel from hazardous voltages, prevents static charge buildup, and provides a return conductive path for fault currents back to the power source so that the protective circuit breaker or fuse can clear faulted current. To protect personnel and equipment from hazardous voltages, all exposed metallic elements and enclosures of electrical or electronic equipment shall be connected to the earth electrode subsystem by means of the green wire. A ground bus shall be provided in all electrical equipment cabinets, power panels, and switch gear cabinets, and a separate connecting grounding conductor (green wire) shall be carried within the same conduit or raceway as the ac power conductors. The installation shall comply with the requirements of Article 250 of the NFPA No. 70. Useful guidance information is provided in MIL-HDBK-419. A typical equipment fault protection subsystem conductor arrangement is shown in Figure 8.

5.4.3.2 Conduit, Pipes and Tubes. Metallic conduit, pipes, and tubes shall be electrically continuous and shall be grounded to the equipment fault protection subsystem grounding

network as shown in Figure 8. All conduit, whether used for power, signal, or control wires, shall use lock nuts along with conductive lubricants to provide continuous conductivity. Conduit brackets and hangers shall be electrically continuous to the conduit and to the metal structures to which they are attached.

**5.4.3.3 Cable Trays and Raceways.** The individual sections of cable tray assemblies and raceways shall be electrically bonded to each other and to the structures that support them. All cable tray assemblies and raceways shall be connected to the equipment fault protection subsystem within 0.6 meters (2 feet) of each end of the run and at intervals not exceeding 15 meters (50 feet) along each run.

**5.4.3.4 Equipment Enclosures.** All electrical and electronic wiring, distribution equipment enclosures, and the frames of electrical equipment, such as motors, generators, and filters shall be connected to the equipment fault protection subsystem ground network as shown in Figures 8 and 9.

**5.4.4 Signal Reference Subsystem (Technical Ground).**

**5.4.4.1 General.** A signal reference subsystem (technical ground) shall be provided at each facility in which electronic equipment is installed to provide the ground reference connection from the earth electrode subsystem to all signal circuits in the technical equipment used for operational support. Signal circuits are grounded to control static charges, control electromagnetic interference, and establish a common reference for signals between sources and loads. Additional information on the design of signal reference subsystems is contained in MIL-HDBK-419 and Appendix B of MIL-STD-188-124. Communication and data cables between sensitive electronic equipments shall be referenced to signal ground via surge arrestors where indicated as determined by design analysis.

**5.4.4.2 Low Frequency Circuits.** The signal reference subsystem (technical ground) for low frequency signal circuits (from dc to 30 kilohertz) shall be connected to the earth electrode subsystem at one point only (single point) and shall be configured to minimize conductor path length. Low frequency grounding plates shall be isolated from structure by at least one megohm by test when measured with the ground cable disconnected. This grounding technique reduces stray currents (primarily 60 Hertz) which minimizes voltage potentials between points on the facility, thus minimizing common mode interference between power and signal circuits. For additional guidance, consult MIL-HDBK-419. Power distribution boxes may



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be grounded to structural elements. Power and low frequency signal circuits utilize separate paths to this earth electrode subsystem.

**5.4.4.3 High Frequency Circuits.** The signal reference subsystem, or technical ground, for higher frequency signal circuits (above 30 kilohertz) requires an equipotential ground plane. Digital circuits are considered higher frequency circuits. Figures 2, 3, 9, and 10 provide information on typical equipotential ground planes and how equipment is to be connected to it. If the equipotential plane is imbedded in concrete, stub-ups as shown in Figure 10 or equivalent shall be available at five foot intervals in both directions. The equipotential ground plane shall be connected to the facility structure at multiple points. Various configurations can be used based on the frequencies involved, such as copper grids, structural steel elements, the reinforcing rods (Rebar), or flat copper sheets that can be installed under or over equipment. Equipment cabinets shall be connected to the equipotential plane and become a part of the equipotential plane. Chassis shall be connected to the equipment cabinets and all components, signal return leads, etc., shall be connected to the chassis. Connections from technical equipment to the equipotential ground plane shall be as direct as possible and shall utilize low impedance ground straps. High frequency equipotential ground planes shall be designed and installed in accordance with MIL-HDBK-419. Technical ground plates for multipoint grounding shall be welded directly to the equipotential plane where ever possible or to substantial metallic structure in the local area, or connected to a local common ground point which includes a low resistance conductor to the equipotential plane. The equipotential plane shall be terminated to the earth electrode subsystem to assure personnel safety and a low impedance path for low and high frequency signals.

**5.4.4.4 Equipments Containing Both High and Low Frequency Signal Circuits.** Equipments that have both high and low frequency circuits and must share a common ground because of design or construction requirements, shall be grounded as indicated for high frequency equipments as outlined in MIL-HDBK-419.

## **5.5 FILTERS.**

**5.5.1 General.** This section of the standard establishes the requirements for EMI filters utilized for electromagnetic compatibility (EMC), National Security Requirements, or shielded enclosure integrity and encompasses the design, performance, and testing of EMI filters. Optical isolators

meeting the performance requirements of this standard are acceptable for providing isolation of control and communications circuits in shielded enclosure penetrations.

### 5.5.2 Requirements.

5.5.2.1 Filters. Filters shall be installed where indicated by analysis at distribution panels that provide power to EMI-sensitive equipment, or into rooms where such equipment is installed. The filters shall be part of the distribution panel and shall provide a minimum attenuation of 100 decibels (dB) (unless otherwise specified) between 100 kilohertz and 400 megahertz. Adequate filtering shall be provided on circuits from any source that generates interference that may be conducted into EMI-sensitive equipment areas. Filters used in this application shall conform to MIL-F-15733.

5.5.2.2 Design. Filters shall be designed in accordance with the requirements of MIL-F-15733. The design shall include prevention of underdamped resonant conditions between the source and load which would cause excessive voltages that can degrade the filter elements. Additional performance requirements may be specified in the contract.

5.5.2.3 Fungus Resistance. Materials used in the filter shall be fungus resistant or shall be treated to resist fungus.

5.5.2.4 Dissimilar Metals. Dissimilar metals, as defined by MIL-STD-889, shall not be used in contact with each other unless protected against galvanic corrosion. When it is necessary that dissimilar metals be assembled together, a material compatible with each shall be interposed between them.

### 5.5.3 Test Requirements.

5.5.3.1 Qualification Testing. Filters shall be tested in accordance with the requirements and test methods of MIL-F-15733. Except for the insertion loss test, it is acceptable for the contractor to submit certified copies of test reports of units of the same design.

5.5.3.2 Insertion Loss. The full load insertion loss shall be measured utilizing the approach outlined in MIL-STD-220, except that the insertion loss shall be measured for the full frequency range of the filter. The minimum number of measurements shall consist of three measurements per decade (factor of ten in frequency). Simulated load impedances shall be used during the test. If load impedances are not known, the load impedances to be used shall be as estimated and approved by the contracting officer.

## 5.6 BONDING

5.6.1 General. Bonding is the process by which a low impedance path for the flow of electric current is established between two metallic objects. Facilities containing electrical or electronic equipment shall be constructed so that interconnections between metallic objects prevent electric shock hazards, provide lightning protection, establish references for electronic signals, and reduce EMI. The joints shall be protected against corrosion or other means of degradation.

5.6.2 Corrosion Protection. Bonds shall be galvanically compatible as defined by MIL-STD-889. Bonds shall be protected against weather, corrosive atmospheres, vibrations, and mechanical damage if the possibility of exposure to these environments exist where they are located at the facility.

5.6.3 Bond Straps. Bonding straps installed across shock mounts or other suspension or support devices shall not impede the performance of the mounting device and not suffer metal fatigue or other means of failure. High frequency bond straps shall have a width-to-length ratio of at least 1 to 5 to provide low RF impedance. Where two items are to be bonded that must remain capable of movement by either turning, twisting, or partial rotation, a solid laminated or braided type strap shall be used. Properly shaped copper straps may be used for applications requiring moderate movements; beryllium copper or phosphorous bronze straps should be used for greater movement. All bonding shall meet the criteria established by MIL-HDBK-419.

5.6.4 Bond Resistance. Bonds for ground conductors whose primary function is to provide a reference for power circuits, electrical equipment, control circuits, signal circuits, or to provide lightning protection shall have a maximum resistance of 1 milliohm or less. The resistance across joints, seams, or RFI seals in metallic members required to provide electromagnetic shielding shall also be 1 milliohm or less. Facility metallic structural members shall have a maximum bonding resistance of 10 milliohms or less between joining members. Such structures shall include, but not be limited to:

- a. Building metallic support structures.
- b. Mechanical fixtures such as air conditioning ducts, water lines, hydraulic lines, air lines, fuel lines, stairs, and railings.

- c. Metallic pipes, conduits, cable trays and supporting structures.
- d. Movable platforms, hinged doors, and other movable devices.

5.6.5 Welding. Structural steel members shall be welded at least one place to joining members. If the reinforcing rods are used as an equipotential plane, each rod crossing shall be welded.

5.6.6 Brazing and Silver Soldering. Welding, brazing or silver soldering shall be acceptable for the permanent bonding of copper and copper alloy materials for applications inside structures. For external (outside) applications, including below-earth level, welding shall be used. Alternate methods require contracting officer approval.

5.6.7 Bonding of Copper to Steel. Either brazing or exothermic welding shall be used for the permanent bonding of copper conductors to steel or other ferrous structural members.

5.6.8 Structural Steel. The structural steel and reinforcing steel rods of a structure, such as launch pads, facility buildings, tracking stations, and safety shelters, shall be bonded to the earth electrode ground subsystem located underneath or near the facility.

5.6.9 Metal Passageways. Metal passageways shall be designed to provide a maximum dc resistance of 50 milliohms between any two points on a passageway.

5.6.10 Facility Structural Steel. The structural framework and reinforcing steel shall be bonded to provide a single homogeneous construction with a maximum dc resistance of 50 milliohms between any two points of the interconnected structural members.

5.6.11 Movable Metallic Items. Movable articles, such as sliding equipment, movable platforms, metal doors, and hinged panels, shall be provided with flexible bonding straps to ensure a maximum bonding dc resistance of 10 milliohms across any one bond.

5.6.12 Bond Protection. Bonds shall be protected against weather, corrosive atmospheres, vibrations and mechanical damage. Under dry conditions, a corrosion preventive or sealant shall be applied within 24 hours of assembly of the bond materials. Under high humidity conditions, sealing of the bond shall be accomplished

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immediately after joining. Each bonded joint shall be protected against corrosion by assuring that the metals to be bonded are galvanically compatible. Bonds shall be painted with a moisture proof paint or shall be sealed with a silicone or petroleum-based sealant to prevent moisture from reaching the bond area. Bonds which are located in areas not reasonably accessible for maintenance shall be sealed with permanent waterproof compounds. Iridited or other similarly protected bonds do not require painting to meet the requirements of this standard.

**5.6.13 Compression Bonds in Protected Areas.** Subject to the approval of the contracting officer, compression bonds between copper conductors or between compatible aluminum alloys which are located in readily accessible areas not subject to weather exposure, corrosive fumes, or excessive dust may not require sealing.

**5.6.14 Bonding Tests.**

**5.6.14.1 Facility Bonding Test.** A bonding resistance test shall be performed on all metal structures. Joints requiring bonding, whether by jumper or clamp-on metal-pressure fixture, shall be tested, but it is not necessary to test all joints individually. The number and location of the facility bonding tests shall be as approved by the contracting officer.

**5.6.14.2 Bonding Joints.** All structural steel elements shall be bonded and connected to the earth electrode subsystem. The facility bonding test shall include measurements of these items. Critical bonding joints are defined as those connecting sensitive electrical and electronic equipment enclosures, cable trays to and from these areas, and all protection subsystems (for fault currents and lightning) and their connections to ground.

**5.6.14.3 Test Equipment.** An acceptable piece of equipment for performing a test is the Shallcross Manufacturing Co. low-resistance test set, Type 673A or 673D. Equivalent equipment may be substituted.

**5.6.14.4 Test Procedure.** Testing shall be performed during all states of facility construction and subsystem installation. One lead of the test instrument shall be connected to one bonded interface and the other lead connected to an adjacent level. A second set of measurements shall be made at the completion of construction to determine the over-all resistance of various joints on the bonded structure to the nearest counterpoise stub-up connection. A random "proof of bonding integrity" test shall be required at

acceptance. The testing shall be performed in accordance with the test procedures in MIL-HDBK-419. Periodic maintenance inspection and testing shall be performed per MIL-HDBK-419.

**5.6.14.5 Success Criteria.** Any single critical joint measurement shall exhibit a dc resistance of 10 milliohms or less and the dc resistance from any point in the bonded structure of the various control rooms to the nearest earth electrode ground plate or rail shall be 100 milliohms or less. No single structural steel joint shall exceed a maximum resistance of 10 milliohms dc. Power, signal, control, and lightning subsystem bonds shall have a resistance of 1 milliohm or less.

**5.6.14.6 Data Requirements.** A record shall be kept of the measurements of all points made in each area. These records shall be coded so that any desired measurement point can be relocated easily for later verification. These records shall be maintained for at least 5 years.

## **5.7 NATIONAL SECURITY INFORMATION (RED/BLACK EQUIPMENTS).**

Unless otherwise specified, the facility grounding, filtering, bonding, and shielding requirements associated with National Security shall be in accordance with NACSIM 5203, NACSEM 5204, and MIL-HDBK-419. NACSIM 5203 refers to MIL-HDBK-419 for RED/BLACK signal grounding.

## SECTION 6

### NOTES

The contents of this Notes section are not compliant. The notes are intended for use by Government Acquisition personnel for guidance and information only.

#### 6.1 INTENDED USE

This standard is intended for use in acquisition contracts for selected space system facilities. The requirements are applicable to all related facilities including, but not limited to, launch complexes, tracking stations, data processing rooms, satellite control centers, checkout stations, spacecraft or booster assembly buildings, and any associated stationary or mobile structures that house electrical and electronic equipment.

Note that this standard would not normally be used in the acquisition of other types of facilities and equipment, such as Long Haul/Tactical Communications Subsystems (which are addressed by MIL-STD-188-124). However, there may be other types of facilities and equipment, where the special considerations stated in this standard would be applicable. For those facilities and equipment, a reference to the applicable provisions in this standard should be included in the acquisition contracts. To avoid any possible misinterpretation, a statement should be included in the contract for those facilities and equipment, that the words "space system facility" and "space equipment" in this standard are to be interpreted as the applicable system facility and equipment.

#### 6.2 TAILORED APPLICATION

The requirements in each contract should be tailored to the needs of that particular program. Military specifications and standards need not be applied in their entirety. Only the minimum requirements needed to provide the basis for achieving the program requirements should be imposed. The cost of imposing each requirement of this standard should be evaluated by the program office against the benefits that should be realized. However, the risks and potential costs of not imposing requirements shall also be considered.

### 6.3 TOTAL QUALITY MANAGEMENT.

The intent of the design and construction requirements, and quality assurance requirements, specified in this standard is to assure that acceptable space facilities are acquired. In-process controls are almost always a more cost-effective way of avoiding defects than the imposition of tests and inspections on completed units. Therefore, appropriate in-process controls and other total quality management steps should be imposed to achieve the high quality and reliability goals required for space facilities. The testing requirements specified are intended to be the last step in assuring the quality of space facilities. When it has been thoroughly demonstrated that the purpose of a testing requirement for any characteristic has been met by the in-process controls or other total quality management steps implemented by the contractor, the contractor may petition the contracting officer for approval to reduce the tests to sampling tests, or if appropriate, for deletion of the test.

### 6.4 SUBJECT TERM (KEY WORD) LISTING

- Air terminals
- Bond straps
- Buildings
- Cable trays
- Cathodic protection
- Earth electrode
- Earth resistivity
- Electrical power
- Electromagnetic compatibility
- Electromagnetic pulse (EMP)
- Equipotential plane
- Facility ground
- Facility power
- Filters
- Ground Fault Detection
- Grounding
- Ground rods
- Harmonic Distortion
- High frequency circuits
- Isolation
- Lightning protection
- Lightning rods
- Multipoint ground
- Power distribution
- Shielded enclosures
- Shielding
- Shielded rooms



Structures  
Technical ground  
Technical power  
Transformers

**6.5 SUPERSESION DATA.**

This issue of MIL-STD-1542B (USAF) is a complete revision that supersedes MIL-STD-1542A (USAF) for new designs. Changes in the text from the previous issue are indicated by a vertical bar in the margins. This was done as a convenience only and the government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations and relationship to the last previous issue. The previous issues remain in effect to cover previous procurements.

Custodians  
Air Force - 19

Preparing Activity  
Air Force - 19

(Project No. EMCS-F097)  
Document 2283b/Arch 1432b

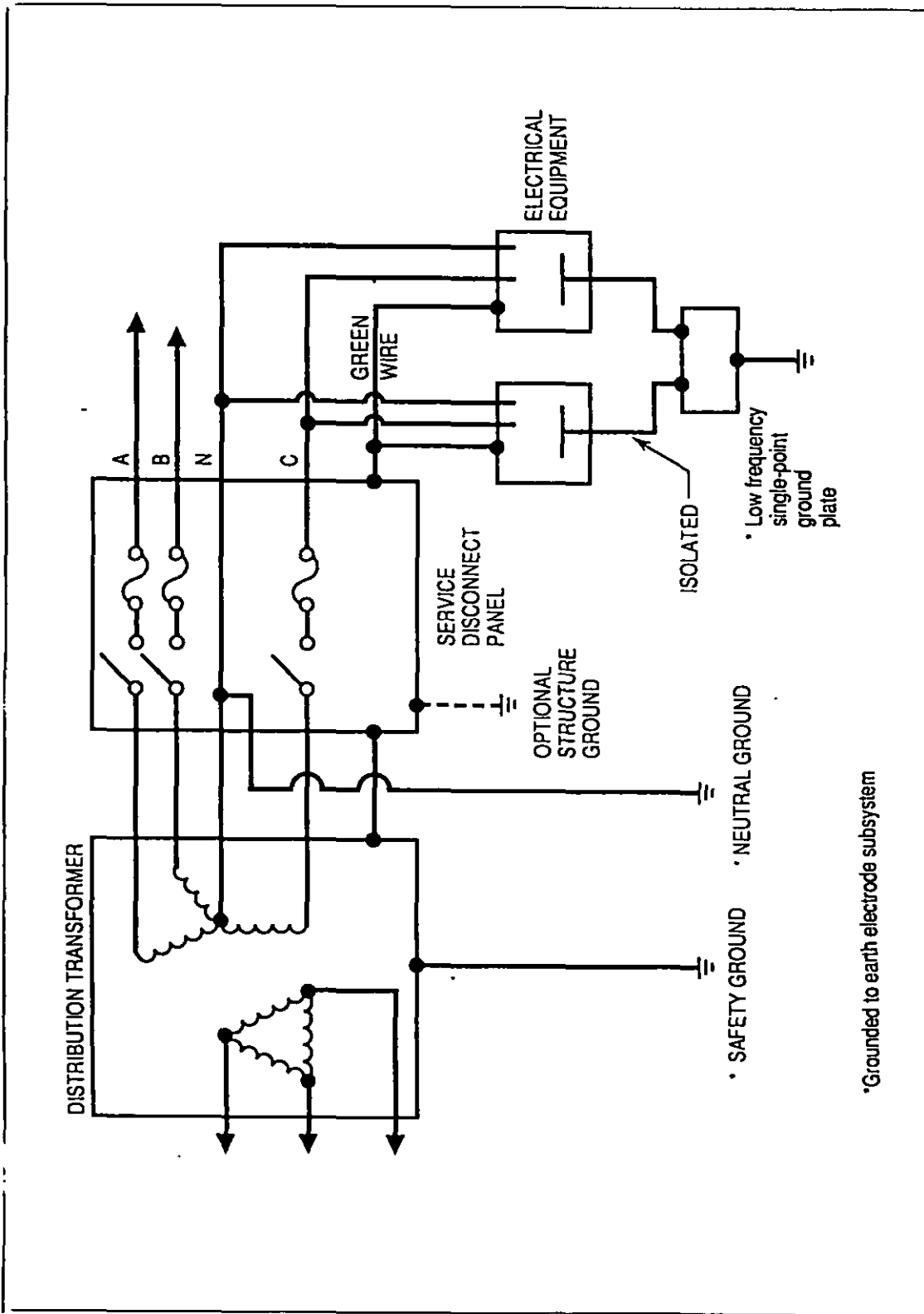


Figure 1 - Low Frequency Technical Grounding

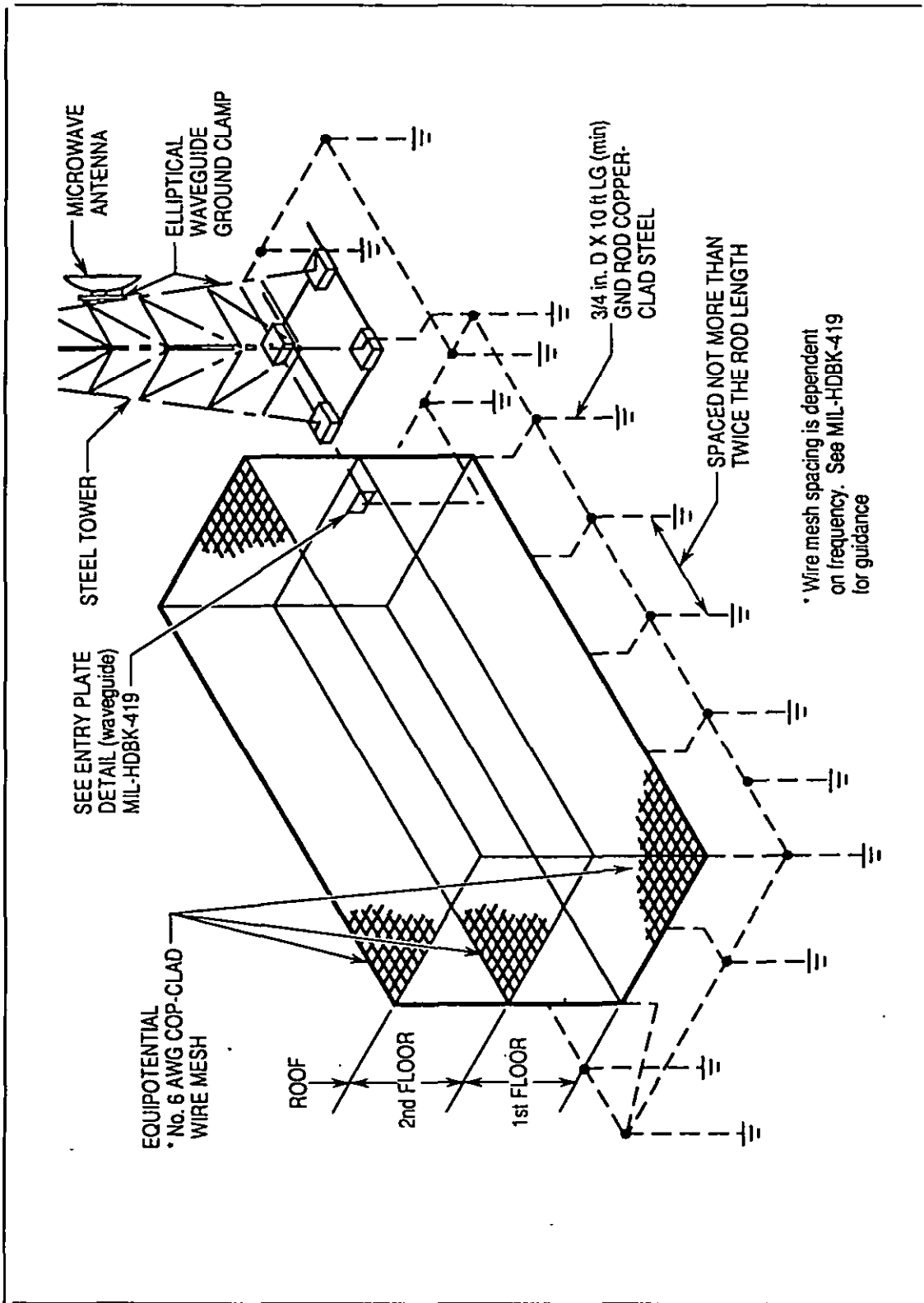


Figure 2 - Typical Equipotential Ground Plane Network for Multistory Buildings

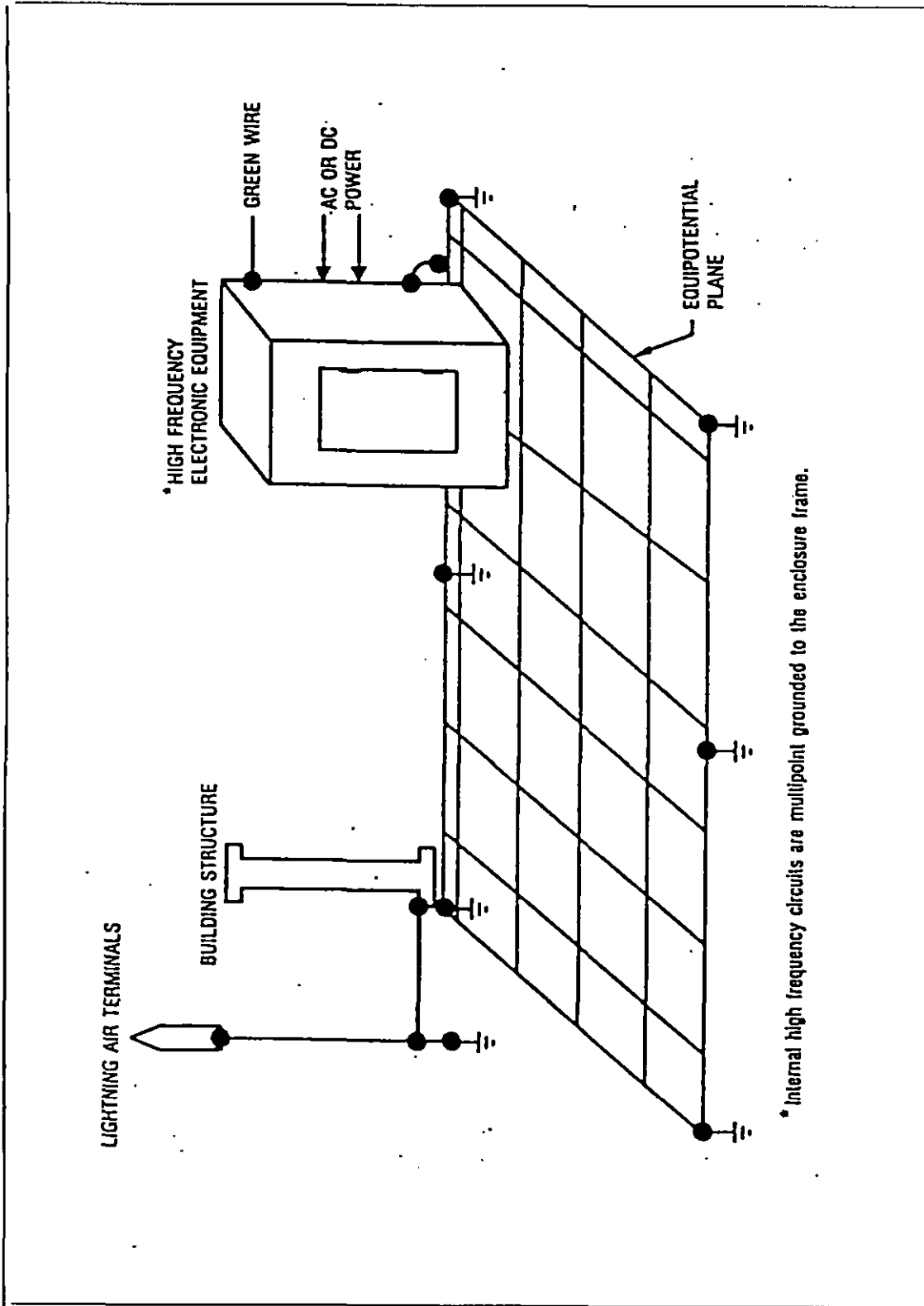


Figure 3. High Frequency Equipment Grounding Network

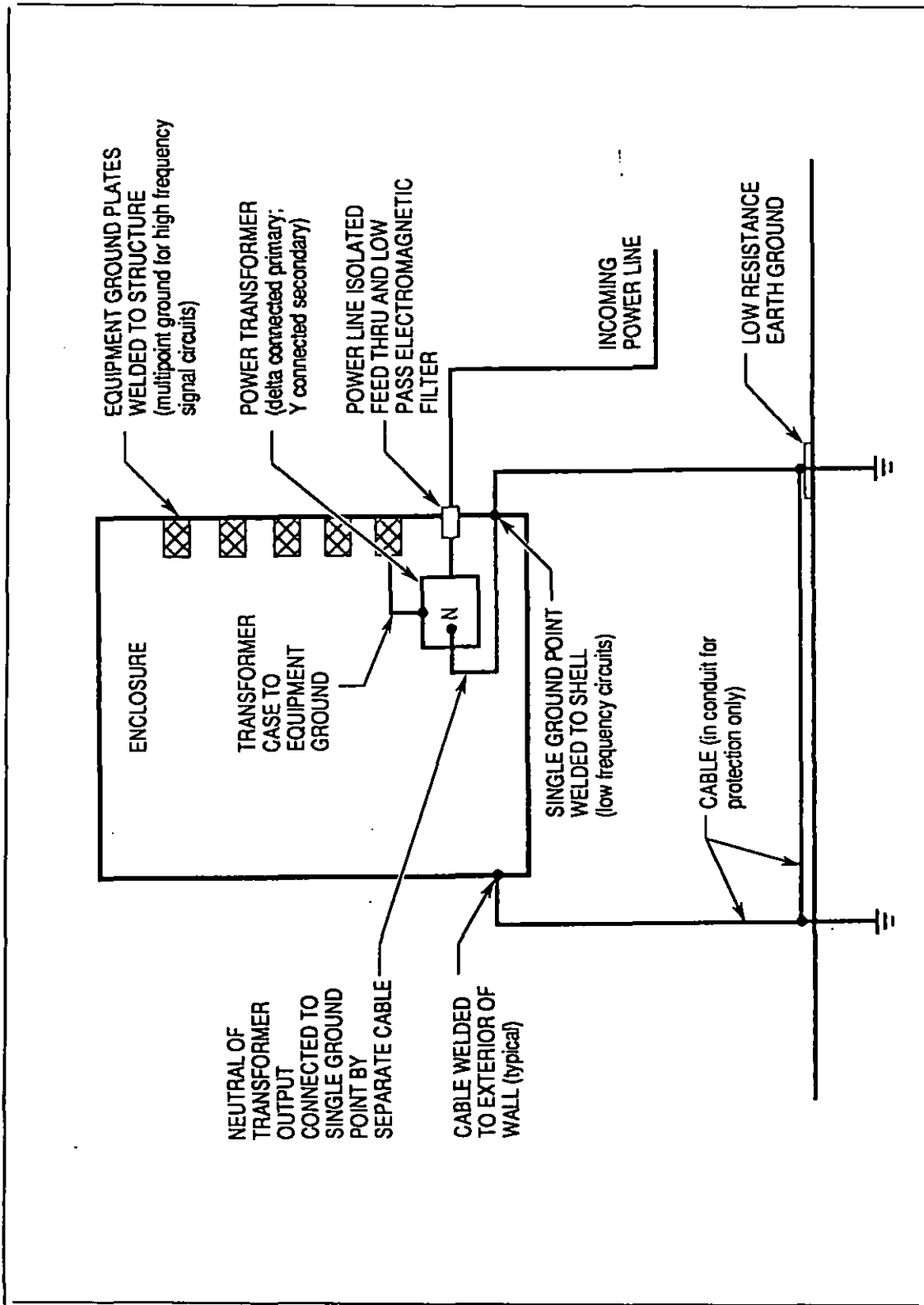


Figure 4 - Shielded Room Grounding Network

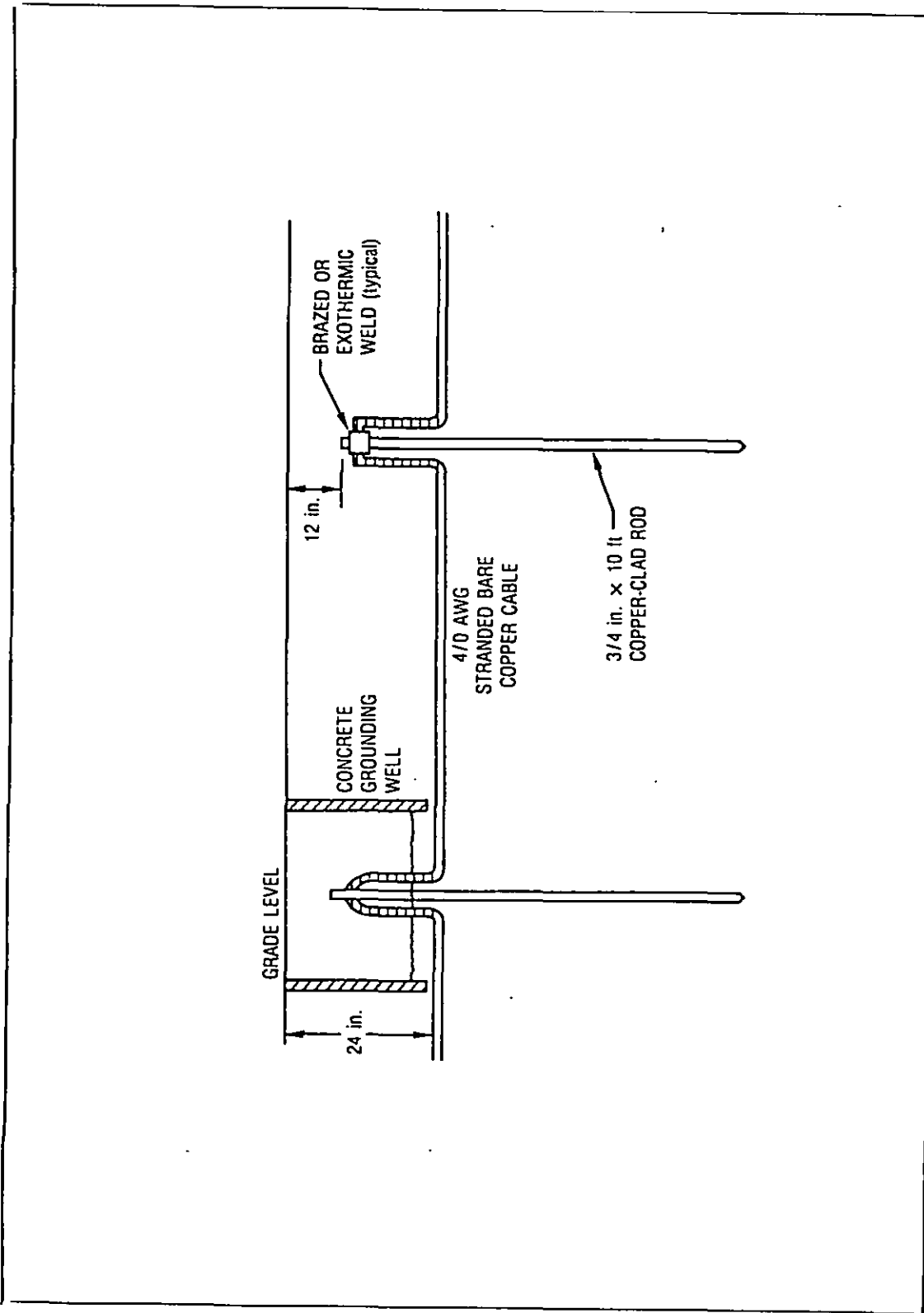


Figure 5 - Details of Ground Rod or Earth Electrode Subsystem Installation

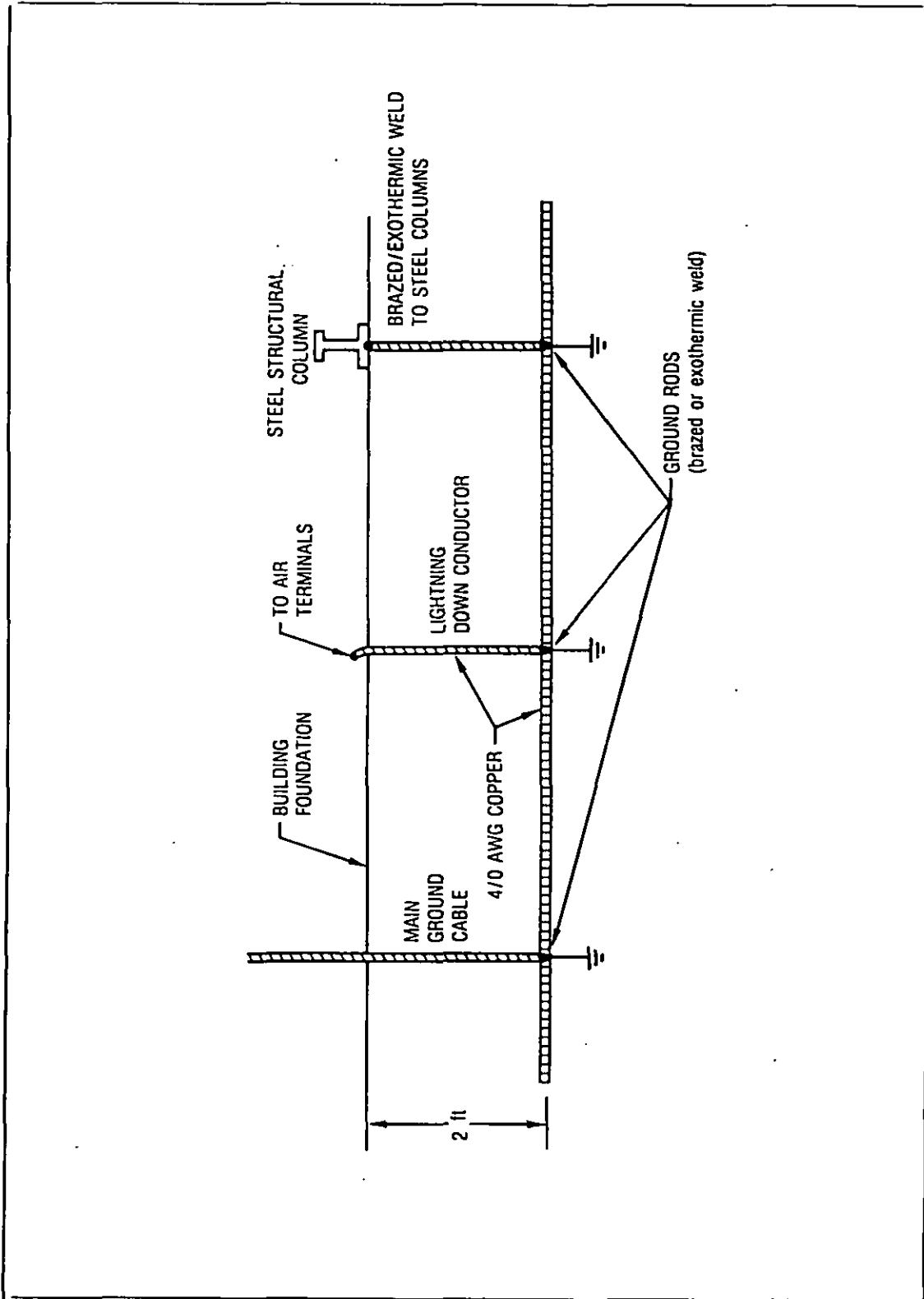


Figure 6 - Connections to Earth Electrode Subsystem

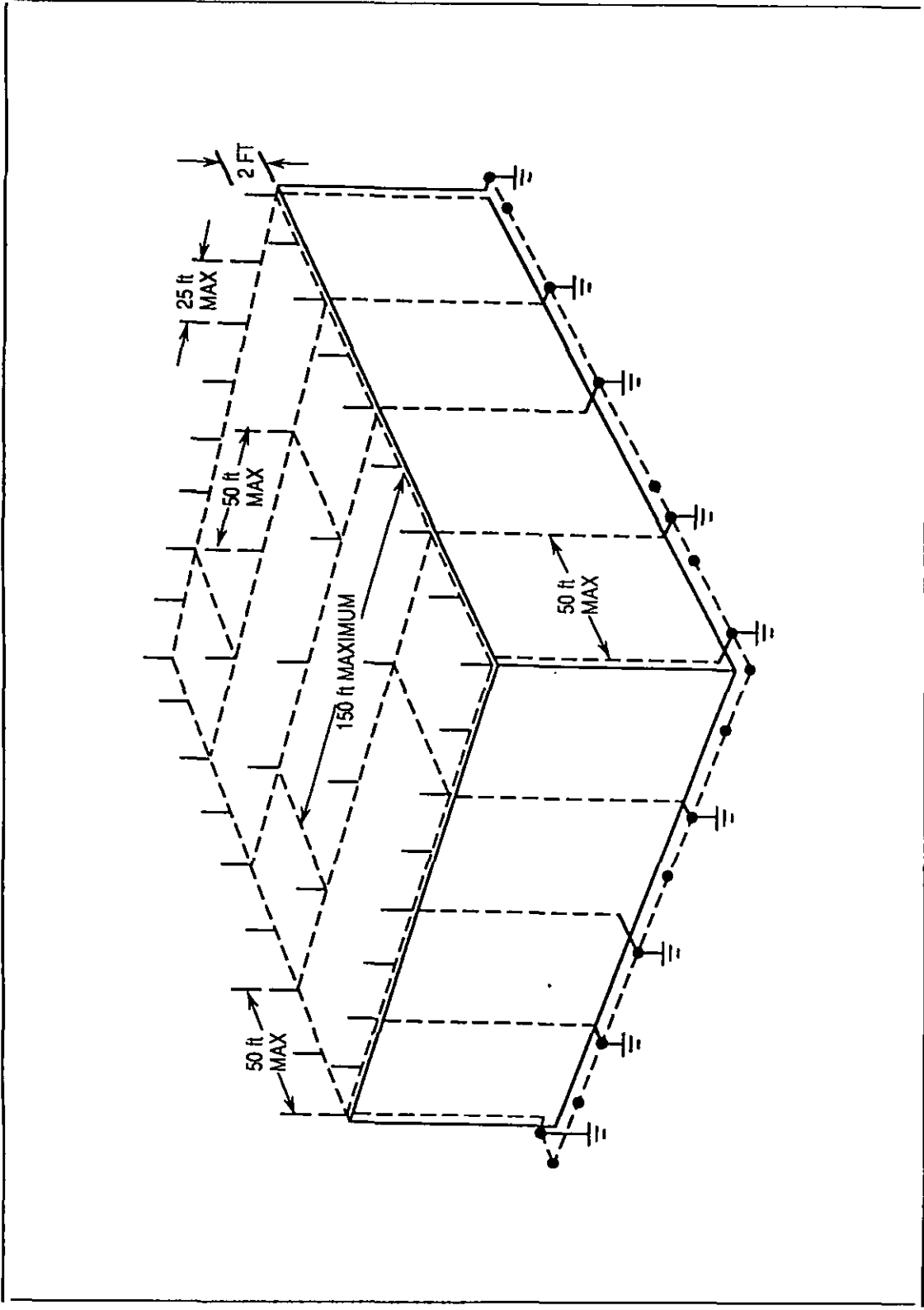


Figure 7 - Air Terminal Placement on Flat-roofed Structure



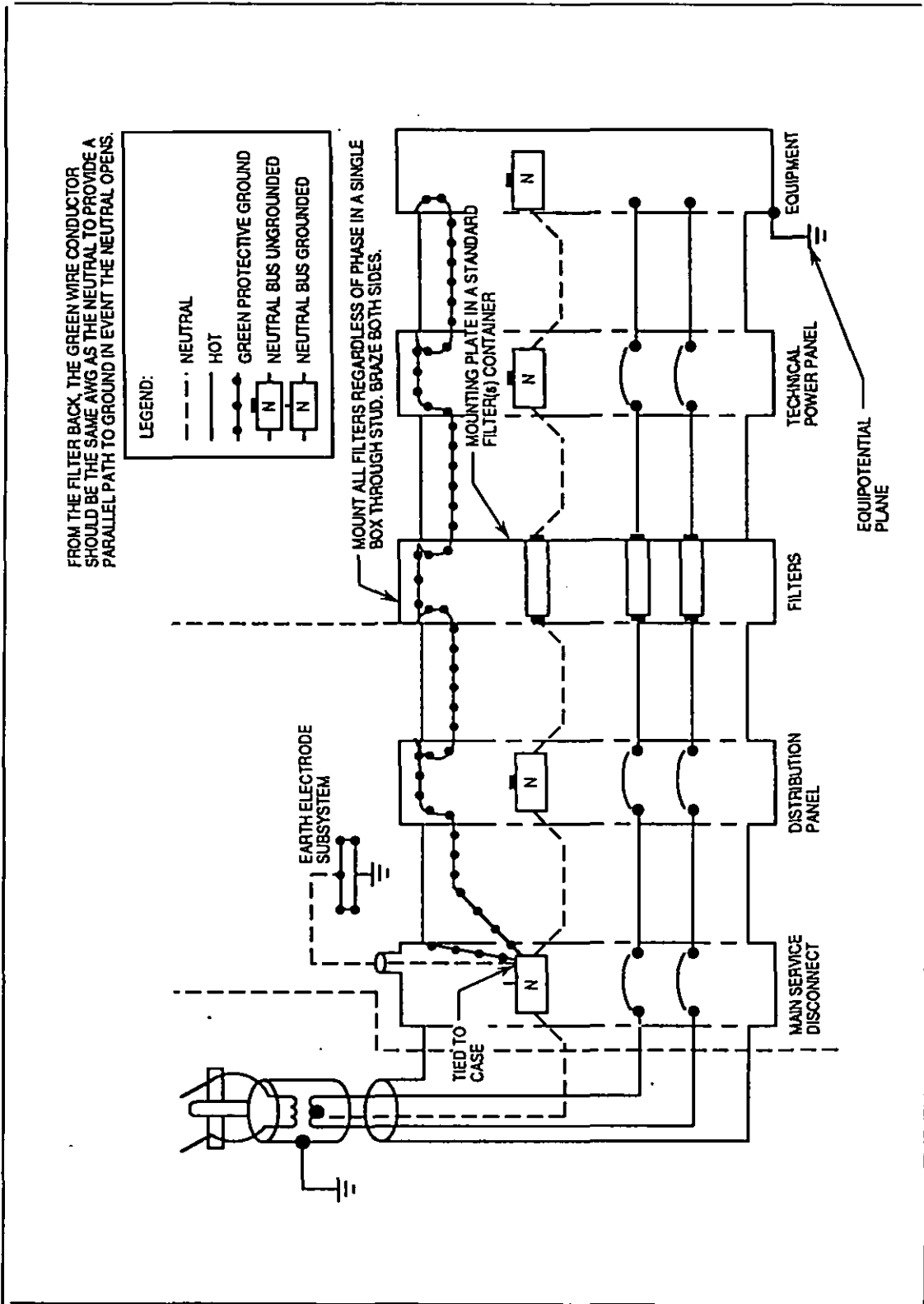


Figure 8 - Equipment Fault Protection Subsystem Grounding

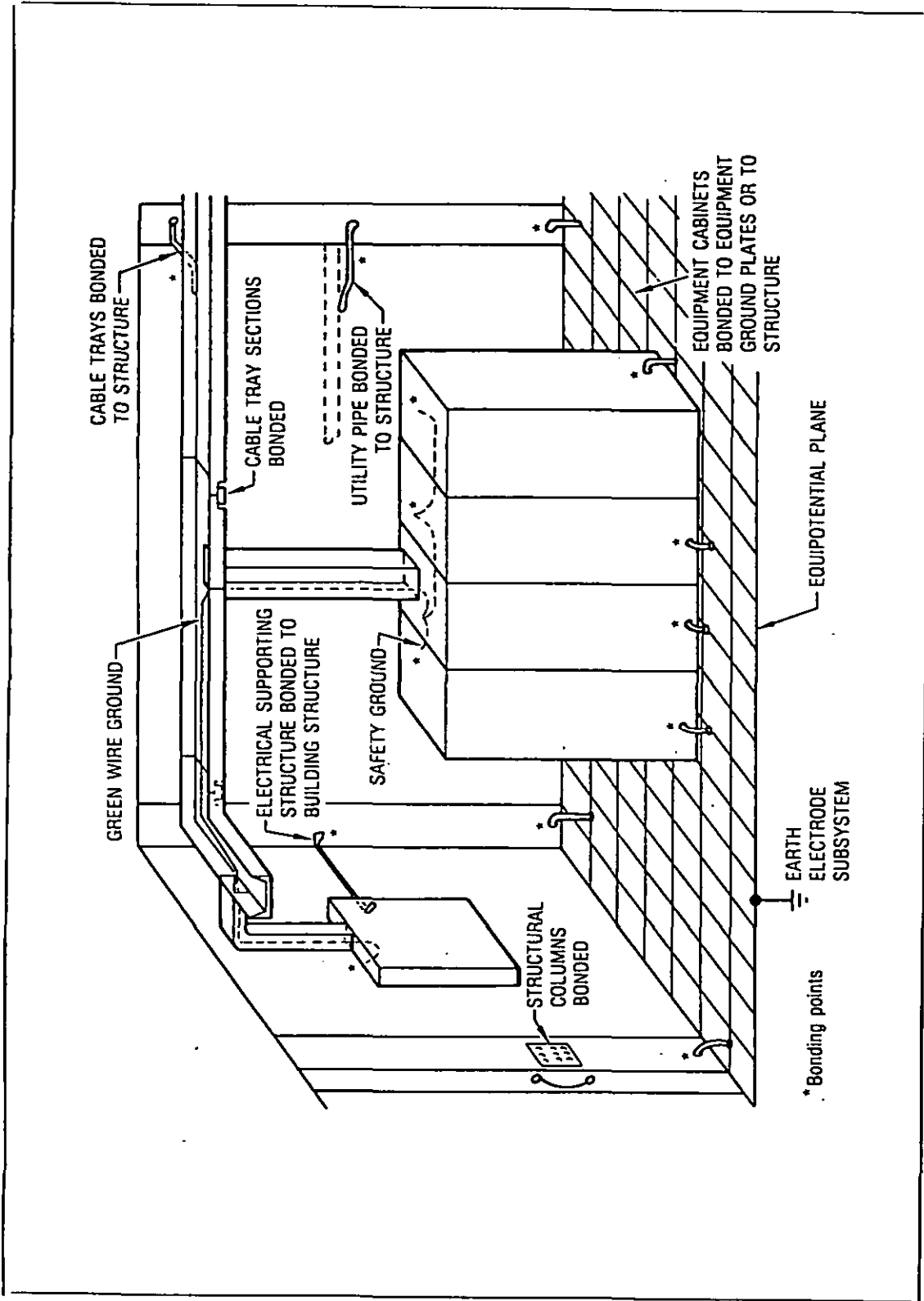


Figure 9 - Elements of the Signal Reference Ground Subsystem  
(with Equipotential Plane Ground)

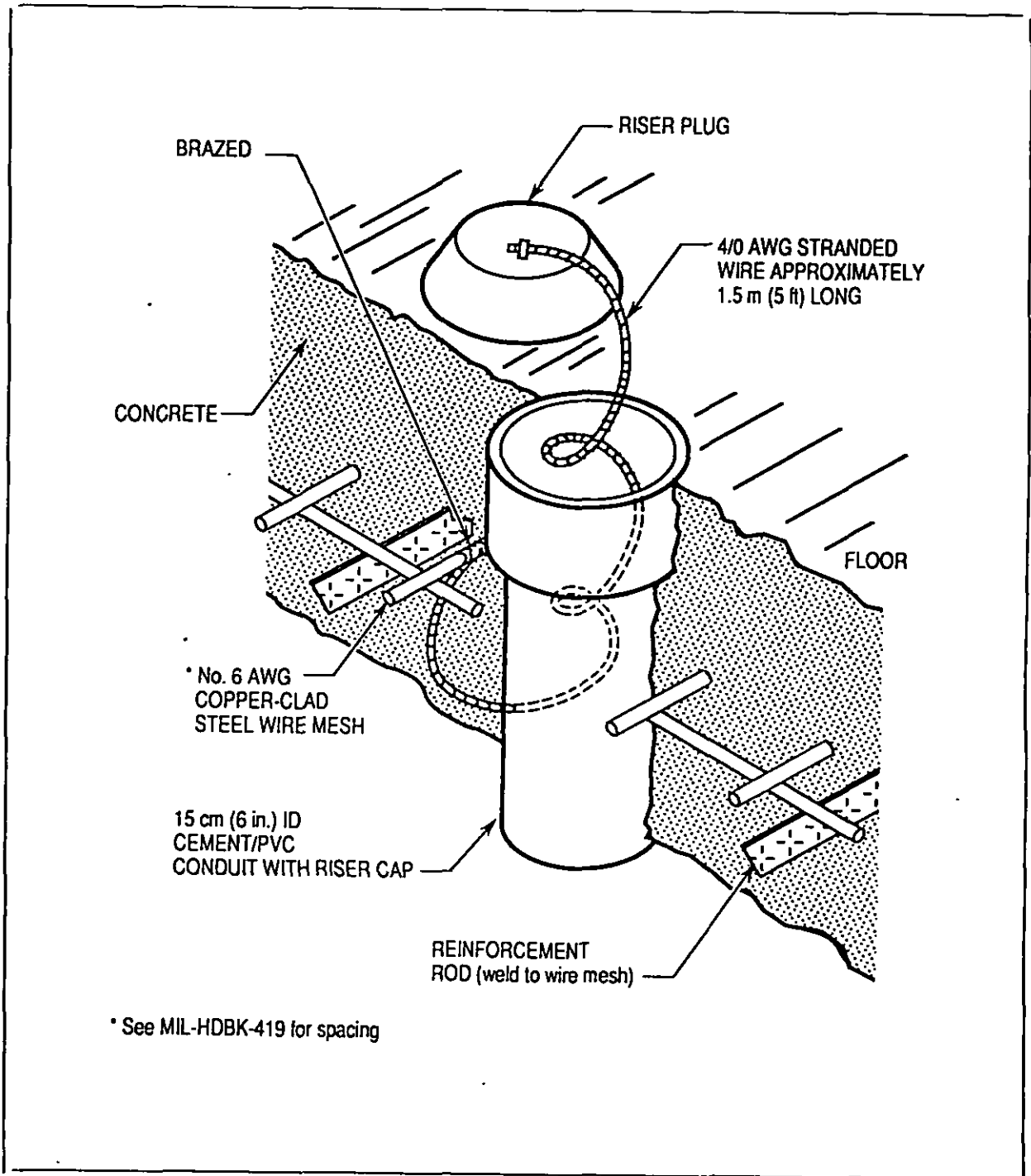


Figure 10 - Detail of Typical Equipotential Ground Plane for New Construction - High Frequency Facilities Installation

