

***LIGHTNING PROTECTION, GROUNDING, BONDING, SHIELDING, AND SURGE
PROTECTION REQUIREMENTS***

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- a. See "record of changes" on the following page.

Signed

4/11/2017

Deirdre Reynolds Jones.
Director, Office of Facilities

Date



**U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service**

Lightning Protection, Grounding, Bonding, Shielding, and Surge Protection Requirements

NWSM 30-4106

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NWSM 30-4106 Technical Manual Deficiency Report

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Record of Changes

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1		1.2 Added: IEEE Std. 1692 as a required reference document & Motorola R56B as a required reference document Page 1-1 (page 27 of 184)	LPGI & Affiliates
2		1.2 Added: definition of a “low resistance as a value = 1.0 ohms”, a value necessary to minimize lightning induced GPR Page 1-1 (page 27 of 184)	LPGI & Affiliates
3		Added an Appendix A ₁ : Lightning Audit and Safety Checklist as a required audit for the protection of equipment and personnel pages 120 of 184 through page 130 of 184	LPGI & Affiliates
4		2.5.2.1 C Added: “Arrester response time shall be less than 5 nanoseconds in order to capture the lightning current spike” Page 2-5 (39 of 184)	LPGI & Affiliates
5		Added a Chapter 3: Radial Grounding, Electrical Protection, Equipment Specifications and Installation Guidelines for NWS Facilities pages 100 of 184 through page 112 of 184	LPGI & Affiliates
6		2.7.5.4 Added: “Nonmetallic fuel storage tanks shall not be installed.” Page 2-15 (page 49 of 184)	LPGI & Affiliates
7		Added: Figures 3-1, 3-2, 3-3, and 3-4 pages 109 of 184 through page 112 of 184	LPGI & Affiliates
8		2.5.1 Surge Levels Added: less than five (5) nanoseconds is required without malfunction Page 2-3 (page 37 of 184)	LPGI & Affiliates
9		2.5.2 Added: Silicone Avalanche Diode (SAD) and Metal Oxide Varistor (MOV) Page 2-4 (page 38 of 184)	LPGI & Affiliates
10		2.5.4.3 C Added: Silicone Avalanche Diode (SAD) with a response time of less than 5 nanoseconds Page 2-8 (page 42 of 184)	LPGI & Affiliates
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12		Index expanded to accommodate additions and changes to NSW Manual	LPGI & Affiliates

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CHAPTER 1

Introduction

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CHAPTER 1

Introduction

1.1 Purpose and Scope

This manual provides design, engineering, acquisition, installation, and maintenance direction and guidance for implementation of effective lightning protection for use by technical staff both at the headquarters and regional levels. The design and installation direction and guidance in this document provide a systematic approach to minimizing electrical hazards to personnel, damage to facilities and electronic equipment from lightning, transients, electrostatic discharge (ESD), power faults, and electromagnetic interference. **These electrical provisions shall apply to any new construction or major renovation being performed after the date of the adoption of this manual.** Existing electrical installations that do not comply with the provisions of this manual shall be permitted to continue in use without any corrections. If major renovations (defined in the [Glossary](#)) are to be made to existing electrical systems, or major renovations to existing buildings are undertaken, or major additions are planned, then compliance with the manual is required.

1.2 Minimum Requirements for Lightning Protection

National Weather Service (NWS) facilities and systems are located in such diverse physical and electrical environments that each may require different design and installation methods. However, all should meet the minimum NWS requirements for safe lightning protection. Users should become familiar with the information contained herein and apply it to specific design and installation requirements for new facilities, as well as for maintaining and retrofitting existing facilities.

The minimum requirements for bonding and grounding are those specified by IEEE Std. 1692: "IEEE Guide for the Protection of Communication Installations from Lightning Effects", and the National Fire Protection Association's NFPA 70, National Electrical Code. The minimum requirements for lightning protection are those specified by IEEE Std. 1692: "IEEE Guide for the Protection of Communication Installations from Lightning Effects", and the NFPA 780, Standard for Installation of Lightning Protection Systems. These guidelines provide information intended to aid engineers in design and installation methods for lightning protection of NWS facilities. A critical link in the proper operation of electronic equipment is to have an effective low-resistance facility grounding system. An effective low-resistance facility grounding system design required to minimize lightning strike current or lightning induced Ground Potential Rise (GPR) is less than one (1.0) ohm to remote earth.

All contractors performing work at an NWS facility involving installation of a lightning protection system shall meet the requirements of this manual, if it is part of the contract statement of work (SOW).

1.3 Organization of the Manual

Chapter 2 of this manual specifies requirements for surge and transient protection, lightning protection, earth electrode system (EES), electronic multipoint ground system (MPG), electronic single-point ground system (SPG), electrostatic discharge (ESD) minimization, control and prevention requirements for cables, and National Electrical Code (NEC) compliance.

Additional information is provided in eight appendixes:

- Appendixes A, A₁ and B include checklists and audit outline for lightning safety and lightning protection.
- Appendixes C through I provide information supplementary to the main text.

A glossary and index are also included at the end of the manual.

Comments and suggestions from users of this manual are welcome and may be submitted in electronically or in hard copy using the Technical Manual Deficiency Report immediately following the title page of this manual.

1.4 Applicable Documents

The following documents are applicable to the subject of this manual. Unless stated otherwise, National Weather Service organizations performing operations shall use the latest available issue or revision of each document listed.

NOTE: If the guidance in this manual differs from that specified in a referenced document, the guidance in this manual shall govern.

American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers

ANSI/IEEE C62.41	Recommended Practice on Surge Voltages in Low Voltage AC Power Circuits
ANSI/IEEE C62.45	IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits
ANSI/IEEE 1100 Emerald Handbook	Recommended Practice for Powering and Grounding Electronic Equipment
ANSI/IEEE 142 Green Handbook	Grounding of Industrial and Commercial Power Systems
Motorola R56B	Standards and Guides for Communication Sites
IEEE STD 100	IEEE Standard Dictionary of Electrical and Electronics Terms
IEEE STD 1692	IEEE Guide for the Protection of Communication Installations from Lightning Effects
IEEE STD 367	IEEE Recommended Practice for Determining the Electrical Power Station Ground Potential Rise and Induced Voltage From a Power Fault

Federal Aviation Administration

FAA-STD-019c	Lightning Protection, Grounding, Bonding and Shielding Requirements for Facilities
FAA-STD-019d	Lightning and Surge Protection, Grounding, Bonding and Shielding Requirements for Facilities and Electronic Equipment

Military Documents

MIL-HDBK 419A

Grounding, Bonding, and Shielding for Electronic
Equipment and Facilities

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code
NFPA 780 (2004 Edition)	Standard for the Installation of Lightning Protection Systems

Underwriters Laboratories, Inc.

UL 96	Standard for Lightning Protection Components
UL 96A	Standard for Installation Requirements for Lightning Protection Systems
UL 1449 (2 nd Edition)	Standard for Safety for Transient Voltage Surge Suppressors

1.5 Acronyms and Abbreviations

The following list contains all approved acronyms and abbreviations used within the National Weather Service Facilities Lightning Protection Manual.

AC	alternating current
AIC	amperes interrupting capacity
AWG	American wire gauge
DC	direct current
EES	earth electrode system
EGC	equipment grounding conductor
EMI	electromagnetic interference
EPP	equipotential plane
ESD	electrostatic discharge
FAA	Federal Aviation Administration
GE	grounding electrode
GEC	grounding electrode conductor
GFCI	ground fault circuit interrupter for personnel protection
GFPE	ground fault protection for equipment
GP	groundable point
GPS	Global Positioning System
HVAC	heating, ventilation, and air conditioning
kmil	kilocircularmil
LPS	lightning protection system
m	meter
mA	milliamp

MCOV	maximum continuous operating voltage
MPG	(Electronic) Multipoint Ground System
MIC	meteorologist in charge
mm	millimeter
MSDS	Material Safety Data Sheet
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NLSI	National Lightning Safety Institute
NFPA	National Fire Protection Association
nS	nanoseconds
NWS	National Weather Service
PVC	polyvinyl chloride
RF	radio frequency
RGS	rigid galvanized steel
RMS	root mean square
SGS	Satellite Ground Station
SPD	surge protection device
SPG	(Electronic) Single-Point Ground
SRG	signal reference grid
SRS	signal reference structure
UL	Underwriters Laboratories Inc.
V	Volt
W	Watt

1.6 Acknowledgments

The National Weather Service would like to thank the Grounding and Surge Protection (GASP) workgroup within the Federal Aviation Administration and the National Lightning Safety Institute (NLSI) for their assistance in developing this manual.

CHAPTER 2

**Lightning Protection Design, Engineering,
Acquisition, Installation, and Maintenance
for NWS Facilities and Equipment**

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CHAPTER 2

Lightning Protection Design, Engineering, Acquisition, Installation, and Maintenance for NWS Facilities and Equipment

2.1 Surge and Transient Protection Requirements

Lines, cables, and facilities will be protected against the effects of lightning. Ferrous conduit should be used to shield external lines and cables to minimize inductive coupling of transients from lightning discharges. Guard wires should be used to protect buried cables from direct lightning strikes. This will minimize inductive coupling of transients from nearby lightning strikes. Fiber-optic lines and balanced metallic lines should be used when feasible. Electrical and electronic equipment will be protected against conducted and radiated surges and transients from all power, signal, control and/or status lines. Integrated circuits, transistors, diodes, solid-state voltage regulators, capacitors, miniature relays, miniature switches, and miniature transformers, etc., are susceptible to damage and operational upset caused by transients. Transient suppression will be provided at the entrance to any National Weather Service (NWS) facility and all electronic equipment for protection against conducted electrical transients. A surge protection device (SPD), capable of shunting energy represented by the surge levels in [Table 2-1](#) (see Section [2.5.1](#)), should be installed at the facility's electric power service entrance. All manufacturer SPDs should be listed and labeled according to the Underwriters Laboratories Inc. (UL) standard UL 1449 (2nd edition), and should be tested according to Institute of Electrical and Electronics Engineers standard IEEE C62.45.

2.1.1 Existing Electronic Equipment Designs

For existing electronic equipment designs, equipment-level transient suppression is required. It may be either internal or external to the equipment it is protecting but must follow the grounding, bonding, and shielding methods indicated herein.

2.1.2 Installation by Others

Electronic equipment not installed by its manufacturer or supplier will have all items of material required for installation of transient protection delivered to the site.

2.2 External Lines and Cables

2.2.1 Fiber-optic Lines

Fiber-optic lines are not susceptible to environmental interference or induction fields produced by lightning. Fiber-optic lines should replace metallic conductors when economically and technically feasible. Ferrous conduit shielding and suppression components are not required for fiber-optic conductors unless these lines use metallic or electrically conductive sheaths or strength members.

2.2.2 Balanced Pair Lines

When possible, signals in metallic conductors routed externally between facility shelters and buildings to externally mounted electronic equipment should be designed as balanced, two-conductor, twisted, shielded circuits.

2.2.3 Ferrous Conduit

In this manual, ferrous conduit is defined as rigid galvanized steel (RGS) conduit. Buried alternating current (AC) power conductors or cables to a facility should be enclosed in watertight, ferrous conduit. The buried ends of this conduit will be bonded to the earth electrode system (EES) with a bare copper conductor No. 2 AWG, minimum. Conduit joints and fittings will be electrically continuous with a bonding resistance of less than 5 milliohms between joined parts. Conduit enclosing AC power service entrance conductors will be terminated using conductive fittings from the distribution transformer case and to the service entrance cabinet as the situation dictates. Conduit enclosing signal, control, status, power, or other conductors to electronic equipment will be terminated using conductive fittings. **Any metallic conduit entering the facility must be bonded to the EES to minimize transient conductance.**

2.2.4 Ferrous Conduit Penetration of Facility

Direct connections will be made from the conduit to a bulkhead connector plate or ground plate (installed externally or immediately after entering the building) that is connected directly to the EES using exothermic welds and a minimum No. 4/0 AWG stranded copper conductor. This will be done at each location where above-ground conduits first penetrate a shelter or a building's exterior wall.

2.2.5 Existing Unused Metallic Conduit, Conductors, and Cables

Bonding of the grounding conductor to its enclosed conduit should be done as shown in the example in [Figure 2-1](#).

2.3 Interior Lines and Cables

All permanently installed interior cables and conductors exceeding 6 feet in length will be enclosed end-to-end in conduit. (Temporary extension cables used for performing maintenance work are excluded.)

2.4 Electronic Equipment Transient Susceptibility Levels

Commercial off-the-shelf (COTS) electronic equipment supplied as part of the facility should be provided with transient protection. This protection will reduce surges and transients to below the equipment susceptibility level determined by the manufacturer. The equipment susceptibility level is the online transient level that may cause damage, degradation, or upset to the connected electronic equipment. The combined facility and equipment entrance protection will be coordinated to limit transients at the equipment entrance to a level below the equipment susceptibility level. The following characteristics should be evaluated. All manufactured electronic equipment must meet the transient susceptibility levels specified in IEEE C62.41.

- a. **Component Damage Threshold.** The transient level sufficient to render the component nonfunctional or operationally deficient.
- b. **Component Degradation Level.** The transient voltage or energy level sufficient to shorten the useful life of the component.
- c. **Operational Upset Level.** The transient voltage or energy level sufficient to cause an unacceptable change in operating characteristics for a duration in excess of 10 milliseconds for analog equipment or a change of logical state for digital equipment.

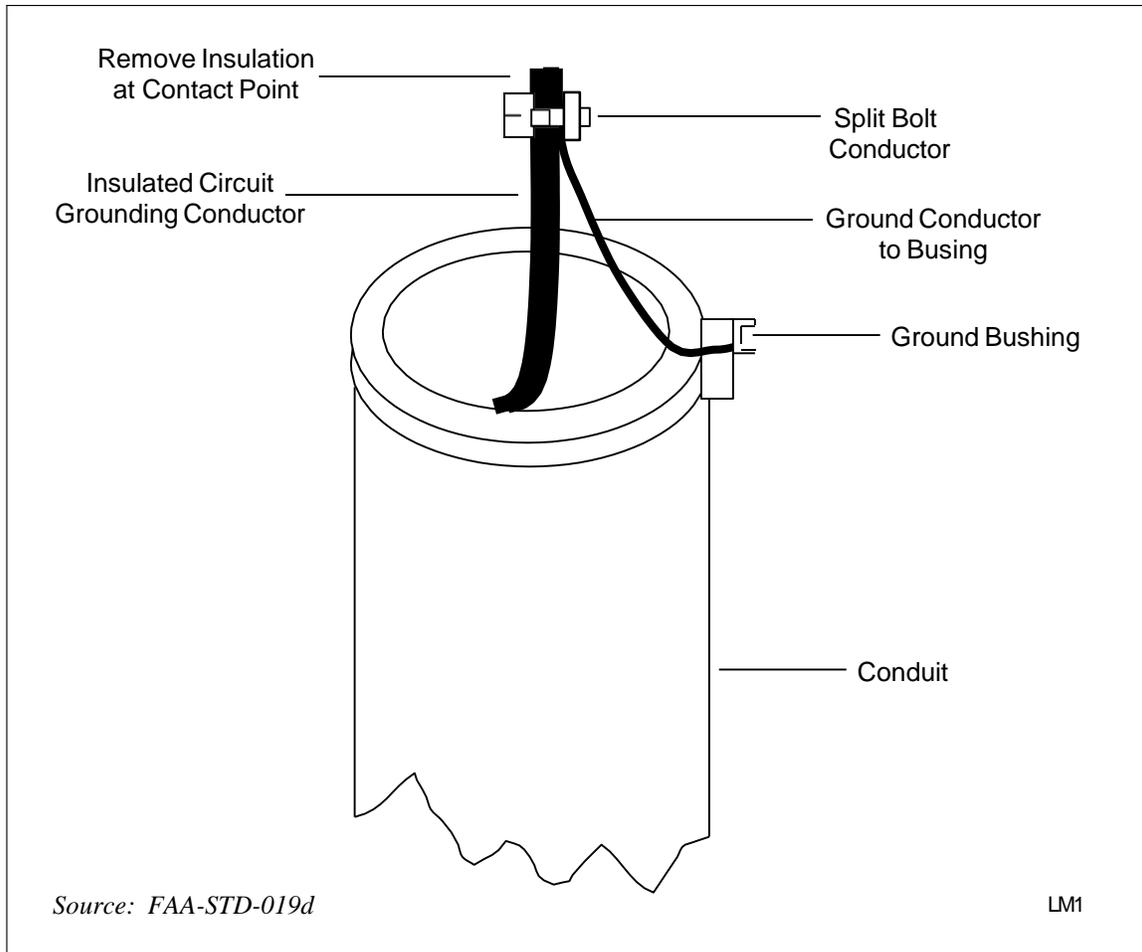


Figure 2-1. Bonding of Grounding Conductor to Its Enclosed Conduit for Used Conductors

2.5 Power Line Surges

A surge protection device (SPD) will be provided at the main service disconnecting means to reduce transients conducted to electronic equipment. SPDs may be installed on the load side or line side at the service entrance. Additional SPDs may need to be provided at power line entrances to electronic equipment. SPDs at the main service disconnecting means, as well as at electronic equipment power line entrances, will be functionally compatible.

2.5.1 Surge Levels

Surge levels and the number of occurrences for selection or design of facility AC arresters are provided in [Table 2-1](#). The table defines line-to-ground surge currents and the number of occurrences for low voltage (less than 600 VAC) services. In the table, the 8/20 microsecond current waveform defines a transient reaching peak value in 8 microseconds and decays to 50 percent of that peak value in 20 microseconds. SPDs should be able to tolerate surges of shorter duration i.e., less than five (5) nanoseconds without malfunction.

Table 2-1. Line-to-Ground Surge Levels for 120/240, 120/208 Y and 277/480 Y Service Line

Surge Current Amplitude 8 by 20 Microsecond Waveform (*4 by 10 Microsecond)	Number of Surges (Lifetime)
10 kA	1,500
20 kA	700
30 kA	375
40 kA	50
50 kA	8
60 kA	6
70 kA	4
100 kA*	2
180-240 kA*	1

2.5.2 Facility AC Surge Protection Device

A facility AC surge protection device should be installed on the load side of the facility service disconnect. The SPD may be a combination of solid-state circuits i.e., silicone avalanche diode (SAD), metal oxide varistor (MOV), or other devices that fire faster than 5 nanoseconds. For services with a neutral, SPD elements will be connected to protect all surge modes of coupling: line to ground (L-G), line to neutral (L-N), and neutral to ground (N-G). For services without a neutral, SPD elements will be installed on the primary side, line to line (L-L) and each line to ground (L-G), of any NWS-owned distribution transformer.

Examples:

- a. 3-phase, 4-wire DELTA-WYE neutral grounded system: The SPD will be connected for 7 modes of coupling: (L-N) 3, (L-G) 3, and (N-G) 1.
- b. 3-phase, 3-wire DELTA grounded system: The SPD will be connected (L-L) 3, (L-G) 3 for 6 modes of coupling.

Using these examples, all possible entry points of overvoltage and surge currents are secured.

2.5.2.1 Characteristics

Minimum functional and operational characteristics of facility SPDs installed at the service disconnect will be as follows:

- a. **Maximum Continuous Operating Voltage (MCOV).** MCOV is the maximum voltage that can be applied across SPD terminals with the device remaining in an off (nonconducting) state. The MCOV of the SPD will not be less than 115 percent of nominal root mean square (RMS) line voltage.
- b. **Leakage Current.** Leakage current across the device terminals will not exceed 100 microamps at MCOV.

- c. Turn-on Voltage.** Turn-on voltage is the minimum voltage across SPD terminals that will cause the arrester to turn on and conduct. Turn on voltage should not exceed 125 percent of MCOV. The arrester response time shall be less than five (5) nanoseconds in order to capture the entire lightning current spike.
- d. Discharge (Clamp) Voltage.** Clamp voltage is the maximum voltage appearing across an arrester output terminal while conducting surge currents. Clamp voltage should not exceed 160 percent of MCOV.
- e. Overshoot Voltage.** Overshoot voltage will not exceed 2 times the SPD clamp voltage for more than 10 ns. Overshoot voltage is the surge voltage level appearing across the SPD terminals before the device turns on and clamps the surge to the specified voltage level.
- f. Self-Restoring Capability.** The SPD will automatically return to an off state after surge dissipation when line voltage returns to normal.
- g. Operating Lifetime.** The SPD will safely dissipate the number and amplitude of surges listed in [Table 2-1](#). Clamp (discharge) voltage should not change more than 10 percent over the operating life of the arrester.
- h. Fusing and Indicator Lamps.** The input to each SPD will be internally fused to protect the AC power supply equipment against overload should an SPD short-circuit. This fusing should not increase the clamp voltage of the SPD and should pass the surge current levels given by [Table 2-1](#) up to the 70KA level without opening. Fusing provided will open on application of a steady state current at a level low enough to prevent damage or degradation to the AC power supply. Indicator lamps per phase on the SPD enclosure cover should visually indicate that fuse(s) have opened.

2.5.2.2 Packaging

All components comprising an SPD will be housed in a single National Electrical Manufacturers Association (NEMA) type 4 enclosure or minimum equivalent for indoor or outdoor use. If the SPD is to be installed in a corrosive atmosphere, it will be packaged in a single NEMA type 4X enclosure (see description in [Table 2-2](#)). **SPDs may be enclosed within panelboards or switchgear, if they are UL-approved for such installation.** Heavy-duty, screw-type studs and/or UL-approved screw pressure connectors will be provided for all input and output connections. The SPD elements, when not connected to phase and neutral conductors, should be electrically isolated from the enclosure by a minimum of 10 megohms. The enclosure door will be electrically bonded to the enclosure. Fuses, lights, fuse conductors, and arrester elements will be readily accessible for inspection and replacement.

Table 2-2. NEMA Enclosure Types

1	General Purpose - Indoor
2	Drip-proof - Indoor
3	Dust-tight, Rain-tight, Sleet-tight - Outdoor
3R	Rain-proof, Sleet-resistant - Outdoor
3S	Dust-tight, Rain-tight, Sleet-resistant - Outdoor
4	Water-tight, Dust-tight, Sleet-resistant - Indoor and Outdoor
4X	Water-tight, Dust-tight, Corrosion-resistant - Indoor and Outdoor
5	Dust-tight - Indoor
6	Submersible, Water-tight, Dust-tight, Sleet-resistant - Indoor and Outdoor
6P	Water-tight - Prolonged Submersion - Indoor and Outdoor
7	Class 1, Group A, B, C, or D Hazardous Locations, Airbreak -Indoor
8	Class 1, Group A, B, C, or D Hazardous Locations, Oil-immersed - Indoor
9	Class 2, Group E, F, or G Hazardous Locations, Airbreak -Indoor
10	Bureau of Mines
11	Corrosion-resistant and Drip-proof, Oil-immersed - Indoor
12	Industrial-use, Dust-tight, and Drip-tight - Indoor
12K	Industrial-use, Dust-tight, and Drip-tight With Knockouts - Indoor
13	Oil-tight and Dust-tight - Indoor

2.5.2.3 Installation

The SPD should be installed as close as practical to the main service disconnecting means. Wiring connections from the SPD to the service disconnecting means should be no longer than 12 inches and may be other than the gauge specified herein if recommended by the manufacturer.

Connections will be made with UL-approved pressure connectors.

- a. **Phase Connections.** Phase lugs of the SPD will be connected to corresponding phase terminals of the service disconnect with insulated No. 4 AWG copper cable. Connections will be as short and direct as possible without loops, sharp bends, or kinks.
- b. **SPD Ground and Neutral Connections.** The ground connection for the SPD element should be from its output terminal to the ground bus in the service disconnect. In a grounded neutral system, the neutral connection for SPD elements will be routed in a similar manner as above to the neutral bus of the service disconnect. These neutral connections should be not less than a No. 4 AWG copper

conductor, insulated, and color-coded white. SPD element terminals will be electrically insulated from the SPD enclosure.

- c. **Equipment Grounding Conductor (EGC).** The SPD enclosure will be connected to the ground bus in the service disconnecting means enclosure with no less than a No. 6 AWG copper conductor. The conductor will have a green insulation.

2.5.3 Surge Protection Devices for Distribution and Branch Panels

SPDs will be installed on all critical and essential panels providing service to NWS electronic equipment. SPDs will be sized using guidance provided in IEEE C62.41 and meet the manufacturer's product testing requirements of UL 1449 (2nd edition) and IEEE C62.45. SPDs for panels serving critical loads will be tested for a location category level C3 application under IEEE C62.41. These devices will be installed, in accordance with the manufacturer's instructions, as close as possible to the panel they serve. The MCOV for SPDs located at branch and distribution panels should be greater than the MCOV of those located at the facility service entrance.

2.5.4 Electronic Equipment Power Entrance

SPDs, components, or circuits for protection of electronic equipment power lines should be provided as an integral part of all electronic equipment. These devices will be positioned at the AC power conductor entrance to electronic equipment provided as part of the facility. Transient protection will be provided on all surge modes of coupling: line to line (L-L), line to neutral (L-N), line to ground (L-G), and neutral to ground (N-G). The MCOV for SPDs located at the equipment should be equal to or greater than the MCOV for those located at branch and distribution panels. SPDs at equipment should provide a clamping level less than the equipment susceptibility level.

2.5.4.1 Characteristics

Basic characteristics of surge suppression components or circuits for equipment power lines should comply with the following requirements:

- a. **Maximum Continuous Operating Voltage (MCOV).** MCOV of the SPD should be equal to or greater than 130 percent of the nominal line voltage.
- b. **Turn-on Voltage.** Turn-on voltage, discharge (clamp) voltage, and the amplitude and time duration of any overshoot voltage should be sufficiently low to preclude electronic equipment damage or operational upset.
- c. **Leakage Current.** Leakage current for each suppression component at MCOV should not exceed 100 microamperes.
- d. **Self-Restoring Capability.** Surge suppressors should automatically restore to an off state when surge voltage falls below the turn-on voltage for the suppressor.
- e. **Operating Lifetime.** Clamp voltage should not change more than 10 percent over the operating lifetime. When not located within a facility protected by the SPD, the electronic equipment surge suppression device should be capable of safely dissipating the number and amplitude of surges specified in [Table 2-1](#).

2.5.4.2 Packaging

Suppression components should be housed in a separate, nonmetallic compartmentalized enclosure as an integral part of the electronic equipment design. Bulkhead mounted feed-through capacitors or equivalent will be used as necessary to prevent high-frequency transient energy from coupling to electronic equipment circuits. Suppression components will be grounded to the electronic equipment case as directly as feasible.

2.5.4.3 DC Power Supply Transient Suppression

Power supplies using 60 hertz (Hz) power and furnishing DC operating voltages to solid-state equipment will have transient suppression components from each outlet of the power supply to the equipment chassis. The ground side of the suppressors should be connected as directly as possible to rectifier output ground. Operating characteristics of suppression components provided for power supply rectifier output lines should be:

- a. **MCOV.** MCOV should be above maximum rectifier output voltage.
- b. **Leakage Current.** Leakage current to ground should not exceed 100 microamperes at MCOV.
- c. **Turn-on Voltage.** Turn-on voltage should be as near MCOV as possible using commercially available SAD suppressors, and should not exceed 125 percent of MCOV. The arrester response time shall be less than five (5) nanoseconds in order to capture the entire lightning current spike.
- d. **Discharge (Clamp) Voltage.** Clamp voltage should be the lowest possible value that can be obtained using commercially available suppressors not exceeding 160 percent of MCOV.
- e. **Overshoot Voltage.** Overshoot voltage should be sufficiently low to preclude electronic equipment damage or operational upset. Time duration of overshoot voltage should be limited to the shortest possible time not exceeding 5 nanoseconds.
- f. **Self-Restoring Capability.** Transient suppression installed in power supplies should automatically restore to an off state when line transient voltage falls below the rated turn-on voltage for the suppressor.
- g. **Testing Criteria.** Transient suppressors should safely dissipate 1,000 surges with an amplitude of 200 amps and a voltage waveform of 1.2 by 50 microseconds. One point two (1.2) microseconds defines the time from the start of the transient to peak current, and 50 microseconds is the time from the peak current of the transient until the transient decays to 50 percent of its peak value.

2.6 Conducted Signal, Data, and Control Line Transients

Transient protection should be provided for all signal, data, and control lines, both at facility entrances and at entrances to electronic equipment. This protection will limit transients at the equipment entrance to below the equipment susceptibility level. This includes all signal, data, control, status and inter-facility power lines installed above and below grade between facility structures and to externally mounted electronic equipment. Additional protection design and packaging requirements specifically applicable to audio, radio frequency (RF), and other signals transmitted by axial cables are specified in the following subparagraphs.

2.6.1 Transient Levels

Electronic equipment using landlines should be protected against the transient levels defined in [Table 2-3](#). Landlines continuously enclosed in ferrous conduit are different from landlines *not* continuously enclosed in ferrous conduit. Landlines continuously enclosed in ferrous conduit require transient protection only at electronic equipment entrances. Landlines not continuously enclosed in ferrous conduit require transient protection both at electronic equipment and at facility entrances.

Table 2-3. Conducted Landline Transient Levels

No. of Transients (8 by 1000µs) Microsecond Waveform	Peak Amplitude (Voltage and Current)	
	Lines Continuously Enclosed in Ferrous Conduit	Lines Not Continuously Enclosed in Ferrous Conduit
1,000	50V, 10A	100V, 50A
500	75V, 20A	500V, 100A
50	100V, 25A	750V, 375A
5	100V, 50A	1000V, 1000A

Source: FAA-STD-019d

2.6.1.1 Surge Protective Device Testing Compliance

All SPDs should comply with the testing standards of IEEE C62.45 or UL 1449 (2nd edition) and be tested to the waveforms (1.2 x 50 microseconds – voltage, and 8 x 20 microseconds – current) specified in IEEE 62.41. SPDs can be control-tested to European surge test EN61000-4-5. Location categories should be as described in IEEE C62.41 (A3, B3, or C3).

2.6.2 Protection Design

Detailed analysis of suppression component and electronic equipment circuit characteristics are required to select components compatible with the requirements herein and to provide suppression circuits that will function without adversely affecting signals and information transmitted by individual circuits. Design requirements for selection of components are:

- a. Unipolar suppression components should be selected and installed for signals and voltages that are always positive or always negative relative to reference ground. Bipolar suppression components should be selected for signals and voltages that are both positive and negative relative to reference ground.
- b. Total series impedance of the suppression circuits at both ends of a landline should not degrade electronic equipment performance. The baud rate of the suppression circuit should be compatible with the equipment.
- c. High-energy protection components at facility entrances will be selected to reduce the magnitude of transient levels to equipment below their electronics susceptibility levels for individual lines.

- d. Suppression components at the facility and electronic equipment entrances and any impedance added to ensure coordination will be selected to function together. The transient protection components at the facility entrance and the transient protection components at the electronic equipment entrance will be selected to clamp and limit the transient voltage and energy safely below circuit susceptibility levels.

2.6.3 Characteristics

The combined operating characteristics for landline transient suppression at facility and electronic equipment entrances and requirements for individual devices should be as follows:

- a. **MCOV.** The MCOV rating of the suppression components should be 15 to 25 percent above normal peak line voltage.
- b. **Leakage Current.** Leakage current to ground should not exceed 100 microamperes at MCOV.
- c. **Turn-on Voltage.** Turn-on voltage of the suppression components should be as close to MCOV as possible using commercially available devices, and should not exceed 125 percent of MCOV. The arrester response time shall be less than five (5) nanoseconds in order to capture the entire lightning current spike.
- d. **Overshoot Voltage.** Overshoot voltage amplitude and duration limits should be low enough to preclude electronic equipment damage or operational upset. The requirement should apply for transients with rise times up to 5,000 V/microsecond.
- e. **Discharge (Clamp) Voltage.** Clamp voltage should be below the electronic equipment susceptibility levels while dissipating the transients listed in [Table 2-3](#).
- f. **Operating Life.** The transient suppression system should dissipate the transients defined in [Table 2-3](#). Clamp voltage levels should not change more than 10 percent over the operating life of the suppression system.
- g. **Self-Restoring Capability.** The transient suppression system should automatically return to the off state when the transient voltage level drops below turn-on voltage for the suppressors.

2.6.4 Location of Landline Transient Protection

Transient suppression components for signaling, data, and control lines of electronic equipment should be housed in nonmetallic compartmentalized enclosures. When landlines terminate at a junction box provided by others, a separate junction box may be provided for installation of suppression components. A ground bus bar, electrically isolated from the enclosure, should be provided in the junction box to serve as an earth ground point for the high-energy transient suppressors. The ground bus bar should be directly connected to the EES with an insulated No. 4 AWG or larger copper wire of minimum length with no loops, sharp bends, or kinks. A UL-approved connector will be used to bond the conductor to the ground bus bar. The bonding connection to the EES will be an exothermic weld. The ground bus bar location should permit a short, direct connection to transient suppressors. The installation should provide easy access to component terminals for visual inspection, testing, and replacement. Each suppression device should be replaceable, or at a minimum, the suppressor and resistor for each line should be replaceable as a unit. Bulkhead mounted, feed-through capacitors should be used, if necessary, to prevent high-frequency transient energy from coupling to electronic equipment circuits.

2.6.5 Installation of Suppression Components at Electronic Equipment

Transient suppression components at electronic equipment will be housed in a separate, nonmetallic enclosure. Components used should be leadless or of minimum length with no loops, sharp bends, or kinks. Access should be provided for visual inspection and replacement of components.

2.6.6 Externally Mounted Electronic Equipment

When landlines are directly connected to externally mounted electronic equipment, the landline SPD specified in this document for both facility and electronic equipment entrances will be provided at the electronic equipment entrance. This combined protection will provide separate high- and low-energy components with a single grounding path. The high-energy suppression components will be grounded directly to the EES. This connection should be accomplished with a minimum No. 4 AWG insulated copper conductor. The low-energy suppression component will be grounded to the reference ground used by the circuit to which the landline is connected, or to the electronic multipoint ground system. The grounding conductors for the high- and low-energy components should be of minimum length and routed to avoid sharp bends, kinks, or loops. Access should be provided for visual inspection of these suppressors and for their replacement.

2.6.7 Axial Landlines

Transient protection for electronic equipment will be provided both at facility entrances and at the electronic equipment. Transient suppression should be provided equally for each conductor and shield that is not grounded directly to the electronic equipment case.

2.6.7.1 Protection Design

Special attention should be given to the design of transient protection for axial-type lines, as noted below:

- a. Suppression circuits should be designed using commercially available components.
- b. Packaging of suppression components and circuits should be designed to minimize the effect on transmitted signals. Feed-through components, leadless components, or short direct-lead connections without bends will improve performance of the suppression circuit and reduce signal degradation.
- c. Analyses and tests must be performed by a recognized engineering laboratory and must meet all surge suppressor tests required by UL 1449 (2nd edition) to ensure suppression components do not degrade signals to an unacceptable degree or cause marginal operation of electronic equipment. Particular attention should be given to the impedance, insertion loss, phase distortion, and voltage standing wave ratio for RF signals.

NOTE: Any critical electronic equipment that has interconnecting cables extending outside the facility lightning protection system will be protected by surge suppression devices.

2.6.7.2 Metal Bulkhead Connector Plates

A metal bulkhead connector plate will be provided where axial-type cables, waveguides, conduits, etc., first enter an NWS facility. The connector plate should be a minimum of 1/4 inch thick and constructed of tin-plated copper, or other material compatible with the connectors. Connector plate or plates will have the required number and types of feed-through connectors to terminate all coaxial lines and provide adequate surface area for bonding waveguides, cable shields, conduits, etc. The connectors will provide a path to ground for cable shields. If external and internal cables are of different sizes, the changeover in cable size should be accomplished by the feed-through connectors at the plate. Waveguides, conduits, etc., will be bonded to bulkhead plates with a No. 4 AWG copper conductor minimum. This bonding jumper will be connected to the plate by means of an exothermic weld or a double-bolted lug. The bulkhead plate will be bonded to the EES with a No. 4/0 AWG copper conductor minimum (see [Figure 2-2](#)). Additionally, when building steel is properly bonded to the EES, the bulkhead connector plate can be connected to building steel.

NOTE: Exothermic welds will be used for all connections to the EES.

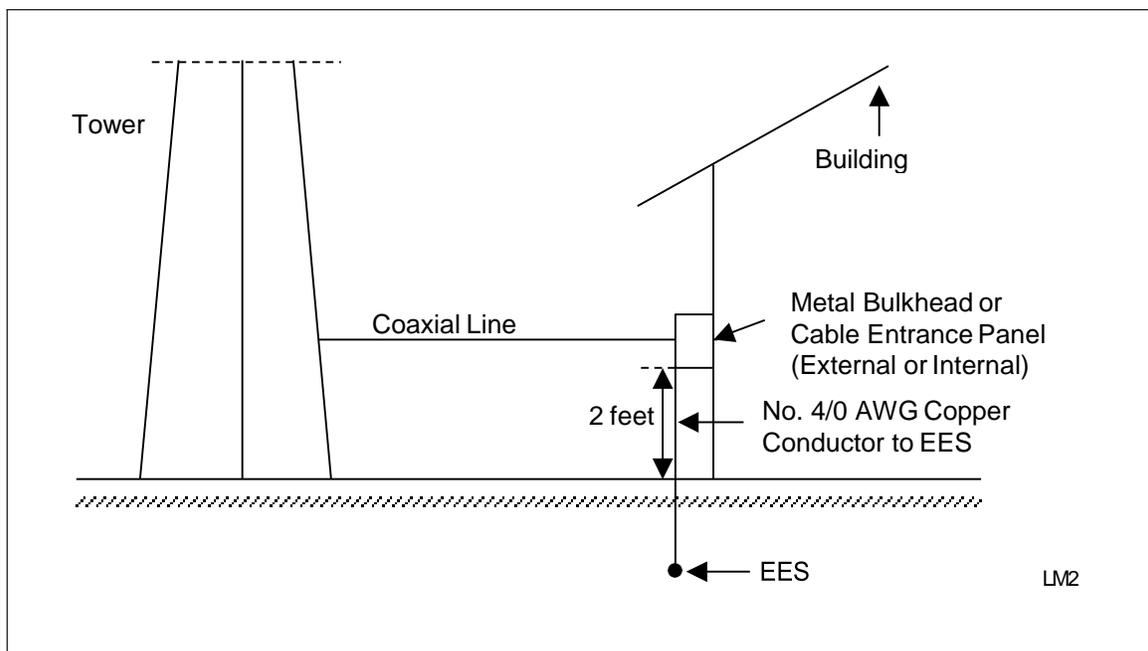


Figure 2-2. Waveguide, Coaxial Line, and Conduit Penetration (for NWS Facility Only)

2.6.7.3 Installation of Suppression Components at Facility Entrances

Transient suppression components for axial-type cables should be packaged in a sealed metal enclosure with appropriate connectors at each end to permit in-line installation at the bulkhead connector plate required in [Section 2.6.7.2](#).

2.6.7.4 Installation of Suppression Components at Electronic Equipment Entrances

Off-the-shelf suppression components should be provided as an integral part of electronic equipment design. When electronic equipment without internal transient suppression is required for the facility, electronic equipment suppression components should be packaged with compatible connectors on each end permitting in-line connection directly to the equipment. When isolation of the cable shield and connector body is required for electronic equipment operation, suppression component grounds should be isolated from the component housing and connected directly to the electronic equipment case. Electronic equipment case entrances should be located in a common area, close to the case ground to minimize circulating currents on the case.

2.6.8 Location of Transient Protection

The location of transient protection for landlines is specified both at entrances to facilities and at entrances to electronic equipment within facilities. Depending on the type of electronic equipment and planned facility installation, combining the transient suppression specified at facility and electronic equipment entrances may be acceptable. Transient protection designs for landlines combining the protection specified herein for installation at one location will:

- a. Provide high-energy suppression component(s) connected from line to the facility EES to remove a major percentage of transient energy from each line.
- b. Be located at the entrance to the facility.
- c. Provide low-energy suppression components connected from line to electronic equipment case ground to reduce transient energy and voltages to safe levels below the electronic equipment susceptibility level for each line.

2.6.9 Fiber-optic Cable

Where fiber-optic cable uses a conductive armor, the armor should be bonded to the EES at the facility entrance. If the cable is internal to the facility, conductive armor will be bonded to the multipoint ground (MPG) system near the equipment entrance. The use of fiber-optic cable without a conductive shield or armor is permitted.

2.7 Lightning Protection System Requirements

The intention of the lightning protection system (LPS) is to provide preferred paths for lightning discharges to enter or leave the earth without causing facility or equipment damage or injury to personnel. The essential components of an LPS are:

- a. Air terminals
- b. Roof, bonding, and down (main) conductors
- c. Ground rods
- d. Surge protection.

These components act together as a system to dissipate lightning energy. The LPS will meet or exceed the requirements of National Fire Protection Association (NFPA) 780, Standard for the Installation of LP Systems. Materials used for an LPS will follow the lightning protection components selections shown in the UL 96, Lightning Protection Components.

2.7.1 Materials

All equipment will be UL-listed for lightning protection purposes and marked following UL procedures. All equipment should be new and of a design and construction to suit the application under UL 96 material requirements; however, aluminum will be used on aluminum roofs, aluminum siding, or other aluminum surfaces. Aluminum materials will not be used on surfaces coated with alkaline-base paint, embedded in masonry or cement, on copper roofing, or in contact with copper and aluminum conductors. Dissimilar materials will conform to the bonding requirements of Section [2.13.2.3](#).

2.7.2 Main Conductors

Roof bonding and down conductors will be stranded and will meet the requirements given in NFPA 780. On upper air domes at upper air sites, four equally spaced 10-inch air terminals will be installed around a full perimeter roof platform, as shown in [Figure 2-3](#).

2.7.2.1 Structural Steel Used as Main Conductors

The steel metallic framework of a structure will be permitted to be utilized as the main conductor of a lightning protection system if it is electrically continuous from roof to ground foundation or is made electrically continuous.

2.7.3 Hardware

Hardware will meet the requirements in the following subsections.

2.7.3.1 Fasteners

Roof bonding and down conductors will be fastened at intervals not exceeding 3 feet (0.9 m). Fasteners will be of the same material as the conductor base material, the bracket being fastened, or other equally corrosion resistant material.

2.7.3.2 Fittings

Bonding devices, cable splicers, and miscellaneous connectors will be UL-approved for use with the installed conductor and will be copper or aluminum with bolt pressure connections to the cable. Aluminum fittings will only be used with aluminum conductors. Copper fittings will only be used with copper conductors.

2.7.4 Guards

Guards will be provided for conductors located in or next to driveways or other areas where they may be displaced or damaged. Guards will extend at least 6 feet (1.8 m) above and 1 foot (0.3 m) below grade level. Guards should be schedule 40 polyvinyl chloride (PVC) pipe where feasible. Metal guards may be used but will be bonded to the down conductor at both ends. Bonding jumpers will be of the same size as the down conductor. PVC guards do not require bonding. Crimp-type fittings will not be used.

2.7.5 Bonds

Certain metallic bodies located outside or inside a structure contribute to lightning hazards because they assist in providing a path to ground for lightning currents. Such metallic bodies will be bonded to the LPS wherever a side flash can occur between the LPS conductors and a metal

body. This will be done following NFPA 780 guidance. Bonding to the LPS conductor will also be applied to other metal bodies permanently affixed to the structure.

2.7.5.1 Metallic Bodies Subject to Direct Lightning Discharge

Metallic bodies, on roofs, subject to direct lightning discharge are generally any large metallic body whose size causes it to protrude beyond the zone of protection of the installed air terminals. This includes, but is not limited to, exhaust pipes; exhaust fans; metal cooling towers; heating, ventilation, and air conditioning (HVAC) units; ladders; railings; antennas; and large louvered structures. When these metallic bodies have a metal thickness of 3/16 inch or greater, they should be bonded to the nearest main LPS roof conductor with UL-listed fittings for lightning protection (see UL 96 for a list of lightning protection components). These fittings will provide bonding surfaces of not less than 3 square inches (approximately 1.75 inches by 1.75 inches). Provisions will be made to prevent corrosion effects introduced by galvanic action of dissimilar metals at bonding points. If the metal parts of these units are less than 3/16-inch thick, additional approved air terminals, bonding conductors, and fittings will be installed to provide an additional path to ground from these additional air terminals.

2.7.5.2 Metallic Bodies Subject to Induced Charges

Metallic bodies on or below the roof level, subject to induced charges from lightning within 6 feet of an exposed LPS element, will be bonded to the LPS using UL-approved pressure connectors and conductors. This includes, but is not limited to, the following metallic items: roof drains, vents, coping, flashing, gutters, downspouts, metal doors, metal door and window frames, balcony railing, conduits, and pipes. Fittings and conductors used will be UL-listed for lightning protection. The 3-square-inch bonding surface contact area will apply.

2.7.5.3 Exhaust Stack Grounding

Exhaust stacks used for either fossil fuel heating or for engine generators create a plume of highly ionized, heated air. This plume may attract cloud-to-ground lightning. Bond all exhaust stacks to the nearest point on the LPS with a conductor equal in size to the down (main) conductor to prevent flashover (see NFPA 780 [2004], Chapter 6). The bond to the exhaust stacks will be made with an exothermic weld or a UL-approved mechanical connector.

2.7.5.4 Above-Ground Fuel and Oil Storage Tanks

Provisions will be made to prevent direct lightning strikes to above-ground storage tanks. A separately mounted LPS should be provided where part of the above-ground storage tank extends outside the facility LPS. When this is the case, a mast with elevated ground wires should be used (see NFPA 780 Figure 7.3.3.9). The separate LPS bonding connection conductor should be exothermically welded to the EES. Nonmetallic (fiberglass) above-ground fuel and oil storage tanks shall not be installed, because elevated ground wires will not protect against lightning induced Ground Potential Rise (GPR) which may result in fire or explosion.

2.7.6 Conductor Routing

Roof and down conductors will maintain a horizontal or downward course. No bend in a roof or down conductor will form an included angle less than 90 degrees (no acute angles), nor will it have a bend radius of less than 8 inches (0.203 m). Conductors will be routed external to buildings and greater than 6 feet (1.8 m) from other power or signal conductors.

2.7.6.1 Down Conductors on Fiberglass Mounting Poles

Where a fiberglass pole is used to mount an air terminal, the air terminal will extend at least 2 feet above the top of the pole and will be securely fastened to the pole following the requirements of NFPA 780. The down conductor from the air terminal will be run on the exterior of the fiberglass pole and will be fastened to the pole at intervals not exceeding 3 feet (0.9 m). The down conductor will be connected to ground and bonded, if necessary, to the EES using Section [2.7.7](#) guidance.

2.7.7 Down Conductor Terminations

Down conductors used to ground air terminals and roof conductors will be a No. 2 AWG (minimum) copper conductor prior to entering the ground. The No. 2 AWG copper conductor will enter the ground and be connected to a ground rod. This ground rod will be bonded to the EES with an exothermic weld using a No. 4/0 AWG copper conductor connection. The top of the ground rod will be located 1 foot (0.3 m) to 2 feet (0.6 m) vertically below ground level and from 2 feet (0.6 m) to 6 feet (1.8 m) outside the foundation or exterior footing of the building.

2.7.8 Buildings

Lightning protection will be provided for all buildings, or parts thereof, not within the zone of protection provided by another building or higher part of the same building. Zones of protection for all structures will be as defined in NFPA 780.

2.7.8.1 Air Terminals

Air terminals will be solid copper, bronze, aluminum, or stainless steel (only in areas of high corrosion). Copper air terminals may be nickel-plated. Air terminals will be a minimum of 10 inches (254 mm) in height, at least ½ inch (12.7 mm) in diameter for copper and 5/8 inch (15.9 mm) in diameter for aluminum. Air terminals will be located according to the recommendations of NFPA 780. Air terminals will extend at least 10 inches above the object or area they are to protect unless they are mounted on walking or working surfaces. In this case, the tip of the air terminal will not be less than 5 feet above the walking or working surface. Air terminals will be placed on the ridges of pitched roofs and around the perimeter of flat or gently sloping roofs at intervals not exceeding 20 feet (6.1 m). Air terminals will be bonded to the nearest roof or down conductor, and connected to the EES following Section [2.7.7](#) guidance.

2.7.8.2 Number of Down Conductors

No less than two down conductors will be provided for buildings with perimeters of 250 feet (76 m) or less. Down conductors will be as widely separated as possible; e.g., at diagonally opposite corners on square or rectangular buildings. Buildings with perimeters in excess of 250 feet (76 m) will have one down conductor for each 100 feet (30.5 m) of perimeter distance or part thereof. Building steel and metal supporting structures, such as conduits, may be used in place of down conductors.

2.7.8.3 Metal Parts of Buildings

Metal roofing, siding, eave troughs, down spouts, ladders, ducts, and similar metal parts will not be used as substitutes for roof or down conductors. ***A lightning protection conductor system will be attached to the metal roof and to the metal siding of a metal-clad building in the same***

manner as on a building without metal covering. Building metal parts will be bonded following Section [2.7.5](#) guidance.

2.7.8.4 Roof-Mounted Antennas

If metallic, the mast of a roof-mounted antenna will be bonded, *in two directions*, to the nearest roof or down conductor using UL-approved fittings and conductors. The bonding jumper will be of the same size and material as the roof or down conductor to which it is connected. If a roof or down conductor is not available, then the antenna mast should be bonded directly to the EES by means of exothermic welding. A suitable connection to the EES is required for the Global Positioning System (GPS) repeater antenna.

2.7.8.5 Radomes Not Mounted on Towers

A 150-foot radius zone of protection will be established to include all radome surfaces. Follow guidance in NFPA 780.

2.7.8.6 Upper Air Buildings

Lightning air terminals will be installed at the four corners of the platform located at the bottom of the dome. Air terminals will be mounted on 14-foot (approximately) fiberglass masts, as shown in [Figure 2-3](#). A single 24-inch air terminal will be installed at the apex of the dome (also shown in [Figure 2-3](#)). See [Appendix I](#) for an alternative catenary type of design.

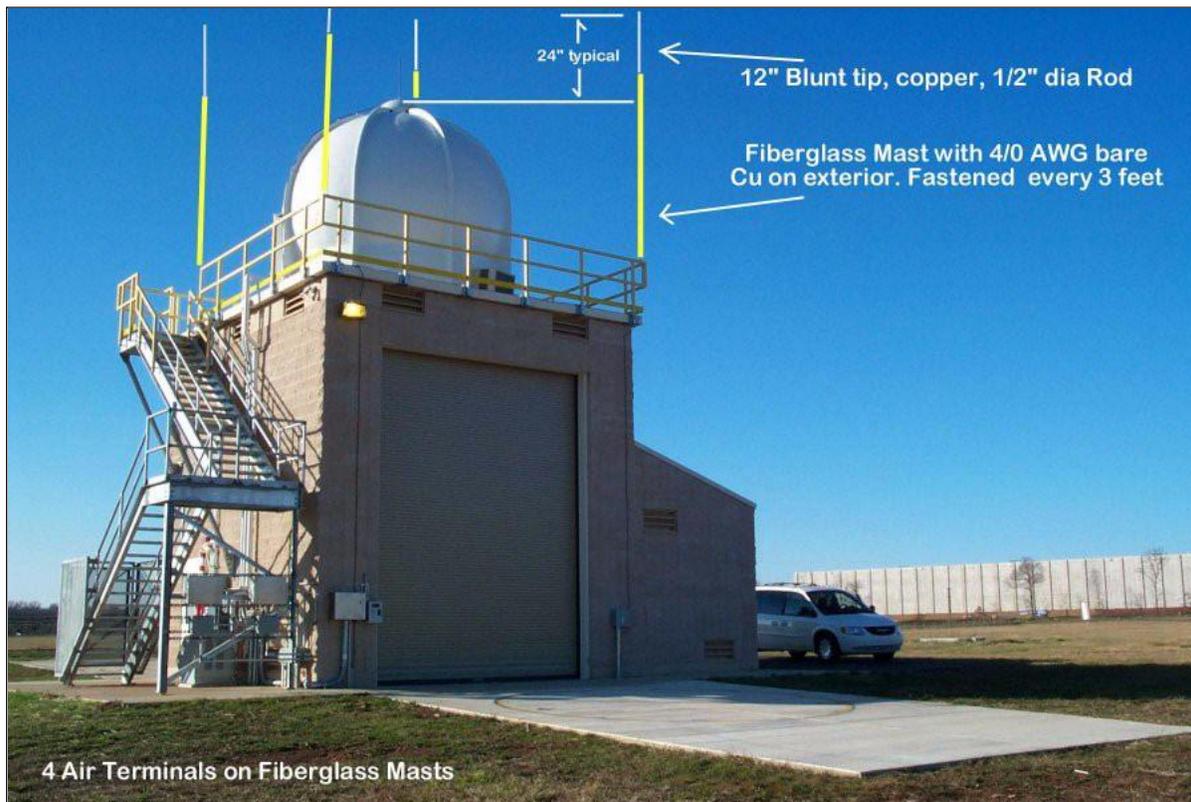


Figure 2-3. Lightning Protection for Upper Air Buildings (Franklin Rod Design)

2.7.9 Antenna Towers

Antenna towers will be protected from lightning by following the guidelines specified below.

2.7.9.1 Number of Down Conductors

Pole-type towers will have one down conductor. Towers consisting of multiple parallel segments or legs that sit on a single pad or footing not over 9 square feet in area are considered pole-type towers. All other towers will have at least two down conductors. Large towers, such as radar towers, will have one down conductor per leg. Down conductors will be routed down the inside of the legs wherever practical and secured at intervals not exceeding 3 feet (0.9 m) following Section [2.7.7](#) guidance.

2.7.9.2 Towers Without Radomes

Pole-type towers will be protected by at least one air terminal to provide a Zone of Protection for all antennas located on the tower following NFPA 780 requirements. Protection may be provided for large radar antennas by extending structural members above the antenna and mounting the air terminal on top as shown in [Figure 2-4](#). The air terminal will be supported on the structural member and will have a UL-approved fitting on its base. The down conductor from the air terminal will be connected to a perimeter cable that forms a loop around the perimeter of the tower platform. Down conductors will be run from the perimeter cable to the EES. Except where only one down conductor is required, each air terminal will be provided with at least two paths to ground. All conductors including the LPS will be exothermically welded to the EES with a size No. 4/0 AWG copper conductor minimum.

2.7.9.3 Radomes

Radomes will be located within a Zone of Protection established according to the 150-foot radius “Rolling Sphere Model” rule (see NFPA 780). This protection can be either from air terminals mounted on the radome or catenary wires mounted independently of the radome. When air terminals are mounted on the radome, they must have two paths to ground. An equalization ring should be established at the radar antenna deck level.

2.7.9.4 Towers With Radomes

Towers with spherical radomes will be protected with a 2-foot (0.62 m) high (minimum) air terminal at the peak and four or more air terminals equally spaced around the circumference of the radome. Spacing of the circumferential air terminals may be adjusted if the antenna pattern is affected; however, their position and height will be interconnected with a main conductor. As indicated in [Figure 2-4](#), this conductor, labeled “Interconnecting Conductor,” will be connected to the air terminal at the peak of the radome. The interconnecting conductor will also be connected to the peripheral conductor that forms a loop around the base of the radome. The down conductors noted above will be run in a path following the contour of the radome as shown in [Figure 2-4](#).

All lightning protection connections will be free of paint and galvanizing. Scrape all steel free of surface contaminants or surface treatments prior to making exothermic welds.

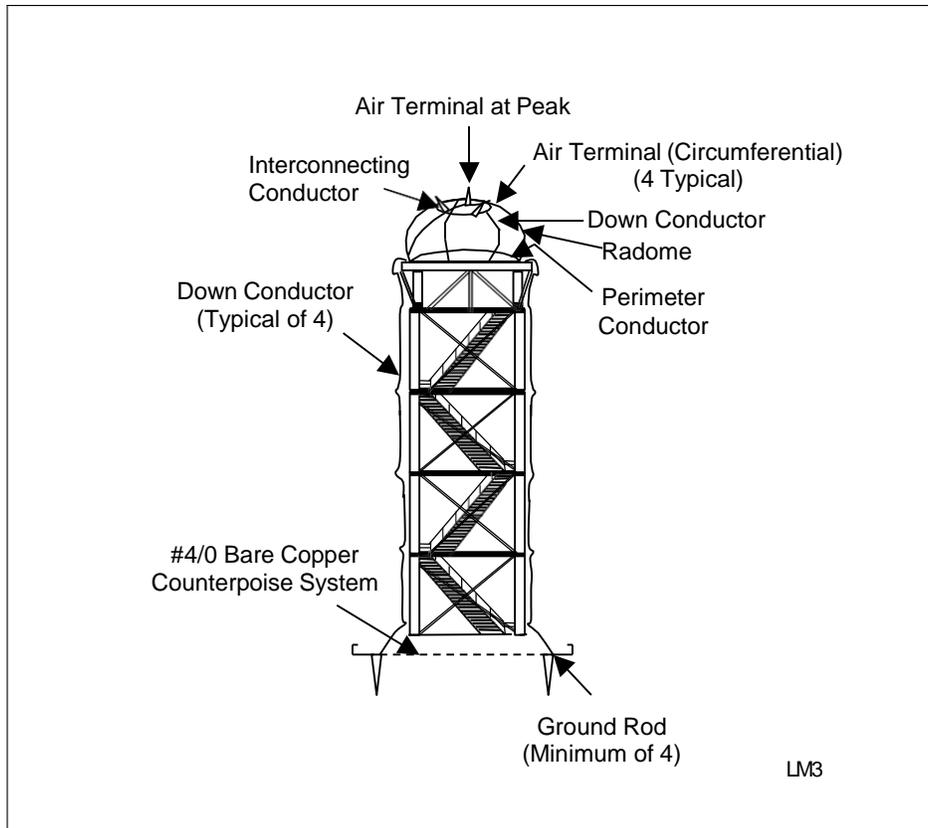


Figure 2-4. Lightning Protection for Radomes and Radar Antenna Platforms (Crown of Thorns)

- NOTE:**
1. Bond down conductors to each tower leg section. Exothermically weld down conductor to a 4/0 AWG copper conductor above grade. Route 4/0 conductor through 1-inch PVC conduit around concrete pier and 12 inches below grade. All conductor bend radii must be 8 inches or greater.
 2. All lightning protection connections will be free of paint and galvanizing. Scrape all steel free of surface contaminants or surface treatments prior to making exothermic welds.

2.7.9.5 Antenna Protection

Air terminals will be placed to protect structural towers and buildings, and antennas mounted to towers and on buildings.

2.7.9.6 Tower Guying

All metallic guy wire systems without insulators will be connected to the ground system.

- a. **Low Conductivity Anchors.** On guy wires terminating in low conductivity anchors (such as concrete), a jumper of the same material as the guy wire should be mechanically bonded to each wire above its lowest turnbuckle. Where multiple guy wires terminate on a single anchor, the jumper may daisy-chain through the guy

wires. The jumper should be exothermically welded to a 3/4-inch by 10-foot ground rod that is exothermically welded and bonded to the EES. Mechanically bonded jumpers of the same material as the guy wire should be placed across any intermediate turnbuckles in a guy wire. All jumper connections to the guy wires should be made with UL-approved connectors (see [Figure 2-5](#) for depiction of guy wire and anchor grounding).

- b. Metallic Anchors.** A jumper of the same material as the guy wire will be mechanically bonded across each turnbuckle in the guy wire with UL-approved connectors.

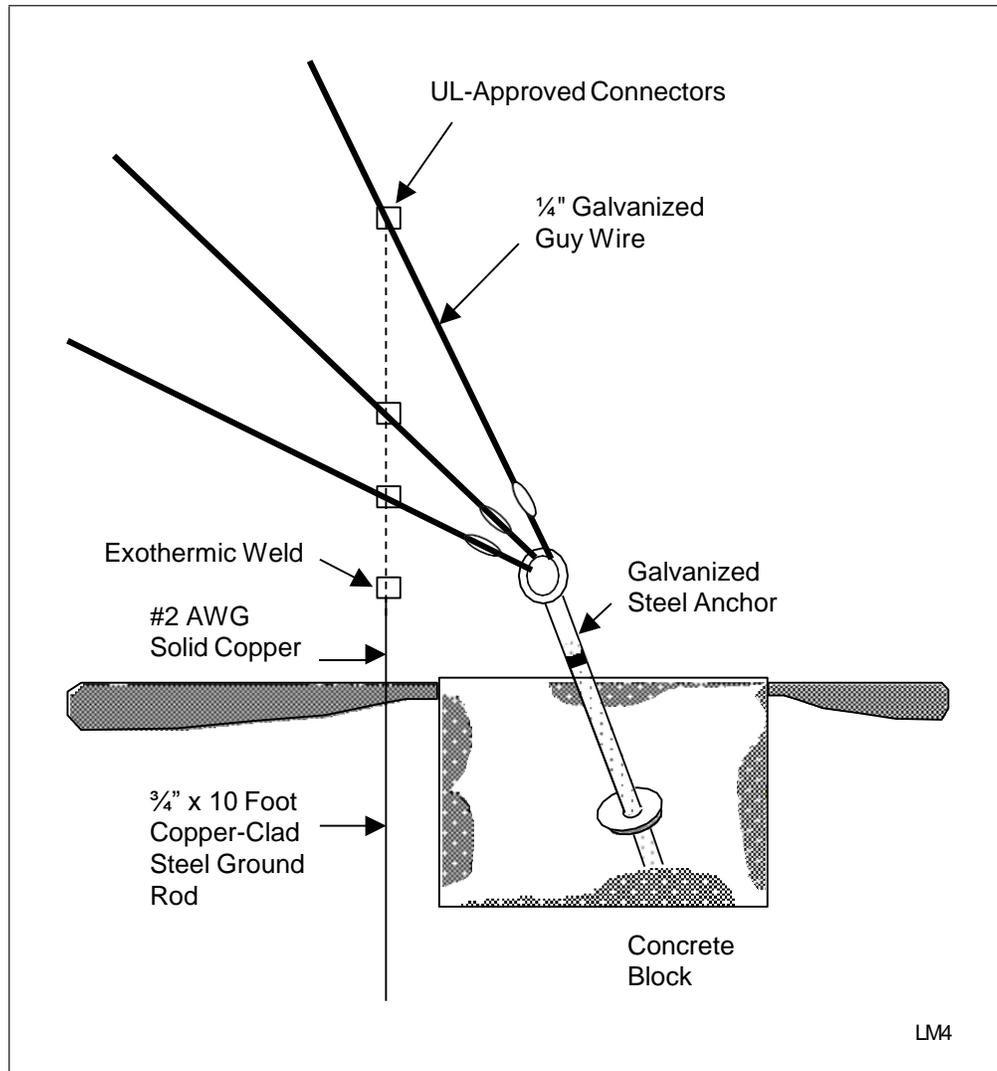


Figure 2-5. Multiple Guy Wire and Anchor Grounding

2.7.9.7 Waveguide, Coaxial Line, and Conduit Protection

Waveguide, coaxial line, and conduit located on the tower and feeding into the facility will be bonded to a ground plate mounted on the tower or directly to the EES. This bond should be at a point no greater than 2 feet above the transition bend (90 degree bend) near the tower's base. The

ground plate will be bonded to the EES with a No. 4/0 AWG copper conductor following the requirement in Section [2.6.7.2](#). An additional bond will be made from the point of origin of the waveguide, coaxial line, or conduit to the metallic tower structure (see [Appendix D](#) for explanation of waveguide grounding).

2.7.9.8 Staircase/Ladder Protection

The metallic access (e.g., staircase, ladder) will be exothermically bonded, near its base, to the EES with a No. 4/0 AWG copper conductor installed in a location that prevents accidental trips or strikes that could result in personnel injury. Where staircase sections are not welded together, bonding jumpers will be installed between sections.

2.7.10 Fences

Grounding and bonding of metal fences will be done to all areas where personnel may come in contact with the fence metal structure or fabric. Grounding and bonding of the fence should be accomplished where a significant step potential can be generated, during lightning activity or during a fault of the utility or facility electrical system. All fences within 20 feet (6.0 meters) of a lightning-protected facility will be grounded to the facility's counterpoise.

2.7.10.1 Fences and Gates

Fences made of conducting material (e.g., chain-link fabric, metal crossbar, stranded wire) should be constructed using metal posts driven a minimum of 2 feet (0.6 m) below grade. Gates should have a 1-inch by 1/8-inch flexible tinned copper bond strap or an insulated No. 4/0 AWG flexible (welding) copper conductor bonded to the adjacent post (exothermic welding is required). The post at each side of the gate will also be exothermically welded, at a height no greater than 1 foot above grade, to their respective ground rods with a No. 4/0 AWG bare copper conductor. The bonding strap to the post will be installed so as not to limit full motion of the gate (whether swing or slide type). Ground rods will also be connected to the EES by an exothermically welded No. 4/0 AWG bare copper conductor. Metallic fence fabric with nonconductive coatings should not be used. A horizontal bare No. 6 AWG stranded copper conductor, woven continuously through the fencing fabric around the perimeter of the facility, will be mechanically bonded to the fence posts at intervals not greater than 40 feet. In turn, fence posts with the noted mechanical connections will be bonded with a No. 4/0 AWG bare copper conductor to the EES. Measures will be taken to ensure fence posts of the entire perimeter of the facility are exothermically welded at the posts, with a No. 4/0 AWG bare copper conductor at intervals not greater than 40 feet. The preferred method of bonding a fence is illustrated in [Figure 2-6](#). This method requires a counterpoise around the facility and an additional counterpoise around and in close proximity to the fence. The two counterpoise systems are connected together in as many places as possible (4 minimum for a small facility <75 square feet, 8 minimum for a large facility >75 square feet) to further equalize step potentials within the facility.

2.7.10.2 Overhead Power Line Considerations

When a fence constructed of conducting material is crossed by overhead power lines, the fence will be bonded to a ground rod with bare No. 6 AWG copper conductors located not less than 20 feet to each side of the power line crossing. (Doing this additional grounding will assure that, in the event the live electrical power line falls on the fence, it will go to ground.) The ground rods

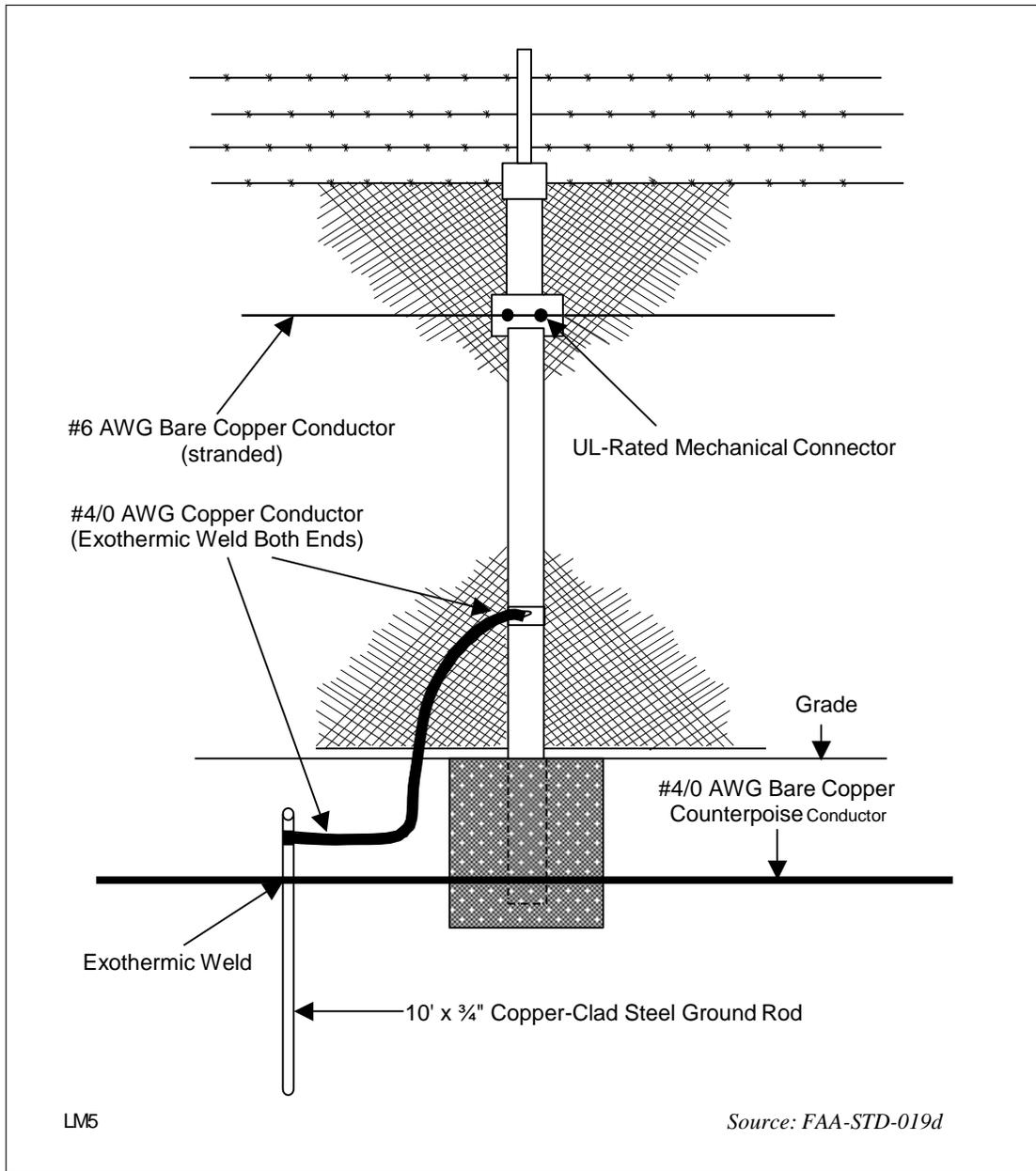


Figure 2-6. Grounding a Fence

will be bonded to the facility's EES with a No. 4/0 AWG copper conductor. For a chain-link fence, the fabric will be bonded to this conductor on each side, crossing at the top, middle, and bottom, as well as at each strand of security wire placed above the fencing fabric. Where cross-bar or stranded wire is used, each horizontal strand or cross-bar will be bonded top-to-bottom to the conductor. The ends of protective wires will be connected, using exothermic welds, to their respective ground rod, while the other ends connected to the top of the fence.

2.7.11 Radar Towers

Towers having electronic areas in the associated base building present a unique set of challenges for implementing lightning and transient protection. The numerous conductors running between

electronic equipment located in the base building and beneath the tower are subject to large electromagnetic fields during a lightning strike. For this reason, special techniques must be applied to provide an environment minimizing lightning's damaging effects.

The lightning protection, electrical, electromechanical, electronic systems, and building steel structures must be bonded together for safety. The National Electrical Code (NEC) NFPA-70 mandates this bonding.

2.7.11.1 Main Ground Plate and Power Distribution

In order to ensure good high-frequency and low-frequency signal grounding during normal operation, a low-impedance connection must be provided to the EES. A main ground plate should be established for this grounding. This main ground plate will be grounded via two 500 kcmil conductors exothermically welded to the EES.

2.7.11.2 Roof, Structural Steel, Reinforcing, and Other Metal Element Bonding

Metal elements composing the tower and its supporting structure, reinforcing bars in both horizontal and vertical elements, building steel, and metal sheathing will be bonded together to provide a Faraday cage. All reinforcing bars within the tower will be tied together and, where independent elements are used, the reinforcing bars should be tied between elements at least once every 4 feet. Reinforcing bars in the floors, overheads, corrugated decking, and footers will be tied to the reinforcing bars in the vertical elements. This bonding is necessary to establish both the Faraday cage and to provide a secondary grounding path for high-frequency (exceeding 10,000 Hz) equipment.

2.7.11.3 Signal, Communications, Coaxial Cables, and Control Line Protection

For purposes of lightning and transient protection, cables running up the tower shaft in open raceways are considered totally exposed to lightning related phenomenon. For this reason, transient protection must be applied at each end of these cables. This protection will be installed where the cables enter the tower equipment area, and where they enter the associated base building. Both facility and equipment levels of protection will be provided for these lines at each location.

2.7.11.4 Signal Grounding

The signal grounding system consists of both single-point and multipoint elements. The single-point ground system is most frequently used in conjunction with the audio and associated switching equipment (low frequency). The MPG system is used for most other electronic equipment (high frequency). All grounds present within the operational or equipment levels will be bonded together at the main ground plate.

2.7.11.5 Multipoint Grounding

An MPG system, consisting of either a raised access floor with a below-floor signal reference grid (SRG) or single conductors, should be installed in:

- a. All facility operational equipment areas
- b. Any area containing electrical equipment installed to address power quality (e.g., isolation transformers, power conditioning equipment).

The SRG should consist of 2-inch wide copper straps arranged in a grid on 2-foot centers. Connections from the SRG to the access floor pedestals should be on a 6-foot spacing. Floor coverings of tile will be of static dissipative material properly installed following manufacturers' specifications and connected to the SRG.

2.7.11.6 Single-Point Grounding

Single-point ground (SPG) systems, if required for the electronic equipment to be installed, will be constructed following Section [2.10.6.1](#). All SPG systems mandated by equipment manufacturers will be bonded to the main ground plate established following the requirements of this paragraph. All electronic grounding systems at a facility will be bonded together to prevent the possibility of large voltage differentials between equipment during a lightning strike.

2.8 Earth Electrode System Requirements

An EES will be installed at each facility to provide a low-resistance contact (less than 5 ohms) to earth for lightning discharges, electrical and electronic equipment grounding, power fault currents, and surge and transient currents. The EES will be capable of dissipating within the earth the energy of direct lightning strikes with no ensuing degradation to itself. The system will dissipate DC, AC, and RF currents from equipment and facility grounding conductors. (For further information, see IEEE Standard 142, Chapter 3, Static and Lightning Protection Grounding.)

2.8.1 Site Survey

A site survey to determine the EES location and configuration should be conducted for all sites. Information to be collected will include location of rock formations, gravel deposits, soil types, etc. A soil resistivity test should be performed at distances of 10, 20, 30, and 40 feet (3, 6, 9 and 12 m), in four directions, from the proposed facility.

2.8.2 Design

The EES will normally consist of driven rods, buried interconnecting cables, and connections to underground metallic pipes, tanks, and structural members of buildings that are effectively grounded. The site survey recommended in this section will be used as the basis for the design of the EES. The design goal for the resistance to earth of the EES will be as low as practicable and should not exceed 5 ohms. Resistance measurements should be done by the "Fall of Potential" method explained in [Appendix G](#) and shown in [Figure 2-7](#). Where conditions are encountered, such as rock near the surface, shallow soils, permafrost, and soils with low moisture or mineral content, the ground enhancements listed in Sections [2.8.2.1](#) through [2.8.2.5](#) may be necessary.

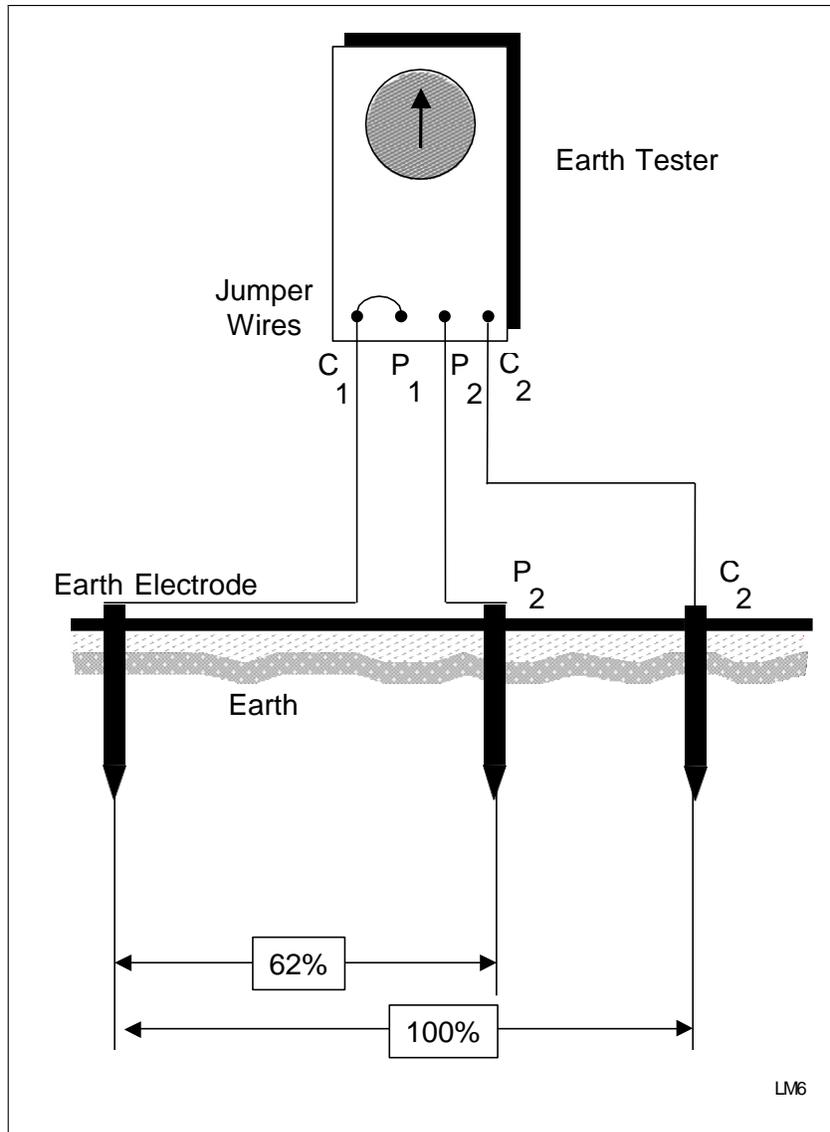


Figure 2-7. Fall of Potential Method for Measuring Ground Resistance

2.8.2.1 Chemical Enhancements

Chemical enhancements (doping) with materials such as mineral salts, Epsom salts, sulfates, etc., should be utilized only as a last resort to lower the resistance to earth value of 5 ohms. Chemical enhancement is dependent on soil moisture content to be effective. Chemicals can leach into the surrounding soil and can migrate into the water table, thereby contaminating it. Typical installation is in bored holes with ground rods and in trenches (see [Figure 2-8](#)).

2.8.2.2 Chemical Rods

Some chemical rods require re-treatment and monitoring to ensure continuous effectiveness. Many of these systems require a drip irrigation system in dry soil conditions. Frequent inspections must be performed to check for excessive corrosion at connection points between the

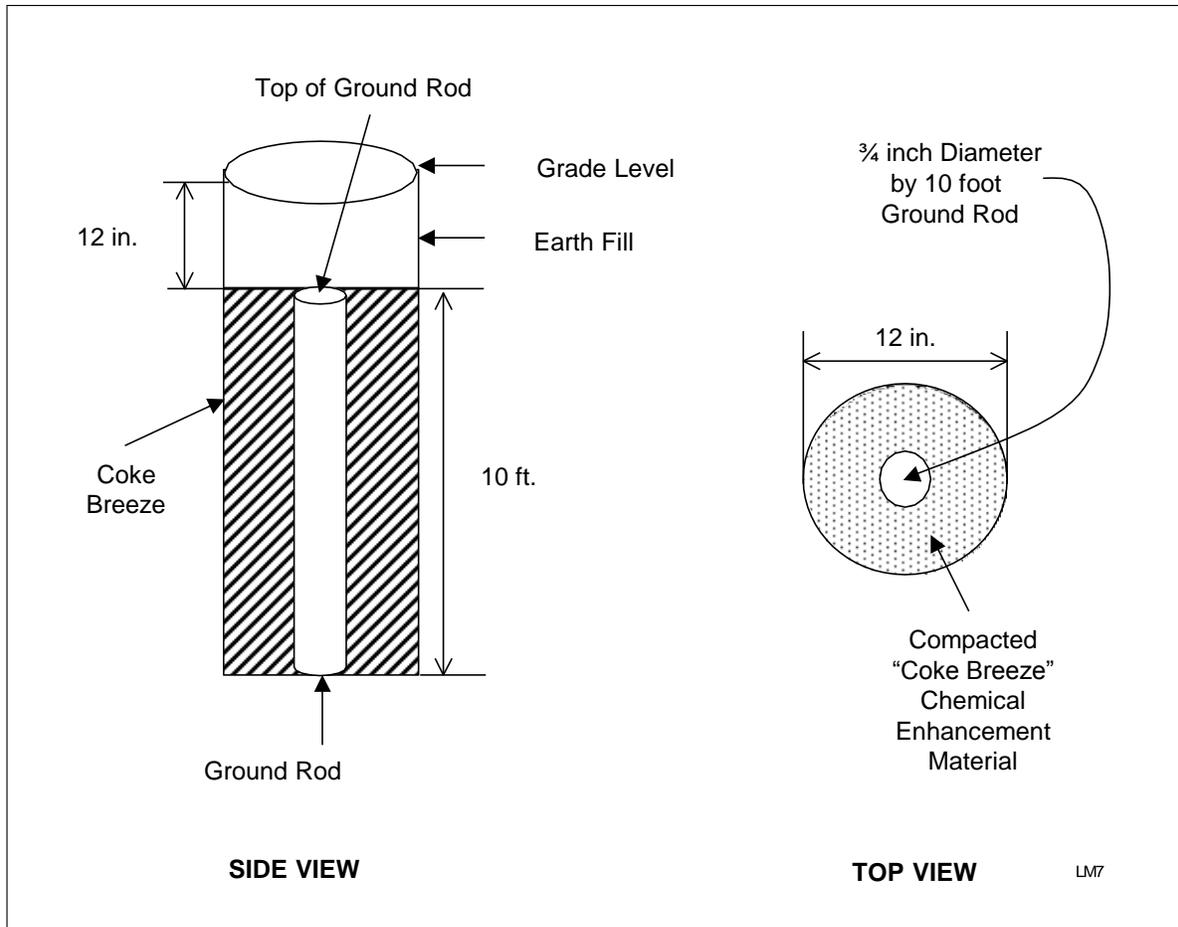


Figure 2-8. Ground Rod and Chemical Enhancement Material Installation

counterpoise and the chemical rod attachment point. Normal installation is insertion into the soil following manufacturer's instructions.

2.8.2.3 Engineered Soils

Engineered soils are soils or clays treated with a variety of materials to enhance their conductive properties. These engineered soils may be a mixture of moisture absorbing materials such as Bentonite, homogenous clays in combination with native soils and/or chemicals. Some engineered soil enhancements utilize ferrous-concrete based materials. These materials should be avoided in areas with soil movement. Engineered soils usually require the presence of moisture (14 percent) in the soil to be effective. A low sulfur content soil enhancement material is advised. Normal installation is in bored holes around ground rods and in trenches.

2.8.2.4 Coke Breeze

Coke breeze is a material produced as a by-product of smelting metals. It is mainly fixed-base carbon. All the corrosives and volatiles have been cooked off at extremely high temperatures. Coke breeze is environmentally safe, stable, and conductive when completely dry or frozen, non-moisture-dependant, compactable, and very economical to install. Normal installation is in a 1-foot-square trench in a counterpoise configuration with a continuous No. 4/0 AWG copper

conductor in the center of the material (see [Figure 2-9](#)). Placement of the trench is based on the geometry of the facility and the physical site location. Radial trenches with a center conductor can be utilized to enhance RF ground plates in communication facilities. The top of the coke breeze trench must be covered by a minimum of 1 foot of native soil. Charcoal should not be substituted for coke breeze. Charcoal typically contains high levels of sulfur, which in the presence of moisture, can accelerate corrosion. Obtain the Material Safety Data Sheet (MSDS) before installing.

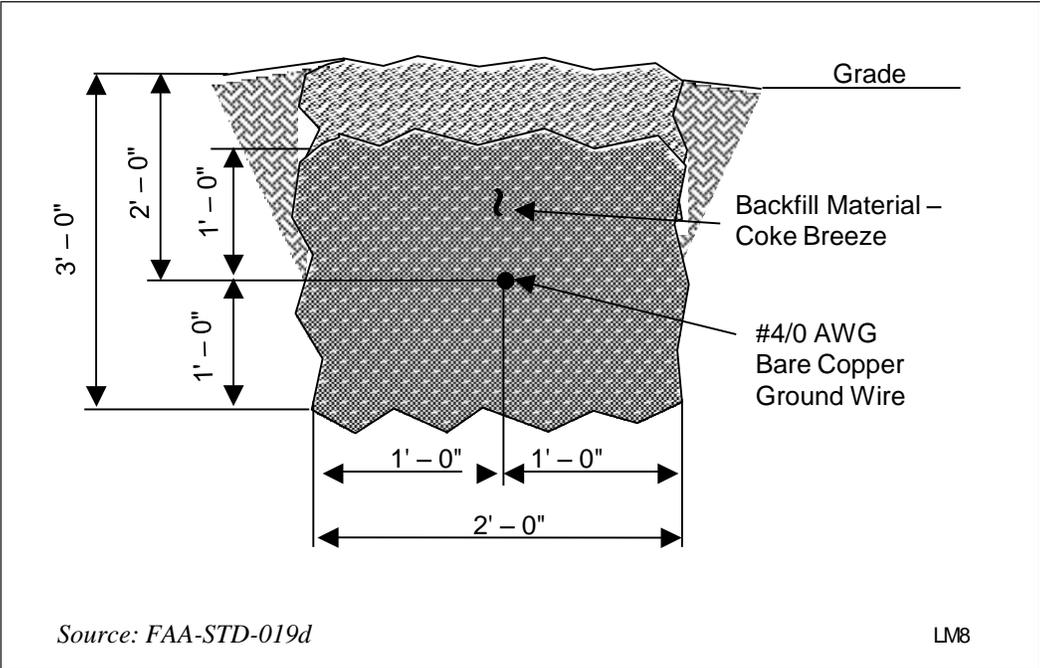


Figure 2-9. Grounding Trench Detail

2.8.2.5 Ground Dissipation Plates (Noncorrosive Soils)

In shallow soil locations with limited surface space, ground dissipation plates must be installed to supplement the counterpoise system. The plates, installed at the corners of the counterpoise system, provide a large surface area of high conductivity at the farthest accessible point from the facility to be protected (see definition of “Plate, Ground” in the Glossary at the end of this manual). This allows the energy to travel away from the facility. Plates should be constructed of 1/4-inch thick copper and be a minimum of 2 feet square. These plates should be installed in a vertical plane to take advantage of seasonal moisture and temperature changes in the soil. Install the plates at the same depth or deeper than the counterpoise, but maintain a minimum of 1 foot of native soil above the upper edge of the plate. Attachment to the counterpoise should be with a No. 4/0 AWG copper conductor, exothermically welded to the counterpoise and the plate. For maximum performance, the attachment point at the plate should be at the center of the plate, not near the edge or the corners. To further enhance the effectiveness of ground dissipation plates, they may be configured as a Jordan Dissipation Plate, (JDP) with *pinking shear edges*, as shown in [Figure 2-10](#). This configuration provides two-thirds more surface area at the edge than a square plate and provides multiple sharp points for increased dissipation capability. In difficult areas, a

combination of coke breeze trenches and dissipative plates is highly recommended (see [Figure 2-9](#) and [Figure 2-10](#)).

2.8.2.6 Installation in Corrosive Soils

Careful considerations must be given to the installation of any grounding system in soils with corrosive elements. Two geological areas of known concern are the volcanic soils in Hawaii and Alaska. Supplemental cathodic protection should be applied to the grounding system at these locations. A buried steel plate acts as a sacrificial anode and is connected to the counterpoise conductor with a No. 4/0 AWG copper conductor. The No. 4/0 AWG copper conductor should be welded to the center of the plate, not near the edge or near the corners. Minimum sizing for the sacrificial plate is 4 feet square and 1/2 inch in thickness. In shallow soils, this would be in addition to the standard copper dissipation plates. For enhanced performance, sacrificial plates may be configured as a JDP (see [Figure 2-10](#)).

2.8.3 Configuration

Unless otherwise specified, the EES will consist of at least four ground rods penetrating the ground to the lowest resistance as determined by the site survey. Facilities with two or more structures (e.g., a building and antenna tower) separated by 15 feet (4.6 m) or less, one EES surrounding both structures will be provided. Where structures are separated by more than 15 feet (4.6 m) but less than 30 feet (8.2 m), the EES may share a common side. Where the structures are separated by more than 30 feet (8.2 m), an EES will surround each structure and will be bonded together by two No. 4/0 AWG cables buried and exothermically welded.

2.8.4 Ground Rods

Ground rods and their installation will meet the requirements specified in the following paragraphs.

2.8.4.1 Material and Size

Ground rods will be copper or copper-clad steel, a minimum of 10 feet in length and 3/4 inch in diameter. Rod cladding will not be less than 0.012 inch thick.

2.8.4.2 Spacing

The spacing between ground rods should be at least two times a single rod length. Nominal spacing between rods should be between two and three times a single rod length (e.g., 10-foot ground rods spaced at 20 feet apart).

2.8.4.3 Depth of Rods

Tops of ground rods should be not less than 1 foot (0.3 m) below grade level.

2.8.4.4 Location

Ground rods should be located 2 to 6 feet (0.6 to 1.8 m) outside the foundation or exterior footing of the structure. On buildings with overhangs, ground rods may be located further out to take advantage of the drip line moisture.

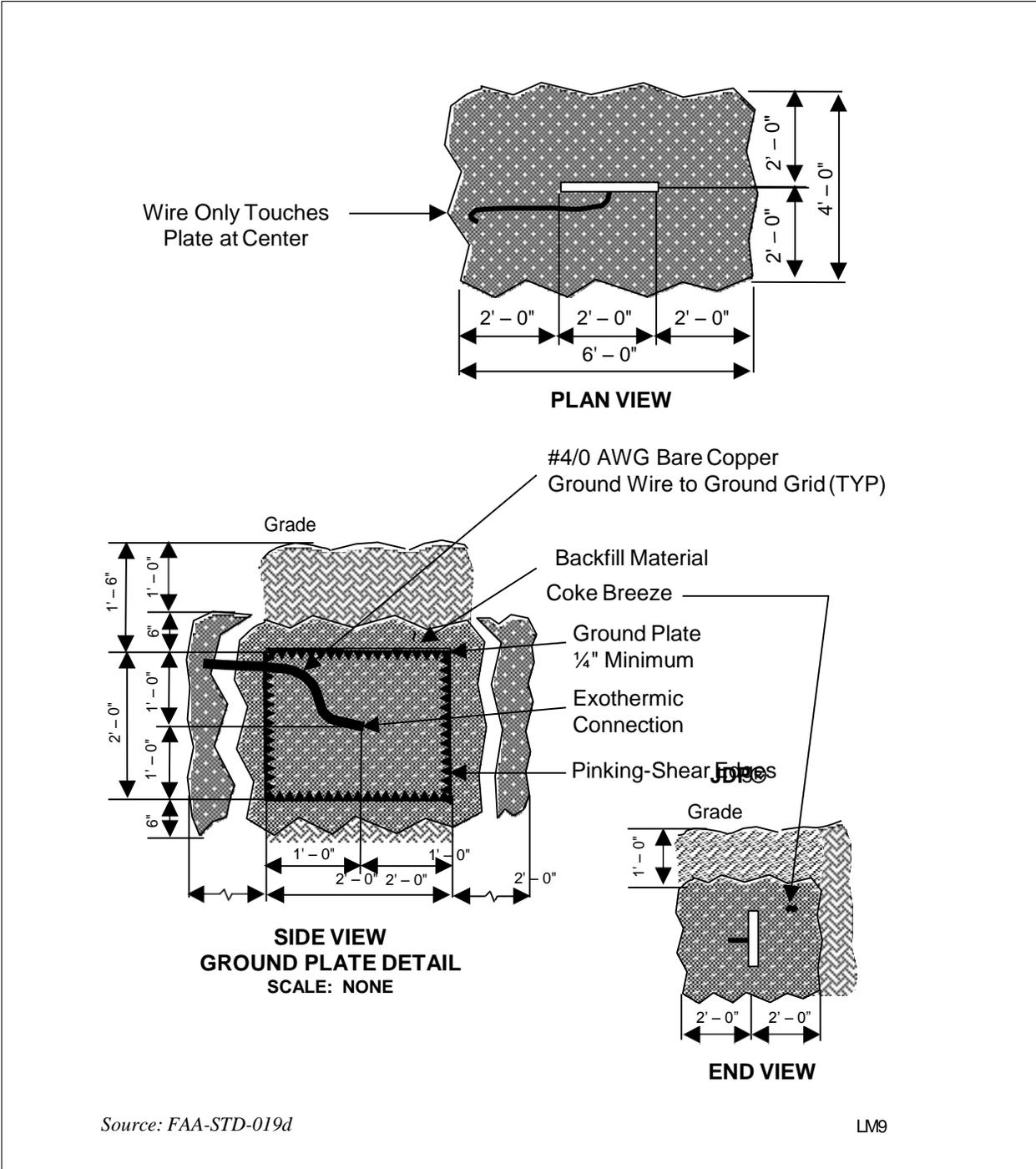


Figure 2-10. Ground Plate Detail

2.8.4.5 Chemical Enhancement

For chemical enhancement to lower ground rod resistance to earth, consider using coke breeze (see Section [2.8.2.4](#)).

2.8.5 Interconnections

Ground rods will be interconnected by a buried, bare, No. 4/0 AWG stranded copper conductor. The cable will be buried at least 30 inches (0.8 m) below grade level. Connections to the ground rods will be made by an exothermic weld. The interconnecting conductor will close on itself forming a complete loop with the ends exothermically welded. The structural steel of buildings will be connected to the EES at approximately every other column at intervals not over 60 feet (18.3 m) with a bare, No. 4/0 AWG stranded copper cable. Connections will be by exothermic welds. The grounding electrode conductor (GEC) for the electric service, sized following the NEC requirements (Article 250) for GECs, will not be smaller than No. 2 AWG and will be connected to a ground rod in the EES with an exothermic weld. All underground metallic pipes, tanks, and the telephone ground, except metal gas lines, if present, will be connected to the EES by a copper conductor no smaller than No. 2 AWG. Where routed underground, interconnecting cables will be bare. Bonding resistance of all interconnections to the EES will not exceed 1 milliohm for each bond.

2.8.6 Access Well

Access wells are permissible at all NWS facilities. The well will be located at a ground rod in an area with access to the open soil so checks of the EES can be made once the facility is in use. The access well will be made from clay pipe, poured concrete, or other approved wall material and will have a removable cover. The access well will be constructed to provide a minimum measurement of 12 inches circular clearance from the ground rod. Connections at the access well can be made with UL-approved pressure connectors, but connections to the ESS must be made by means of exothermic welding (see [Figure 2-11](#) for installation diagram).

2.9 Electronic Multipoint Ground System Requirements

Electronic facilities require separate grounding systems for the electronic equipment and the power distribution system. The power distribution grounding system protects equipment and personnel from hazards, such as direct shorts or arc faults in the power distribution system. ***All NWS facilities will have a separate multipoint ground (MPG) system for electronic equipment.*** Protection of electronic equipment against potential differences and static charge buildup will be provided by interconnecting all non-current-carrying metal parts to an electronic MPG system effectively grounded to the EES (see Glossary at the end of this manual). The MPG for electronic equipment systems consists of electronic equipment racks, frames, cabinets, conduits, raceways, wireways, cable trays enclosing electronic conductors, structural steel members, and conductors used for interconnections. The MPG will also provide multiple low (less than 1.0 ohm) impedance paths to the ESS as well as between various parts of the facility, electronic equipment within the facility, and any point within the system and the EES to minimize the effects of spurious currents and ground loops that may be present in the ground system (see Electrical Ground Loops, [Appendix E](#)).

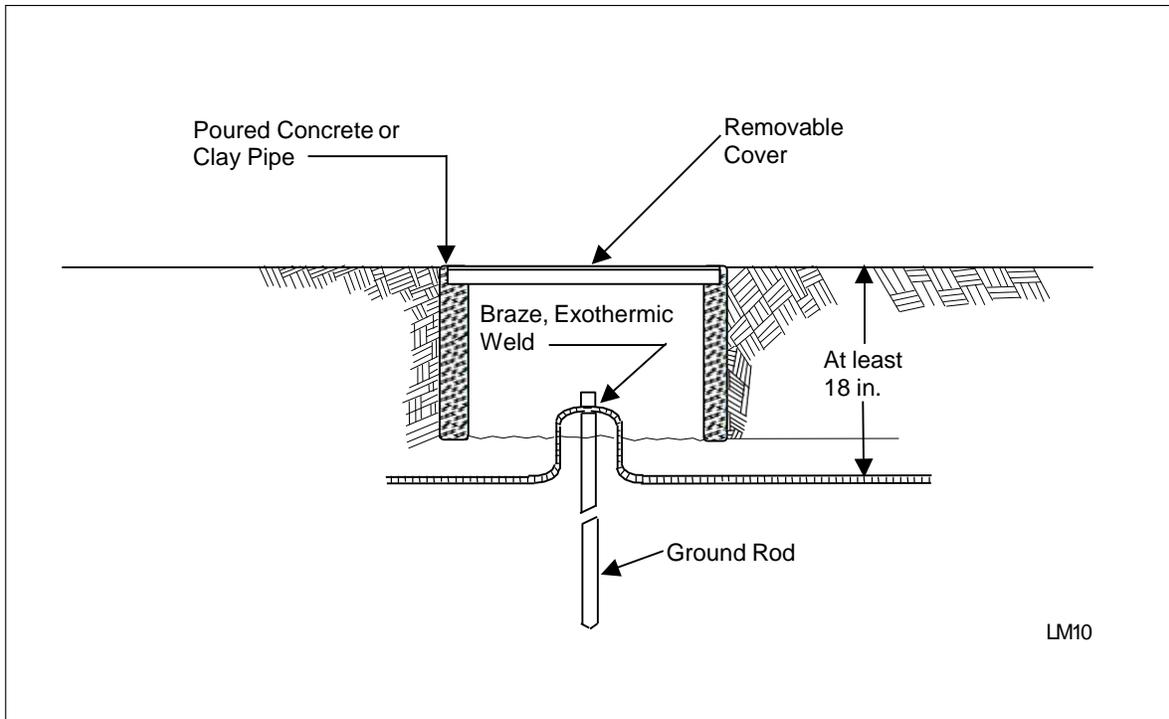


Figure 2-11. Concrete Grounding Access Well

NOTE: It is essential that no power or single-point grounds utilize this system. The multipoint ground system will not be used as a signal return path.

A typical facility grounding system is shown in [Figure 2-12](#).

2.9.1 Facilities Requiring a Signal Reference Structure

The Signal Reference Structure (SRS) will serve as the MPG system for those areas so equipped. As areas are renovated in facilities, they may be equipped with an SRS. In areas where an SRS is installed under the requirements of this paragraph, multipoint ground plates are not required.

2.9.1.1 Equipotential Planes in New Facilities

The SRS to be installed in new facilities should consist of a grid of 2-inch wide, 0.01-inch thick copper strips, placed on a 2-foot grid or bolted stringer connected to the computer access floor. The grid and access floor will be bonded together at least every 6 feet by means of exothermic welding. A No. 4/0 AWG bare copper conductor should run around the perimeter of all areas where this SRS is utilized. Bond this perimeter conductor to the below-floor grid at every intersection. All building structural steel, such as columns, within 6 feet of the grid will be bonded to the grid with a No. 4/0 AWG or larger conductor. Bonding means will be by exothermic welding. All concrete encased steel should be equipped with a grounding terminal. All conduits, wireways, pipes, cable trays, or other metallic elements penetrating the area will be bonded to the grid where they enter the area and every 25 feet for their entire length. All conduits, wireways, pipes, cable trays, or other metallic elements within 6 feet of the grid will be bonded to the grid. Bonding means will be either by UL-approved pressure connections or exothermic welding. This

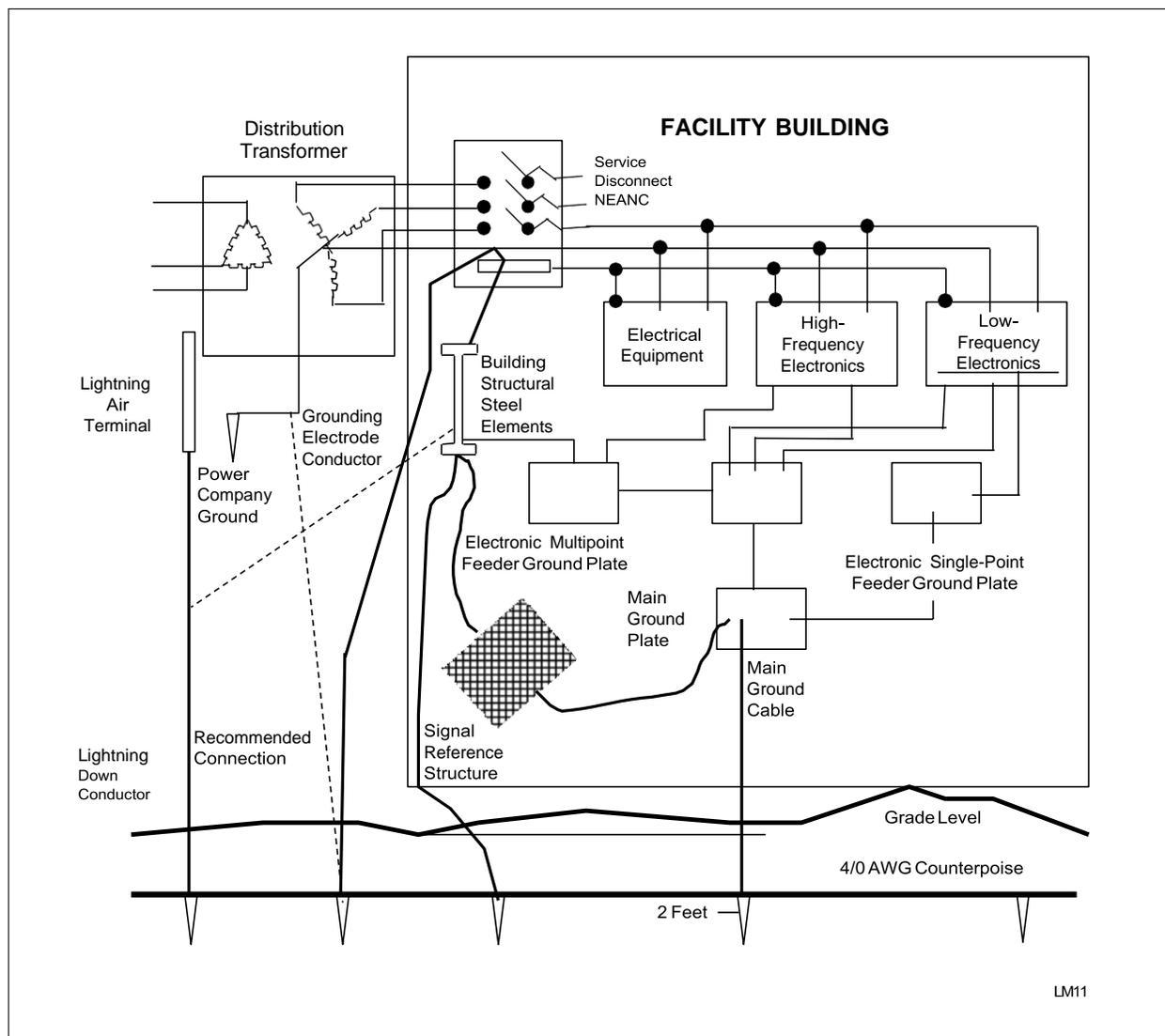


Figure 2-12. Facility Grounding System

interconnection of the access floor system, with metal-backed panels; below-floor grid; and structural steel elements and electrical supporting structures creates an equipotential plane (EPP) (see [Figure 2-13](#)).

2.9.1.2 SRS Methods in Existing Facilities

In existing NWS facilities, it may not be feasible to implement the techniques used to install an EPP. In these cases, the alternative methods described in IEEE 1100-1999, Section 8.5.4 (High Frequency Grounding Configuration) will be used.

2.9.1.3 Bonding Electronic Equipment to the SRS

Signal grounding connections for all equipment connected to the SRS may be either to the below-floor grid or directly to the access floor system, or alternatively to the SRS as constructed in Section [2.9.1.2](#). To prevent the possibility of problems due to resonance of a single bonding

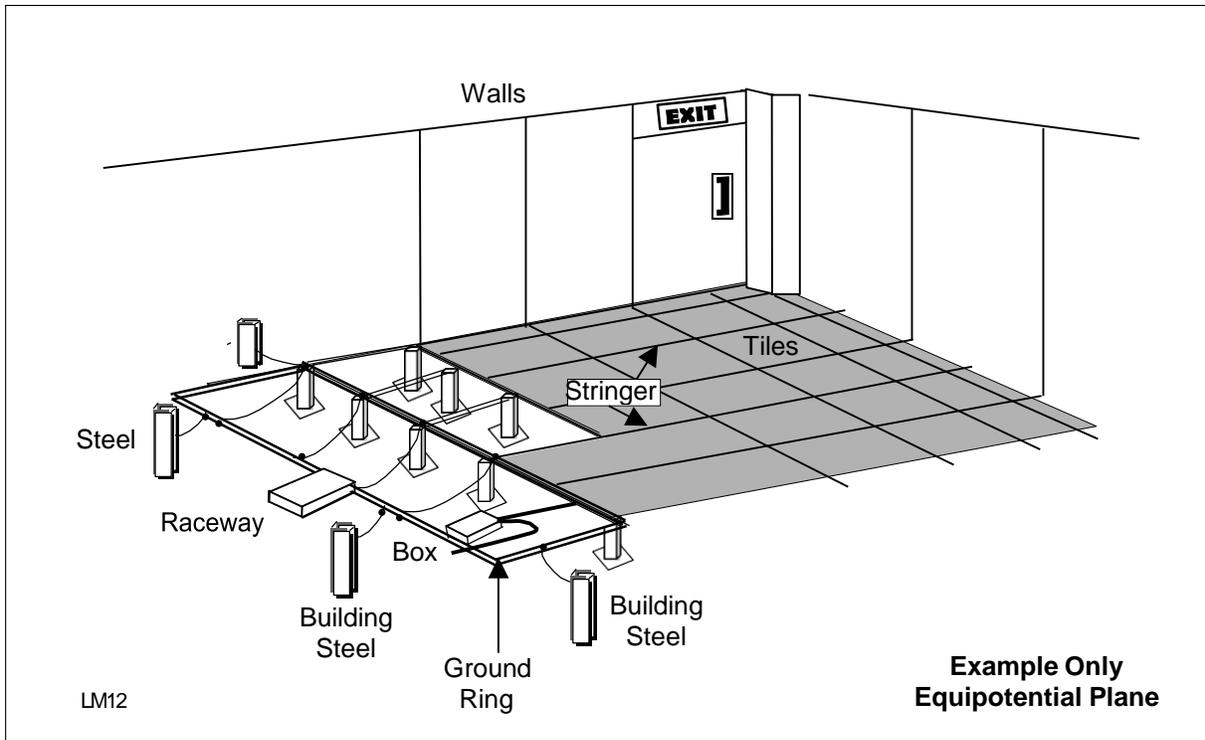


Figure 2-13. Grounding Ring Used for a Signal Reference Grid

strap, two widely spaced straps of unequal length will be used to connect the equipment to the SRS. Bonding will follow the recommended practices as expressed in IEEE 1100-1999, Section 8.5.4.6 (Connection of Equipment to the SRG). For additional guidance, see [Figure 2-13](#).

2.9.1.4 Facilities Without SRS

New facilities will be equipped with an electronic MPG system consisting of conductors and plates meeting Section [2.9.1.2](#) requirements.

2.9.2 Ground Plates, Cables, and Protection

The MPG will not replace the NEC-mandated equipment power grounding conductor routed with the phase and neutral conductors. Conductors from the ground plate to the EES will be exothermically welded to the EES.

2.9.2.1 Ground Plates and Busses

A ground plate should be used when a centralized connection point is desired. The location should be chosen to facilitate the interconnection of all equipment cabinets, racks, and cases within a particular area. If more than one ground plate is required, they should be installed near a structural steel location within the facility (this minimizes the bonding distance of the ground plate to structural steel). Ground busses will be used when distributed grounding is desired with a long row of equipment cabinets. Ground plates will be copper and at least 12 inches long, 6 inches wide, and 1/4 inch thick. Ground bus width and thickness will be selected from [Table 2-4](#), according to the length required.

Table 2-4. Size of Electronic Multipoint Ground Conductors

Cable Size	Maximum Path Length		Bus Bar Size (Width x Thickness)		Maximum Path Length	
	Feet	(Meters)	Inches	(Millimeters)	Feet	(Meters)
750 kcmil*	375	(114.3)	4 x 1/4	(100 x 6.4)	636	(193.9)
600 kcmil*	300	(91.4)	4 x 1/8	(100 x 3.2)	318	(96.9)
500 kcmil	250	(76.2)	3 x 1/4	(75 x 6.4)	476	(145.1)
350 kcmil	175	(53.3)	3 x 1/8	(75 x 3.2)	238	(72.5)
300 kcmil	150	(45.7)	2 x 1/4	(50 x 6.4)	318	(96.9)
250 kcmil	125	(38.1)	2 x 1/8	(50 x 3.2)	159	(48.5)
4/0 AWG	105	(32.0)	2 x 1/16	(50 x 1.6)	79	(24.1)
3/0 AWG	84	(25.6)	1 x 1/4	(25 x 6.4)	159	(48.5)
2/0 AWG	66	(20.1)	1 x 1/8	(25 x 3.2)	79	(24.1)
1/0 AWG	53	(16.2)	1 x 1/16	(25 x 1.6)	39	(11.9)
1 AWG	41	(12.5)				
2 AWG	33	(10.1)				
4 AWG	21	(6.4)				
6 AWG	13	(4.0)				

*kcmil – Where these cables are not available, parallel cables may be used, such as three 250 kcmil cables in place of one 750 kcmil cable, or two 300 kcmil cables in place of one 600 kcmil cable. The cable sizing is based on providing a cross-sectional area of 2000 circular mill per linear foot. The bus bar sizes are based on providing a cross-sectional area of 2000 cmil per linear foot.

Source: FAA-STD-019d

2.9.2.2 Ground Conductors

Interconnections in the MPG between ground plates and buses will be made with insulated, stranded copper cable, as noted in [Table 2-4](#). Interconnections in the MPG between ground plates and structural steel will be made with insulated, stranded copper cable, conforming to [Table 2-4](#), but in no case may the cable be smaller than No. 4/0 AWG. The use of uninsulated (bare) conductors are not permitted inside structures, except when used for short grounding jumpers, bonding jumpers, and similar items not enclosed in a conduit or raceway.

2.9.2.3 Protection

Provide mechanical protection for all cables in the MPG where they may be subject to damage. This protection may be provided by conduit, floor trenches routing behind permanent structural members, or other means. Where routed through metal conduit, the conduit will be bonded to the cable at both ends.

2.9.3 Building Structural Steel

All structural members such as building columns, wall frames, roof trusses of steel frame buildings, and other metal structures will be made electrically continuous by bonding each joint and interconnection following Section [2.13](#) guidance. Structural steel will be connected to the EES, as specified in Section [2.8.5](#).

2.9.3.1 Metal Building Elements

Requirements of this paragraph apply to facilities with sensitive receiver or computing systems and those located in areas where radiation from radar or other high-power emitters is expected. Metal building elements and attachments such as walls, roofs, floors, doors and window frames, gratings, and other architectural features should be directly bonded to structural steel complying with Section [2.13](#). Where direct bonding is not practical, indirect bonds with copper cable conforming to [Table 2-4](#) will be used. Removable or adjustable parts and objects will be grounded with appropriate type bond strap as specified in Section [2.13.3](#). All bonds will conform to the requirements of Section [2.13](#). Metal elements with a maximum dimension of 3 feet (0.9 m) or less are exempt from the requirements of this section.

2.9.4 Interior Metallic Piping Systems

The interior metallic cold water piping system will be bonded to the service disconnecting means ground or to the EES. The bonding jumper will be the same size as the GEC that is selected from NEC Table 250-66. All other interior metallic piping, which may become energized, will be sized following the NEC Table 250-122 using the rating of the circuit that may energize the piping.

2.9.4.1 Ground Connections

Approved pressure clamps will be used to bond pipes and tubes to the equipment ground system. In highly humid or corrosive atmospheres, adequate corrosion protection will be provided, complying with Section [2.13.10](#). Do not use the building main incoming water pipe as the sole EES. Many buried metal water pipes are coated with corrosion-resistant insulating fibers or are connected to buried plastic pipe, making the main incoming water pipe unsuitable (nonconductive) as a primary earth electrode.

2.9.5 Electronic Supporting Structures

All metallic electronic support structures will be electrically continuous and will be bonded to the MPG and to the EES.

2.9.5.1 Conduit

All metal conduit used for electronic signal and control wiring should be grounded as follows:

- a. Conduit should have a means to be bonded, prior to entering the facility, to a bulkhead plate located outside the facility and connected directly to the EES. The bulkhead plate should be bonded to the EES with an insulated No. 4/0 AWG copper conductor (minimum size).
- b. All joints between conduit sections and between conduit, fittings, and boxes will be electrically continuous. All pipe and locknut threads should be treated with a conductive lubricant rated for the metal prior to assembly. Surfaces should be prepared complying with Section [2.13.9](#). Joints not otherwise electrically continuous will be bonded with short jumpers of No. 6 AWG or larger copper conductor. The jumpers will be welded or brazed in place or will be attached with clamps, split bolts, grounding bushings, or other devices approved for the purpose. All bonds will be protected against corrosion, and comply with Section [2.13.10.4](#).
- c. Cover plates of conduit fittings, pull boxes, and outlet boxes will be grounded by securely tightening all available screws (see [Table 2-7](#) in Section [2.13.2.4](#) for torque requirements).
- d. Every component of metallic conduit runs such as individual sections, couplings, line fittings, pull boxes, junction boxes, and outlet boxes will be bonded, either directly or indirectly, to the MPG or facility steel (which is bonded to the EES) at intervals not exceeding 50 feet (15 m).
- e. Conduit brackets and hangers will be securely bonded to the conduit and metal structure.

2.9.5.2 Cable Trays and Wireways

Individual sections of all cable tray systems for electronic conductors will be bonded together with a No. 6 AWG insulated copper conductor and each support bracket or hanger will be bonded to the cable trays they support. All bonds will comply with procedures and requirements specified in Section [2.13](#). All tray assemblies for electronic conductors will be connected, either directly or indirectly, to the MPG or properly grounded facility steel within 2 feet (0.6 m) of each end of the run and at intervals not exceeding 50 feet (15 m). Resistance of each connection will not exceed 1 milliohm. The minimum size bonding conductor for connection of a cable tray and wireway to the MPG will be No. 2 AWG copper conductor.

2.9.6 Multipoint Grounding of Electronic Equipment

When permitted by circuit design requirements, all internal ground references will be directly bonded to the chassis and the equipment case. Where mounted in a rack, cabinet, or enclosure, the electronic equipment case will be bonded to the rack, cabinet, or enclosure complying with Section [2.12.1](#). The DC resistance between any two points within a chassis or electronic equipment cabinet serving as ground will not exceed 1 milliohm. Shields will be provided as required for personnel protection and EMI reduction.

2.9.6.1 Electronic Signal Return Path

The electronic signal return path will be routed with the circuit conductor. For coaxial circuits, the shield serves this purpose. For multiconductor signal cables, each signal function will have a return. The electronic equipment case and MPG will not be used as a return conductor.

2.9.6.2 Shield Terminations of Coaxial and Other Cables

All connectors will be of a type and design providing less than 1 milliohm impedance path from the signal line shield to the electronic equipment case. If the electronic signal reference plane must be isolated from the electronic equipment case, and if the shielding effectiveness of the case must not be degraded, a connector of a tri-axial design properly grounding the outer cable shield to the case will be used. Shields of co-axial cables and balanced transmission lines will be terminated by peripherally grounding the shield to the electronic equipment case. Bonding of connectors will comply with Section [2.13.13](#). Use of pigtailed to terminate high-frequency line shields outside the electronic equipment case is not permitted. Coaxial shields and connector shells will be grounded to the MPG at junction boxes, patch panels, signal distribution boxes, and other interconnection points along the electronic signal path.

2.9.7 Electronic Equipment Containing Both Low- and High-Frequency Circuits

If the low- and high-frequency circuits in electronic equipment are functionally independent and if construction and layout permit separate electronic signal references (electronic chassis and equipment case isolated from each other), low-frequency circuits may be grounded by complying with Section [2.10](#). If low-frequency and high-frequency circuits share a common electronic signal reference (both electronic chassis and equipment case connected to each other), both circuits will be grounded by complying with Sections [2.9.6](#), [2.9.6.1](#), and [2.9.6.2](#).

2.10 Electronic Single-Point Ground System Requirements

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. The single-point ground (SPG) system will be isolated from the power grounding system and the MPG system. The SPG system will be terminated at the EES. The SPG system will be configured to minimize cable lengths. Conductive loops should be avoided by maintaining a trunk and branch arrangement as shown in [Figure 2-14](#).

2.10.1 Ground Plates

Main, branch, and feeder ground plates should be made of copper and be at least 12 inches (305 mm) long, 6 inches (152 mm) wide, and 1/4 inch (6.4 mm) thick. The plates should be mounted on phenolic or other nonconductive material of sufficient cross-section to rigidly support the plates after all conductors are connected. Plates should be mounted in a manner providing ready accessibility for future inspection and maintenance.

2.10.2 Isolation

Minimum resistance between the SPG system and the MPG system will be 10 megohms. The resistance should be measured after the complete network is installed and before connection to the EES.

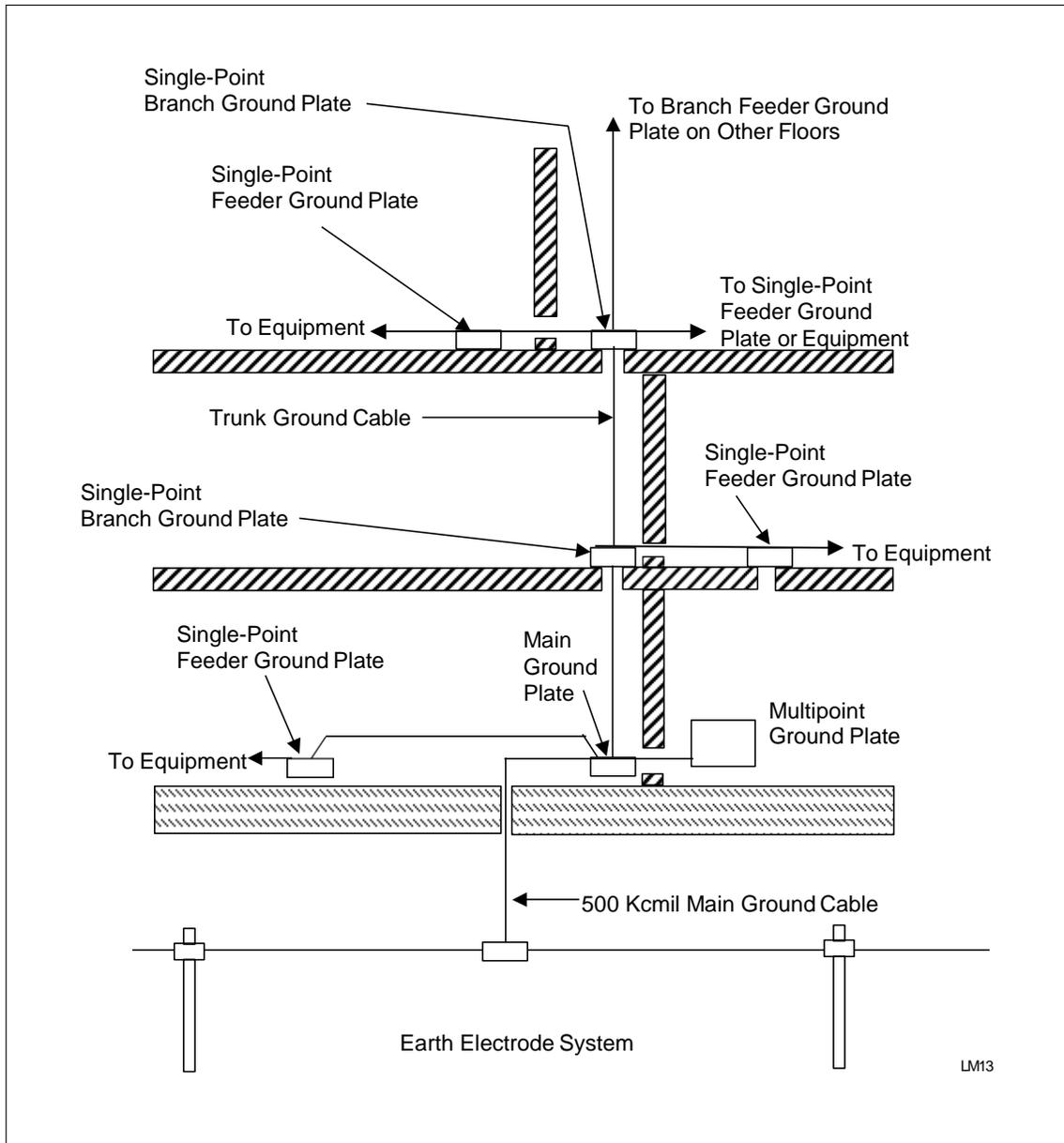


Figure 2-14. Electronic Single-Point Ground System Installation

2.10.3 Resistance

Maximum resistance between any ground plate and any cable connected to the plate will not exceed 1 milliohm.

2.10.4 Ground Conductor Size

The size of the main, trunk, and feeder ground cables will comply with the following requirements.

2.10.4.1 Main Ground Conductor

The main ground conductor to the EES will be an insulated 500 kcmil copper not exceeding 50 feet in length. The main ground conductor will be connected to the EES by exothermic weld.

2.10.4.2 Trunk and Branch Ground Conductors

An insulated trunk ground conductor should be installed in each facility from the main ground plate to each of the branch plates as shown in [Figure 2-14](#). Insulated copper branch ground conductors will be installed between feeder and branch ground plates. These conductors should be routed to provide the shortest practical path. These cables will be No. 4/0 AWG insulated copper conductors. Trunk ground conductors will be exothermically welded or connected with UL-approved double-bolted connectors to the feeder ground plates in compliance with Section [2.13.2.4](#).

2.10.4.3 Electronic Equipment Ground Conductors

The minimum-size electronic equipment ground conductor will be insulated No. 6 AWG for cable lengths not exceeding 50 feet (from the last plate to cabinet bus or equipment chassis), and for runs over 50 feet the conductor size should be increased following NEC Article 250.122 and Table 250-122 guidance.

2.10.4.4 Interconnections

All connections to the SPG system will be made on ground plates or buses. Split bolts, Burndy clamps, and other connections to existing conductors will not be used.

2.10.5 Labeling

The SPG system should be clearly labeled “ELECTRONIC SINGLE-POINT GROUND” to preserve its integrity and isolation from the MPG.

2.10.6 Equipment Requiring Electronic SPGs

When electronic equipment performance dictates an isolated SPG system for proper operation, all the equipment and its installation will comply.

2.10.6.1 Electronic SPGs

The SPG system for the internal circuits will be isolated from the electronic equipment case. If a metal chassis is used as the SPG, the chassis will be floated relative to the case.

2.10.6.2 Electronic SPG Terminals

Insulated and isolated SPG system terminals will be provided on each electronic equipment case where an isolated signal reference is required. *The SPG system will be isolated from the electronic equipment case.* The terminals will be used to terminate cable shields, and to connect the isolated signal ground of the electronic equipment to the facility SPG system.

2.10.6.3 Isolation

With all external power, signal, and control lines disconnected from the electronic equipment, isolation between the SPG system terminals and the case will not be less than 10 megohms.

2.10.6.4 Electronic Signal Lines and Cables

Electronic signal lines should be twisted shielded pairs with the shield insulated. Cables consisting of multiple twisted pairs will have the individual shields isolated from each other. Cables with an overall shield will have the shield insulated.

2.10.6.5 Termination of Individual Shields

Termination of individual shields will follow Section [2.14.1.2](#) guidelines.

2.10.6.6 Termination of Overall Shields

Termination of overall shields will follow Section [2.14.1.3](#) instructions.

2.10.6.7 Single-Point Grounding of Electronic Equipment

Each SPG terminal will be connected to the facility SPG system conforming with the following:

- a.** Individual units of electronic equipment that by nature of their location or function cannot or should not be mounted with other electronic equipment will have an insulated copper conductor installed between the electronic SPG terminal specified in Section [2.10.6](#), and the nearest electronic SPG plate. See [Figure 2-15](#) for an illustration of this connection
- b.** Where two or more units of electronic equipment are mounted together in a rack or cabinet, a single-ground bus bar will be installed as shown in [Figure 2-16](#). The bus bar will be copper and will provide a minimum cross-sectional area of 125,000 square mils. The bus bar should be drilled and tapped for No. 10-24 screws. The holes will be located as required by the relative location of the isolated electronic SPG terminals on the electronic equipment. The bus bar will be mounted on insulating supports that provide at least 10 megohms DC resistance between the bus bar and the rack or cabinet.
- c.** Each electronic equipment isolated SPG terminal will be interconnected to the bus bar by means of a solid or flexible tinned copper jumper of sufficient cross-sectional area so that its resistance is 1 milliohm or less (No. 6 AWG minimum). The jumper will be insulated or mounted in a manner ensuring a minimum isolation of 10 megohms. The interconnecting jumper will be attached to the bus bar at a point nearest to the SPG terminal to which the strap is attached. An insulated copper conductor will be installed from the bus bar in the cabinet to the nearest SPG system. This conductor will be a minimum of a No. 6 AWG.

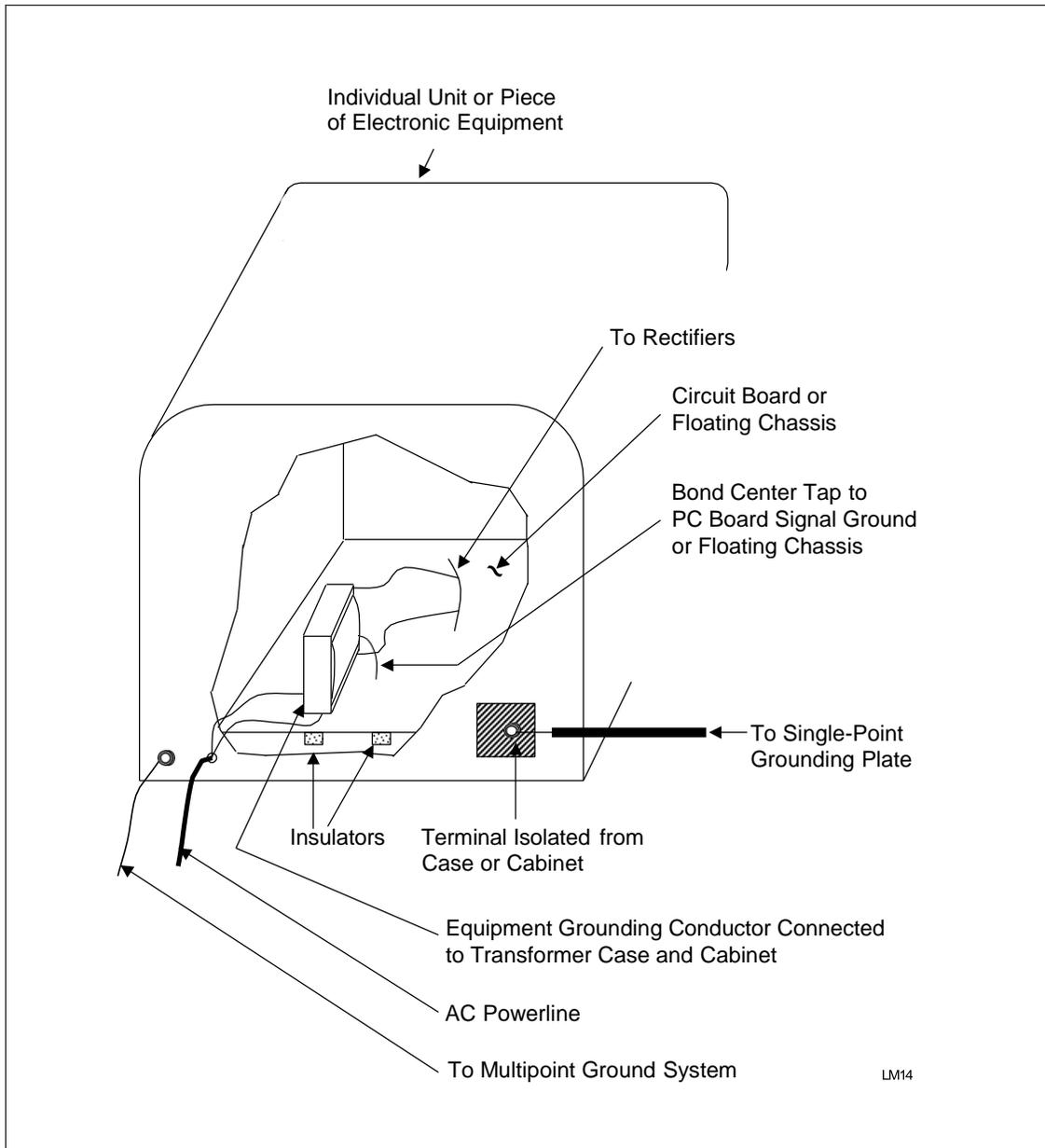


Figure 2-15. Single-Point Grounding for an Individual Unit or Piece of Electronic Equipment

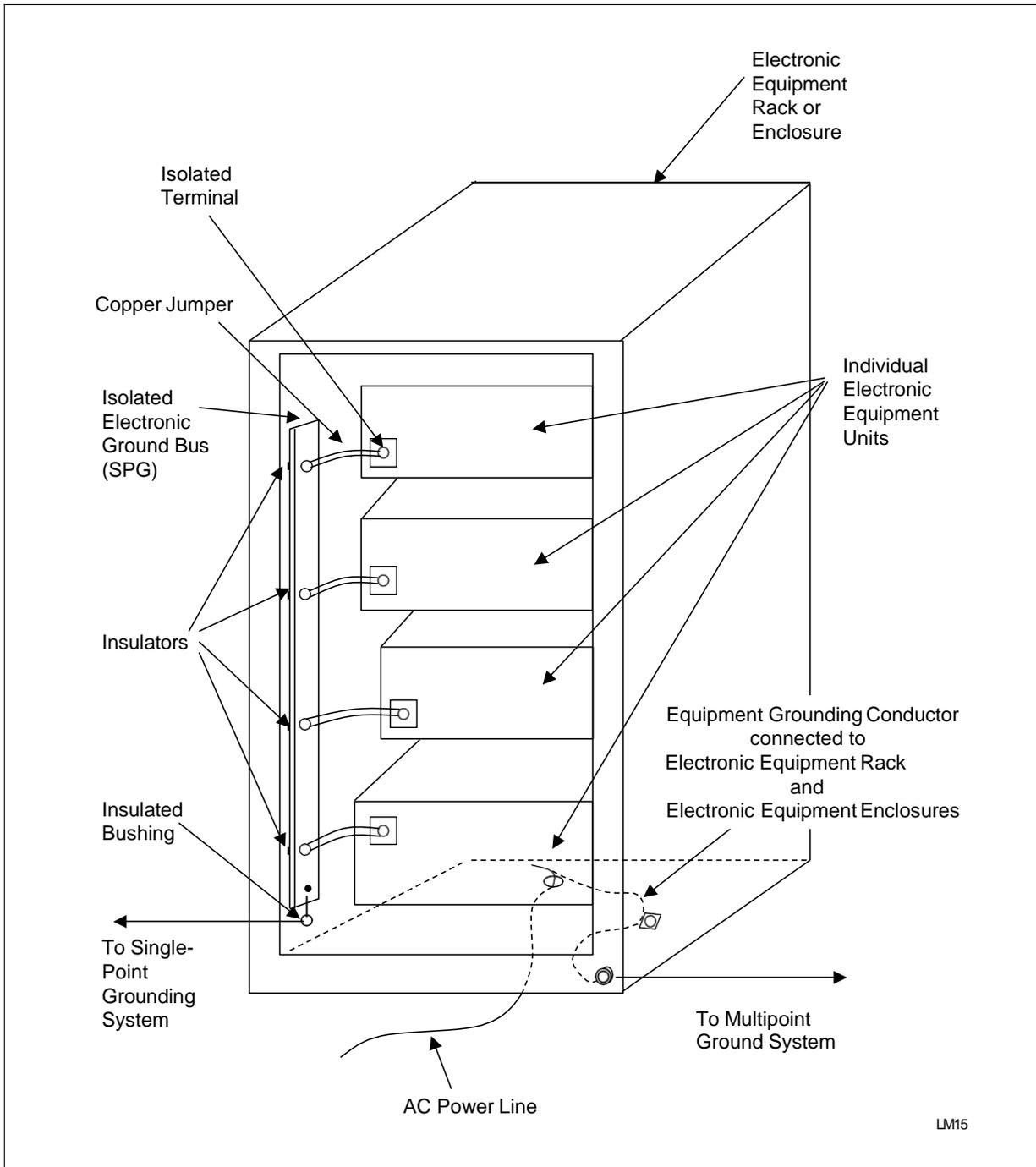


Figure 2-16. Single-Point Electronic Ground Bus Bar Installation in Rack or Cabinet

2.11 National Electrical Code Grounding Compliance

The facility electrical power grounding will meet or exceed the minimum requirements of Article 250 of the National Electrical Code (NEC). The electronic MPG conductor will not replace the EGC required by the NEC.

2.11.1 Grounding Electrode Conductors

Grounding electrode conductors (GEC) will conform to the following guidelines:

- a. Premises wiring, as required by the NEC to be grounded, will have the identified neutral (grounded conductor) connected to the EES by a copper GEC at the service disconnecting means, and connected by an additional copper grounding conductor from the neutral of the transformer secondary to a grounding electrode (GE). The GEC will be sized to comply with NEC Table 250.66.
- b. The GEC connecting the identified neutral conductor (grounded conductor) to the EES will be continuous and unspliced, except where splices and taps are permitted by the NEC. When a GEC is routed through a metal enclosure (e.g., a conduit), the enclosure will be bonded at each end to the GEC. Where two or more facilities are separately supplied by a common AC service in one building, the grounded conductor will be connected to the EES at each facility on the supply side of the disconnecting means. The grounded conductor from the common service to the separate building(s) will be grounded to the EES and will not be grounded at other points within the building(s). This grounding of the grounded conductor at several separate building(s) is only to be made when there is a common Ground Fault Protection for Equipment (GFPE) surge protection provided at the separate services where the feeder or branch circuit originates.
- c. Where one facility receives its electrical power from another facility, the EGC will be carried with the phase and neutral conductors in the same conduit or raceway and the grounded conductor (neutral) of the receiving facility will not be grounded at that facility.
- d. For separately derived systems, the GE from the grounded conductor (e.g., transformer secondary neutral) will be connected directly to the nearest electrically continuous effectively grounded structural steel. Where it is not feasible to connect the GEC to structural steel, the EES may be used. The required connections will be made only at one point on the separately derived system, before any system disconnecting means or over-current device, and at one point on the EES. This GEC should be copper and sized in compliance with NEC Table 250.66. In addition, the grounded conductor will be bonded to the frame and case of the separately derived system. EGCs (safety grounds) will also be connected between the separately derived system ground connection to the case and (1) its supply side distribution panel ground bus, and (2) its load side disconnecting means enclosure ground connection. These EGCs will be green insulated, unspliced, and the same size as the associated phase conductors. No neutral to ground connection will be made on the load side of the disconnecting means enclosure (see [Figure 2-17](#)).

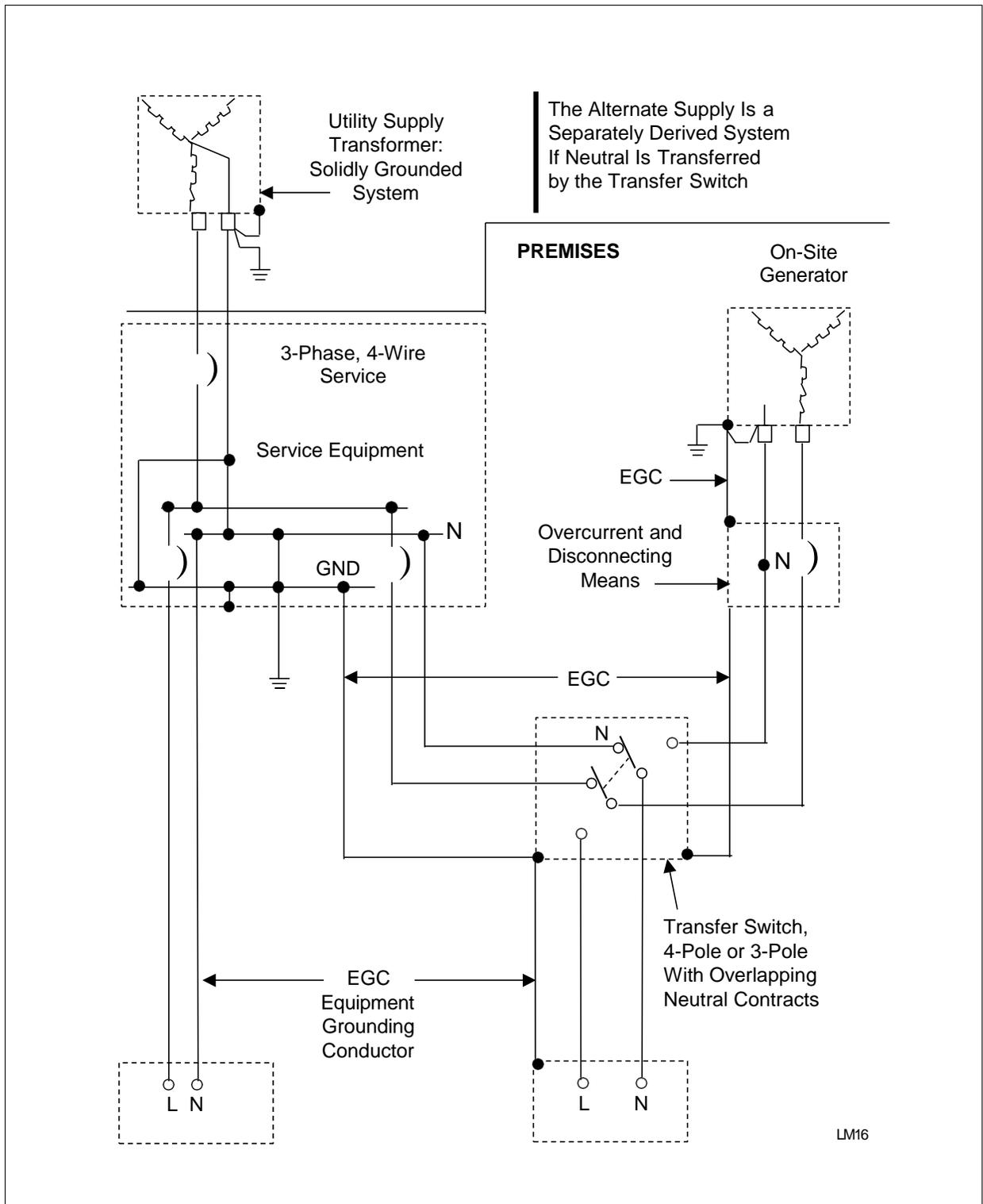


Figure 2-17. Separately Derived System

2.11.2 Equipment Grounding Conductors

If any commercially produced equipment allows for NEC-required power grounding, the equipment must be grounded. If the equipment is nonmetallic or does not allow for grounding, it is not necessary to ground. The equipment grounding conductor (EGC) will be a green insulated conductor and run in the same access way as its related phase and neutral conductors. Cord connected equipment will include the EGC as an integral part of the power cord. EGCs will be installed in all branch circuits and feeders and comply with NEC requirements.

2.11.3 Color-Coding of Conductors

2.11.3.1 Ungrounded Conductors

The color-coding of ungrounded conductors will be consistent throughout the facility as follows:

- a. For two ungrounded 120/240 V conductors, colors should be black and red.
- b. For three ungrounded 120/208 V service conductors, colors should be black, red, and blue for phase A, B, and C, respectively. For 277/480 V service, colors could be yellow, brown, and orange for phases A, B, and C, for example. A color distinction should be made from the 120/208 V service mentioned above.
- c. Where color-coded conductors larger than No. 6 AWG are not available, other colors, except white, natural gray, or green, may be used if they are re-identified with tape as specified below in paragraph d.
- d. When ungrounded conductors are re-identified, color-coding will be applied at each end and at every location where the conductor is visible. When routed through raceways or wireways, the coding will be visible by opening any cover. When conductors are routed through cable trays, coding 3 inches (75 mm) in length at intervals not exceeding 3 feet (0.9 m), should be provided.

2.11.3.2 Grounded Conductors

Color-coding of grounded conductors will be consistent throughout the facility:

- a. Neutral conductors (grounded conductors) will be insulated and color-coded white for 120/240 V and natural gray for 277/480 V. Conductors larger than No. 6 AWG may be re-identified as the grounded (neutral) conductor except that insulated green conductors will not be re-identified. Re-identification of conductors is permitted only if proper color-coded conductors are not available.
- b. In any room, conduit, pullbox, raceway, wireway, or cable tray, where two or more grounded conductors of different systems are present (branch circuits, feeders, services, voltages, etc.), conductors for each system will be consistent throughout the facility. The grounded conductor of one system may be white or natural gray. The grounded conductors of the other systems will be identified by a colored stripe (not green) on white insulation.
- c. Color-coding of grounded conductors will be applied at each connection and at every point where the conductor is accessible. Where routed through raceways or wireways, the color-coding will be visible by removing or opening any cover. Where

conductors are routed through cable trays, color-coding 3 inches (75 mm) in length should be provided at intervals not exceeding 3 feet (0.9 m).

2.11.3.3 Equipment Grounding Conductors

Equipment grounding and neutral conductors will be installed with the shortest most direct route with no sharp bends or kinks. Bend radius of the neutral and grounding conductor will be the same as it is for phase conductors, as specified in NFPA 70 (NEC). EGC color-coding will be green throughout the facility.

2.11.3.4 Conductor Routing

The neutral (grounded conductor) and EGCs will be routed through the same conduit, raceway, or cable tray as the phase conductors. Power conductors should not be routed in the same conduit or enclosed raceway with control, communications, or signal conductors or cables. Where power conductors must be routed in the same cable tray with electronic cables, the power conductors will be twisted to comply with [Table 2-5](#). For conductor sizes larger than No. 2 AWG, conductors will be twisted to the maximum extent practical. The minimum separation distance between power and signal cables should comply with specifications in [Table 2-9](#) (see Section [2.14.1.4](#)). Power and signal cables should cross each other at right angles wherever possible.

Table 2-5. Minimum Number of Twists for Power Conductors

Size (AWG)	Twists per Foot (0.3 m)			
	No. of Conductors			
	Two	Three	Four	Five
12	7	5	4	3
10	6	4	3	2.5
8	5	4	3	2
6	4	3	2	1.5
4	3	2	1.5	1
2	2.5	2	1.5	1

Source: FAA-STD-019d

2.11.3.5 Non-Current-Carrying Metal Equipment Enclosures

Metal enclosures will meet the following requirements:

- a. All non-current-carrying metal enclosures such as conduit, raceways, wireways, cable trays, and panel boards will be electrically continuous. Insulating finishes will be removed between grounding/bonding areas of mating surfaces and bonding jumpers (see [Figure 2-18](#)). All rigid galvanized steel conduits will be equipped with a bonding bushing at each end.
- b. Maximum use will be made of ferrous materials for enclosures, conduits, raceways, and cable trays to provide shielding from magnetic fields.

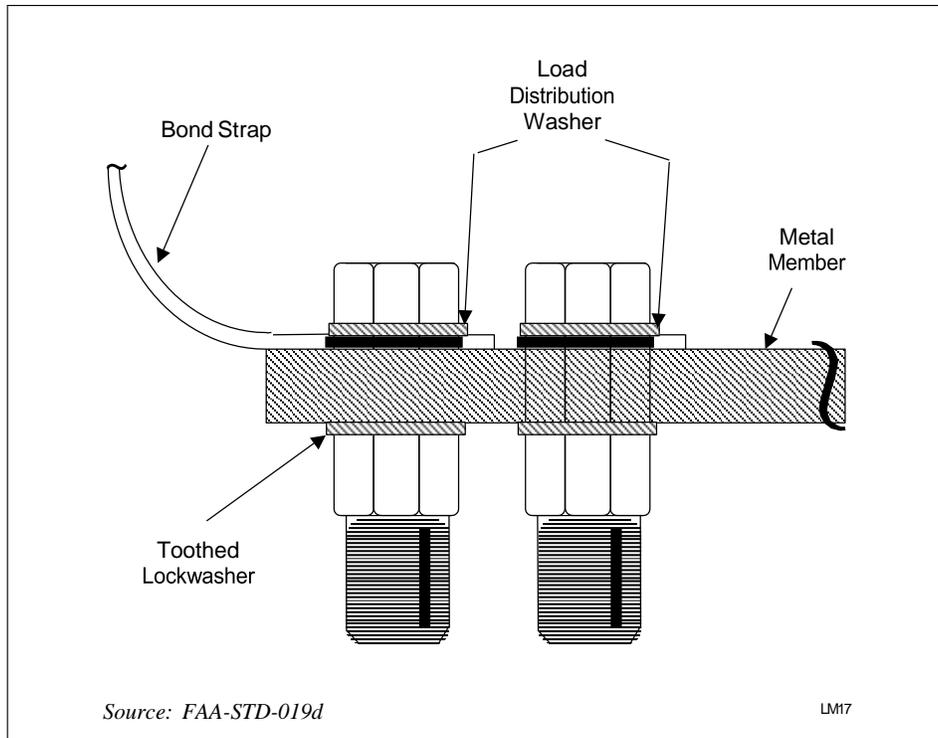


Figure 2-18. Order of Assembly for Bolted Connections

2.12 Other Grounding Requirements

2.12.1 Electronic Cabinet, Rack, and Case Grounding

All electronic cabinets, racks, and cases will provide a grounding terminal or means whereby a grounding jumper or wire can be mechanically connected through an electrically conductive surface to the basic frame. (See [Figure 2-18](#) for guidance.) The metal enclosure of each individual unit of electronic equipment will be bonded to its cabinet, rack, or directly to the MPG system.

2.12.1.1 Mounting Surfaces

Electronic equipment mounting surfaces on cabinets and racks will be free of nonconducting finishes. Mounting surfaces for electronic equipment to be mounted in cabinets or racks will also be free of nonconducting finishes (see [Figure 2-19](#)).

2.12.2 Receptacles

Receptacles (convenience outlets) will be provided with a ground terminal. An EGC whose path is electrically continuous and is in the same raceway as the power conductors feeding the receptacles will be connected to the ground terminal. Where required for the possible reduction of electrical noise (electromagnetic interference) on the grounding circuit, receptacles will be permitted in which the grounding terminal is purposely isolated from the receptacle mounting. The receptacle grounding terminal will be grounded by means of an isolated EGC run with the circuit conductors (phase and neutral). This grounding conductor will be permitted to pass through one or more panelboards without connection to the panelboard grounding terminal. This

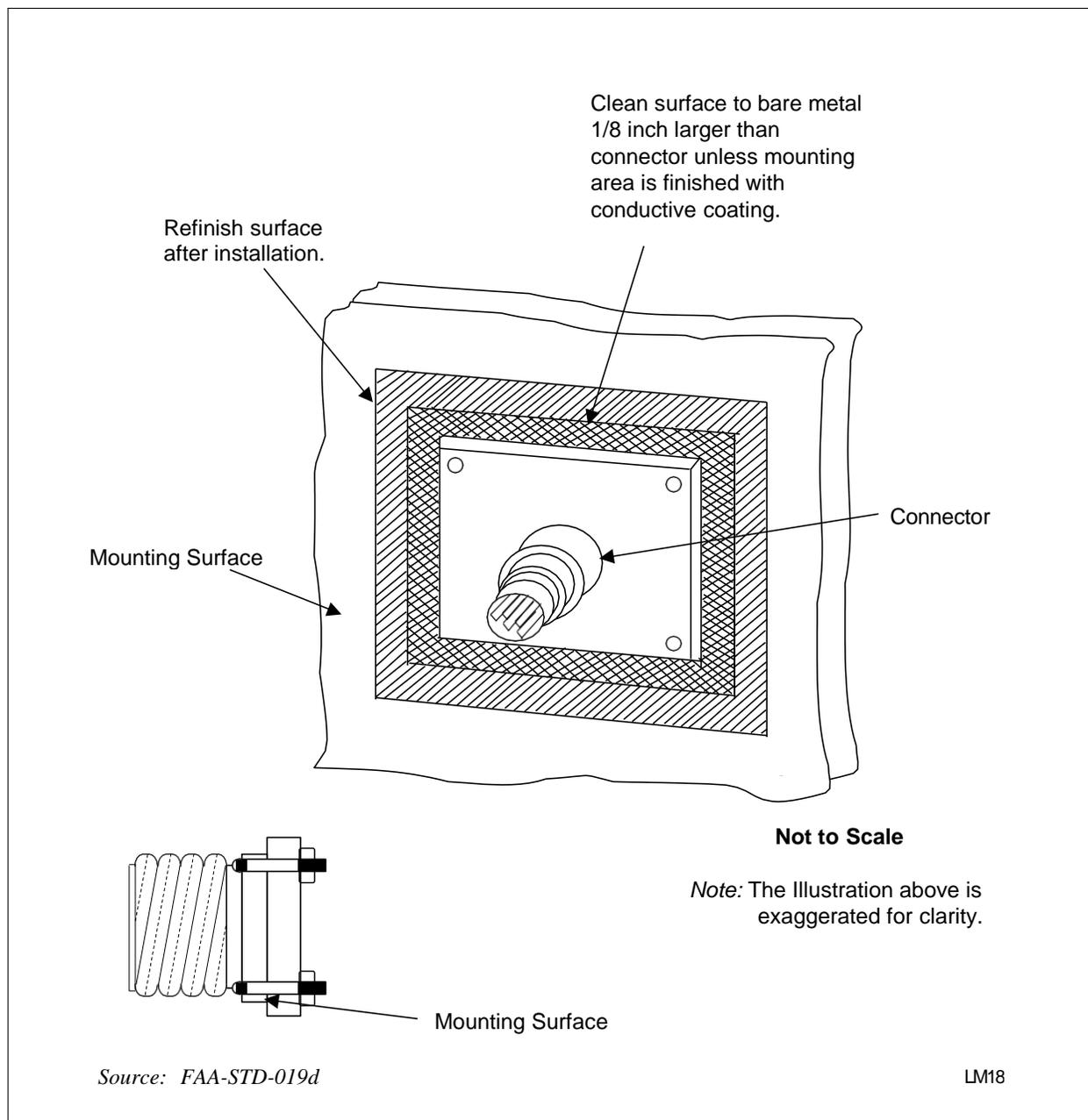


Figure 2-19. Bonding of Connectors to Mounting Surface

EGC should terminate directly at the service. All EGCs will be run in the same conduit with their associated phase and neutral conductors. The EGC will be color-coded green.

2.12.3 Equipment Power Isolation Requirements

With the equipment power cord or connector disconnected and the equipment power switch or circuit breaker in the ON position, resistance between each conductor (including AC neutral) and the equipment case, and between each power line conductor and the SPG system, will not be less than 10 megohms.

2.12.4 Portable Operational Equipment

Portable electrical or electronic equipment cases, enclosures, and housing will be considered to be adequately grounded for fault protection through the EGC of the power cord, provided continuity is firmly established between the case, enclosure, or housing and the receptacle ground terminal.

NOTE: The power cord equipment grounding conductor (EGC) will not be used for signal grounding.

2.12.5 Fault Protection

Equipment parts such as panels, covers, knobs, switches, and connectors that are subject to human contact during operation and maintenance will be prevented from becoming electrically energized when there are faults or component failures. Such parts will be grounded by a low impedance path to the chassis or cases of the equipment on which they are mounted. When grounded conforming with Section [2.12.3](#), equipment chassis, cases, racks, cabinets, and other enclosures will be considered adequately grounded for fault protection.

2.12.5.1 Metal Control Shafts

Metal control shafts will be grounded to the equipment case.

2.12.5.2 Shielded Compartments

Shields will be bonded to the chassis for fault protection complying with Section [2.13](#).

2.12.6 AC Power Filters

All filter cases will be directly bonded according to Section [2.13.12](#) to the equipment case or enclosure. Filter leakage current will not exceed 5 mA per filter. Where practical and where the equipment is compatible, common power line filters will be used to limit total leakage current to 5 mA. Transient suppression devices, components or circuits will be installed according to Section [2.6](#).

2.12.7 Grounding of RF Transmission Lines and Antennas

Antenna and transmission line terminals should be at ground potential, except for RF energy on their external surfaces. This requirement should be met by providing a DC path from such terminals to ground that is of sufficiently low resistance and heavy current carrying capacity (complying with NEC Tables 250-66 and 250-122) to disable the source of any internal high-voltage supply that may be applied to the terminals by accident or failure of some part.

2.12.7.1 Satellite Ground Station Antenna Grounding (Directly to Building EES)

The buried conductor used to bond the satellite ground station (SGS) antenna's ground rod to the building's EES will be a bare stranded copper conductor of a size No. 4/0 AWG minimum. Connection to the buried EES will be made to the closest and direct point from the antenna's ground rod. Directly burying the conductor and connecting it to the building's EES outside of the Weather Forecast Office (WFO) is the preferred method.

2.12.7.2 Satellite Ground Station Antenna Grounding (Connecting to the Ground Test Well)

The buried conductor may be connected to the EES by way of a test well connection. In this case, UL-approved connectors may be used at the test well. The SGS antenna's bonding conductor should be installed in as straight a line as practical to minimize any self inductive reactance created by the conductor's configuration. This bonding conductor will not have a bending radius less than the NEC's allowable 8 inches. If Section [2.12.7.1](#) is the method of bonding, a No. 4/0 AWG buried copper conductor should be exothermically welded to both the EES and the antenna's ground rod, unless the test well is located in a flammable area, in which case, UL-approved pressure connectors may be used. This bonding requirement is an NEC requirement (Article 250.106). This conductor will be buried at least 30 inches below grade level. Annual antenna grounding checks should be made to ensure its continuity as well as its ground ohmic value, which should be less than the 5 ohms.

2.12.7.3 Rooftop Antennas With an Existing LPS

If the antenna is mounted on the roof of a building having an existing LPS, the antenna's metal mast will be bonded to the nearest roof or down conductor of the LPS. Thermal welding or U.L. approved pressure connectors may be used at either the roof or down conductors. If the bonding to the conductors noted above requires the use of a separate conductor, its size should be at minimum a No. 4 AWG bare stranded copper. Electrical grounds of the LPS and EES will be bonded together to comply with the National Electrical Code (NEC Articles 250.106 and 810.21f).

2.12.7.4 Rooftop Antennas Without an Existing LPS

Air terminals are required on metal obstacles less than 3/16 inch thick. If a rooftop-mounted antenna's material thickness is 3/16 inch or greater, the antenna should be externally grounded. If a rooftop-mounted antenna's material thickness is less than 3/16 inch, an air terminal (strike termination device) should be within 5 feet of the antenna. The antenna should be bonded to the air terminal using a Class I or Class II conductor. From the air terminal, there should be two independent conductor paths to ground.

2.13 Bonding Requirements

2.13.1 Resistance

Unless otherwise specified in this standard, bonding will be accomplished by a method that provides the required degree of mechanical strength, achieves and maintains the low-frequency and high-frequency impedance required for proper functioning of the equipment, and is not subject to deterioration through vibration or corrosion in normal use. Surface contact area of bolted connections to flat surfaces in the LPS will be 3 square inches or greater. Soft soldered or brazed connections will not be used for any part of the power grounding system or the LPS (air terminals, roof conductors, down conductors, fasteners, and conduit). Soft solder will only be used to improve conductivity at load bearing joints. Soft solder will not be used to provide mechanical restraint.

2.13.2 Methods

2.13.2.1 Exothermic Welds

Exothermic welds *may* be used for any type of bond connection specified herein. Exothermic welds *will* be used for all underground connections between earth electrodes, counterpoise cable or other connections to the EES.

2.13.2.2 Welds

Welding generally requires only the removal of foreign material that can prevent the establishment of a homogeneous weld. Before exothermic welding can be performed, dirt and other debris must be wiped or brushed away from the weld area and the area must be completely dry before the molds are positioned.

Welds will meet the following minimum requirements:

- a. Welds will support the mechanical load demands on bonded members.
- b. On members with a maximum dimension of 2 inches (50.8 mm) or less, the weld will extend completely across the side or surface of the largest dimension.
- c. On members with a maximum dimension between 2 inches and 12 inches (305 mm), one weld of at least 2 inches in length will be provided.
- d. On members with a dimension of 12 inches or more, two or more welds, each not less than 2 inches (50.8 mm) in length, will be provided at uniform spacings across the surface. The maximum spacing between welds will not exceed 12 inches.
- e. At butt joints, complete penetration welds will be used on all members whose thickness is 1/4 inch (6.4 mm) or less. Where the thickness of the members is greater, the depth of the weld will exceed 1/4 inch.
- f. Fillet welds will have an effective size equal to the thickness of the members.
- g. At lap joints between members whose thickness is less than 1/4 inch, double fillet welds will be provided.
- h. For metal interfaces requiring to be RF-tight, the interface will be continuously welded.

2.13.2.3 Dissimilar Metals

- a. Only exothermic welding will be used for the permanent bonding of copper conductors to steel or other ferrous structural members.
- b. All residual fluxes will be removed or neutralized to prevent corrosion.
- c. Brazing material will meet the requirements for dissimilar metals as specified in [Table 2-6](#).

Table 2-6. Acceptable Couplings Between Dissimilar Metals

Magnesium	●
Magnesium Alloy	●
Zinc	●
Clad 755	●
Clad 615	●
525	●
Clad 245	●
35	●
615-T6	●
755-T6	●
Cadmium	●
A175-T4	●
245-T4	●
145-T6	●
Wrought Steel	●
Steel Cast	●
50-50 Solder	●
50-50 Solder	●
Lead	●
Tin	●
Manganese Bronze	●
Brass	●
Aluminum Bronze	●
Copper	●
Nickel	●
Inconel	●
Type 410	●
Type 431	●
18-8 NiCr Steel	●
Titanium	●
Monel	●
Silver	●
Graphite	●

Notes:

1. Stainless steels, nickel, and inconel are considered passive on this chart.
2. Each metal on the chart is considered anodic (sacrificial) to the metals following it.
3. A solid dot (●) indicates an acceptable combination.

Source: FAA-STD-019c

2.13.2.4 Mechanical Connections

- a. Bolted Connections.** Bolts and machine screws should be used primarily as mechanical fasteners for holding component members of the bond in place. They will be tightened sufficiently to maintain the contact pressures required for effective bonding but should not be over-tightened to the extent that deformation of bond members occurs. Where lockwashers are required to prevent loosening, they should not be placed between the bond members. Bolts and screws will not be used as indirect bonds for high-frequency signals. Bolted connections will conform to the following:

- (1) All bolted connections will conform to the torque requirements noted in [Table 2-7](#).

Table 2-7. Torque Requirements for Bolted Bonds

Bolt Size	Threads per Inch	Minimum Torque (in-lbs)	Tension (lbs)	Bond Area (sq. in.)
No. 8	32	18	625	0.416
	36	20	685	0.456
No. 10	24	23	705	0.470
	32	32	940	0.626
1/4 in.	20	80	1840	1.225
	28	100	2200	1.470
5/16 in.	18	140	2540	1.690
	20	150	2650	1.750
3/8 in.	16	250	3740	2.430
	24	275	3950	2.640
7/16 in.	14	400	5110	3.400
	20	425	5120	3.420
1/2 in.	13	550	6110	4.070
	20	575	6140	4.090
5/8 in.	11	920	7350	4.900
3/4 in.	10	1400	9300	6.200
7/8 in.	9	1950	11100	7.400
1 in.	8	2580	12900	8.600

Source: FAA-STD-019c

- (2) Bolted connections should be assembled in the order shown in [Figure 2-18](#) (see Section [2.12.1](#)). Load distribution washers, if used, should be positioned directly underneath the bolt head. Lockwashers will be placed between the nut and the primary members. Washers will not be placed between bonded members (see Section [2.13.9](#) for surface preparation).
 - b. **Sheet Metal Screws.** Sheet metal screws will not be used to provide a continuous and permanent electrical bond. The use of sheet metal screws will be restricted to the fastening of covers. These covers are to eliminate dust or other foreign matter from the equipment, and to discourage unauthorized or untrained personnel access to the equipment.
 - c. **Hydraulically Crimped Terminations.** Mechanical connections such as a Burndy “Hyground” connector, a Thomas and Betts compression connector, or an approved

equivalent, when operated at the manufacturer's recommended pressure to develop a minimum force of 6 tons, are acceptable pressure connectors. (These connectors are *not* acceptable in the LPS.)

- d. **Soldering.** Soldered joints should be carefully made to prevent cold solder joints. Where there are mechanical loads and stresses, including those resulting from temperature differentials existing at the joint, soldered bonds will utilize auxiliary fasteners such as bolts, screws, or rivets to provide mechanical strength. **Solder** connections will not be used as part of the power grounding system or the LPS.
- e. **Riveting.** Riveting will be employed primarily as mechanical fasteners to hold smooth, clean metal surfaces together or to provide mechanical load bearing capability to a soldered bond. **Rivets** will not be used as indirect bonds for high-frequency signals.

2.13.3 Bonding Straps and Jumpers

- a. Bonding straps will be attached to the basic member rather than through any adjacent parts.
- b. Bonding straps will be installed to be unaffected electrically by motion or vibration.
- c. Braided bonding straps will not be used for bonding transmitters or other sources of RF fields.
- d. Bonding straps will be installed whenever possible in areas accessible for maintenance and inspection.
- e. Bonding straps will be installed so they will not restrict movement of the members being bonded or other members nearby which must be able to move as part of normal functional operation.
- f. Two or more bonding straps will not be connected in series to provide a single bonding path.
- g. The method of installation and point of attachment of bonding straps will not weaken the members to which they are attached.
- h. Bonding straps will not be compression-fastened through nonmetallic material.
- i. Bonding straps will be designed not to have resonant impedances at equipment operating frequencies. Two short, low-impedance grounding straps between the MPG system and two corners of the equipment should be used. These straps should be connected as far apart as possible on the piece of equipment (ideally on opposite corners) in order to reduce mutual inductance and they should have few bends or sags. Two straps with a 20 percent to 30 percent difference in length should be used so that if one strap experiences resonance, limiting current flow, the other strap will not experience resonance.
- j. Broad flat conductors with a large surface area should be used for equipment grounding straps since they have a lower inductance than other (round) conductors.

2.13.4 Fasteners

Fastener materials for bonding aluminum and copper jumpers to structures will conform to the materials listed in [Table 2-8](#).

Table 2-8. Metal Connections for Aluminum and Copper Jumpers

Metal Structure (Outer Finish Metal)	Connection for Aluminum Jumper	Screw Type*	Tinned Copper Jumper	Screw Type*
Magnesium (Mg) and Mg alloys	Direct or Mg washer	Type I	Al or Mg washer	Type I
Aluminum (Al), Al alloys, Cadmium (Cd) and Zinc (Zn)	Direct	Type I	Al washer	Type I
Steel (except stainless steel)	Direct	Type I	Direct	Type I
Tin (Sn), Lead (Pb), and Sn-Pb solders	Direct	Type I	Direct	Type I or II
Copper (Cu) and Cu alloys	Tinned or Cd-plated washer	Type I or II	Direct	Type I or II
Nickel (Ni) and Ni alloys	Tinned or Cd-plated washer	Type I or II	Direct	Type I or II
Stainless Steel	Tinned or Cd-plated washer	Type I or II	Direct	Type I or II
Silver, Gold, and precious metals	Tinned or Cd-plated washer	Type I or II	Direct	Type I or II
*Screw Type: Type I – Cadmium, zinc plated, or aluminum Type II – Passivated stainless steel				

Source: FAA-STD-019c

2.13.5 Metal Elements Requiring Bonding

2.13.5.1 Earth Electrode Risers

The EES will be connected by exothermic welding to the down conductors of the LPS, the GEC, the grounding conductor from the main ground plate of the electronics grounding system, and the conductors from the structural steel columns.

2.13.5.2 Counterpoise Cables

Counterpoise cables will be attached to ground rods following the requirements of Section [2.8.5](#).

2.13.5.3 Underground Metallic Pipes and Tanks

Underground metallic pipes and tanks will be bonded to the EES according to the Section [2.8.5](#) requirements.

2.13.5.4 Steel Frame Buildings

Structural members (columns, wall frames, and roof trusses) will be electrically continuous. Where joints are not electrically continuous, they will be bridged to obtain continuity, with an exothermically welded No. 4/0 AWG stranded copper cable.

2.13.5.5 Interior Metallic Pipes

Interior metallic pipes and conduits will be bonded according to Section [2.9.4](#) requirements.

2.13.5.6 Electrical Supporting Structures

Conduit and cable trays will be bonded to comply with Section [2.9.5](#) requirements.

2.13.5.7 Flat Bars

Flat bars should be bonded by high compression bolts (see [Table 2-7](#) for bolt-torque specifications).

2.13.6 Temporary Bonds

Alligator clips and other spring-loaded clamps will be employed only as temporary bonds while performing repair work on equipment or facility wiring.

2.13.7 Inaccessible Locations

All bonds in concealed or inaccessible locations should be exothermically welded.

2.13.8 Coupling of Dissimilar Metals

Compression bonding with bolts and clamps will be used between metals with acceptable coupling values (see [Table 2-6](#)). When the base metals form couples that are not allowed, the metals will be coated, plated, or otherwise protected with a conductive finish, or a (toothpick-type) washer made of a material compatible with each will be inserted between the two base metals. The washer will be constructed of, or plated with, an appropriate intermediate metal as determined from [Table 2-6](#).

2.13.9 Surface Preparation

All surfaces to be bonded will be thoroughly cleaned to remove all dirt, grease, oxides, nonconductive films, or other foreign material. Paints and other organic coatings will be removed by sanding or brushing down to bare metal. Use of chemical removers is acceptable, provided all residue is removed from the area to be bonded and provided the chemical does not react with the base metal to produce nonconductive or corrosive products.

2.13.9.1 Paint Removal

Paints, primers, and other nonconductive finishes will be removed from the metal base with appropriate chemical paint removers, or the surface will be sanded with 500-grit abrasive paper or equivalent.

2.13.9.2 Inorganic Film Removal

Rust, oxides, and nonconductive surface finishes (anodized, galvanized, etc.) will be removed by sand blasting, by using abrasive paper or cloth with 320-grit or finer, or by using an appropriate

wire brush technique. Gentle and uniform pressure will be employed when using abrasive papers or cloths or wire brushes to obtain a smooth, uniform surface. Remove no more metal than necessary to achieve a clean surface.

2.13.9.3 Area To Be Cleaned

All bonding surfaces will be cleaned over an area extending at least 1/4 inch (6.4 mm) beyond all sides of the bonded area on the larger member.

2.13.9.4 Final Cleaning

After initial cleaning with chemical paint removers or mechanical abrasives, the bare metal will be wiped or brushed with an appropriate solvent (e.g., alcohol). Prior to bonding, surfaces not requiring the use of mechanical abrasives or chemical removers will be cleaned with a dry cleaning solvent to remove grease, oil, corrosion preventives, dust, dirt, and moisture.

- a. **Clad Metals.** Clad metal will be carefully cleaned, to a bright, shiny, smooth surface, with fine steel wool or grit so the cladding material is not penetrated by the cleaning process. The cleaned area will be wiped with dry cleaning solvent and allowed to air dry before completing the bond.
- b. **Aluminum Alloys.** After cleaning of aluminum surfaces to a bright finish, a brush coating of alodine or other similar conductive finish will be applied to the mating surfaces.

2.13.9.5 Completion of the Bond

If an intentional protective coating is removed from the metal surface, the mating surfaces will be joined within 24 hours after cleaning. If delays beyond 2 hours are necessary in corrosive environments, cleaned surfaces must be protected with an appropriate coating which must be removed before completion of the bond.

2.13.9.6 Refinishing of the Bond

Bonds will be refinished so as to match the existing finish as close as possible within the requirements of Section [2.13.10](#).

2.13.9.7 Machined Surfaces

Where an RF-tight joint is necessary, both surfaces will be machined smooth to provide uniform continuous contact through the joint area and an RF gasket (see Section [2.13.15](#)) will be used to ensure a low-impedance path across the joint. Fasteners will be positioned and distributed in a manner to ensure uniform pressure is maintained throughout the bond area is maintained.

2.13.9.8 Surface Platings or Treatments

Surface treatments, including platings, provide added wearability or corrosion protection and high conductivity. Plating metals will be electrochemically compatible with base metals, as specified in Section [2.13.8](#). Unless suitably protected from the atmosphere, silver, and other easily oxidized metals will not be used to plate bond surfaces, except where an increase in surface contact resistance cannot be tolerated.

2.13.10 Bond Protection

All bonds will be protected against weather, corrosive atmospheres, vibration and mechanical damage. Under dry conditions, a compatible corrosion preventive or sealant will be applied within 24 hours of assembly of the bond materials. Under conditions exceeding 60 percent humidity, sealing of the bond will be accomplished within 1 hour of joining.

2.13.10.1 Paint

If a paint finish is required on the final assembly, the bond will be sealed with the recommended finish. Care should be taken to ensure all means by which moisture or other contaminants may enter the bond are sealed. A waterproof type of paint or primer will be used if the recommended finish is not waterproof.

2.13.10.2 Inaccessible Locations

Bonds located in areas not reasonably accessible for maintenance will be sealed with compatible permanent, waterproof compounds after assembly.

2.13.10.3 Compression Bonds in Protected Areas

Compression bonds between copper conductors or between compatible aluminum alloys located in readily accessible areas not exposed to weather, corrosive fumes, or excessive dust do not require sealing.

2.13.10.4 Corrosion Protection

All exterior and interior bonds exposed to moisture or high humidity will be protected against corrosion. All interior bonds made between dissimilar metals will be protected against corrosion, according to both [Table 2-6](#) and Section [2.13](#). All exothermic connections will be cleaned. Protection should be provided by a moisture-proof paint or sealed with a silicone or petroleum-based sealant to prevent moisture from reaching the bond area.

2.13.10.5 Vibration

Bonds should be protected from vibration-induced deterioration by assuring bolts and screws, employ lock washers, and self-locking nuts are properly tightened, as all rivets are securely sealed.

2.13.11 Bonding Across Shock Mounts

Bonding straps installed across shock mounts or other suspension or support devices should not impede mounting device performance. Bonding straps should be capable of withstanding the anticipated motion and vibration requirements without suffering metal fatigue or other failures. Extra care should be utilized in the attachment of bonding strap ends to prevent arcing or other forms of electrical noise generation from strap movement. Ensure straps are protected from scrubbing, rubbing, or chaffing.

2.13.12 Enclosure Bonding

Subassemblies and equipment should be directly bonded, whenever practical, at the areas of physical contact with the mounting surface.

2.13.12.1 Subassemblies

Subassemblies should be bonded to the chassis utilizing the maximum possible contact area. All feed troughs, filters, and connectors will be bonded around the periphery to the subassembly enclosure to maintain shield effectiveness. Covers will exhibit intimate contact around their periphery, and contact will be achieved and maintained through the use of closely spaced screws or bolts, or the use of resilient conductive gaskets, or both.

2.13.12.2 Equipment

The chassis or case of equipment will be directly bonded to the rack, frame, or cabinet in which it is mounted. Flange surfaces and the contact surface on the supporting element will be cleaned of all paint or other insulating substances in compliance with Section [2.13.9](#). Fasteners will maintain sufficient pressure to ensure adequate surface contact to meet the bond resistance requirements in Section [2.13.1](#). Sheet metal screws will not be used for fasteners. If equipment must remain operational when partially or completely withdrawn from its mounted position, the bond will be maintained by a moving area of contact or by the use of a flexible bonding strap. Except when necessary to maintain bonding during adjustments, maintenance, or when other constraints prevent direct bonding, use of straps should be avoided. Mechanical designs will emphasize direct bonding.

2.13.13 Connector Mounting

Standard MIL-SPEC type connectors, shell-type connectors and coaxial connectors should be mounted to ensure intimate metallic contact is maintained with the panel on which it is mounted. Bonding will be accomplished completely around the periphery of the flange of the connector. Both the flange surface and the mating area on the panel will be cleaned as specified in Section [2.13.9](#). All nonconductive material will be removed from the panel as illustrated in [Figure 2-19](#). After mounting the connector, the exposed area of the panel will be repainted or otherwise protected from corrosion as noted in Section [2.13.10](#).

2.13.14 Shield Terminations

Cable shields will be terminated in the manner specified by Sections [2.14.1.2](#) and [2.14.1.3](#). Shields of coaxial cables will be fastened tightly to the cable connector shell with a compression fitting or soldered connection. The cable will be able to withstand anticipated usage without becoming noisy or suffering degradation in shielding efficiency. Coaxial connectors will be of a corrosion resistant material. Low-frequency shields will be soldered in place or, if solderless terminals are used, the compressed fitting will afford maximum contact between the shield and the terminal sleeve. Shield pigtailed will extend less than 1 inch from the point of breakaway from the center conductors of the cable.

2.13.15 RF Gaskets

Conductive gaskets will be made of corrosion resistant material, offer sufficient conductivity to meet the resistance requirements of Section [2.13.1](#), and possess adequate strength, resiliency, and hardness to maintain the shielding effectiveness of the bond. Surfaces in contact with the gasket will be smooth and free of insulating films, corrosion, moisture, and paint. The gasket will be firmly affixed to one of the bond surfaces by screws, conductive cement, or other means which do not interfere with the effectiveness of the gasket; or a milled slot will be provided, preventing

lateral movement or dislodging of the gasket when the bond is disassembled. Gaskets will be a minimum of 1/8 inch wide and of a reusable type. The gasket and contact surfaces will be protected from corrosion.

2.14 Shielding Requirements

2.14.1 Conductor and Cable Shielding

Conductor and cable shielding will comply with the following requirements.

2.14.1.1 Signal Lines and Cables

Cables consisting of multiple twisted pairs will have individual shields isolated from each other. Cables with an overall shield will have the shield insulated.

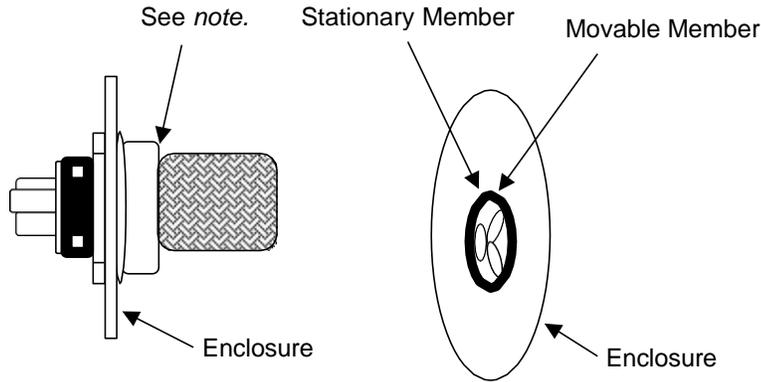
2.14.1.2 Termination of Individual Shields

Shields will be terminated as applicable for equipment operation. Shields of pairs of conductors and the shields of cables containing unshielded conductors will be terminated according to the following:

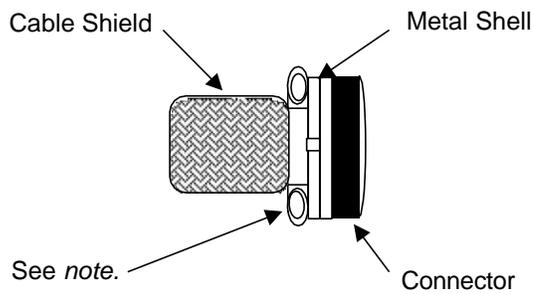
- a.** Shield terminations will employ minimum-length pigtailed between the shield and the connection to the bonding halo or ferrule ring and between the halo or ferrule ring and the shield pin on the connector.
- b.** Shields, individually and collectively, will be isolated from overall shields of cable bundles and from electronic equipment cases, racks, cabinet, junction boxes, conduit, cable trays, and elements of the MPG. Except for one interconnection (where the shield is grounded at one end only), individual shields will be isolated from each other. This isolation will be maintained in junction boxes, patch panels and distribution boxes throughout the cable run. When a signal line is interrupted such as in a junction box, the shield will be carried through.
- c.** Circuits and chassis will be designed to minimize the distance from the connector or terminal strip to the attachment point of the shield grounding conductor to the electronic signal reference. The size of the wire used to extend the shield to the circuit reference will be as large as practical but will not be less than No. 16 AWG or the maximum conductor size that will fit the connector pin. A common shield ground conductor for input and output signals, for both high-level and low-level signals, for signal lines and power conductors, or for electronic signal lines and control lines is prohibited. Each signal and power line will have its own ground.
- d.** Nothing in this requirement may preclude the extension of the shields through the connector or past the terminal strip to individual circuits or chassis if required to minimize unwanted coupling inside electronic equipment. Where extensions of this type are necessary, overall cable or bundle shields grounded complying with Section [2.14.1.3](#) will be provided.

2.14.1.3 Termination of Overall Shields

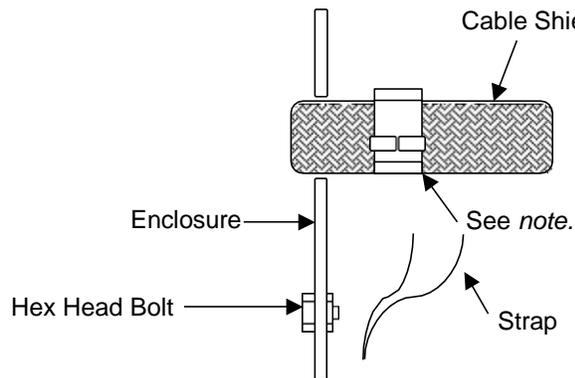
Cables with an overall shield over individually shielded pairs will have the overall shield grounded at each end and at intermediate points according to the following:



a) Box Connector



b) Grounding of Multi-pin Connector



c) Partition Penetration

Note:
Be sure cable shield is clean and securing clamp is tightened to provide a good ground.

Source: FAA-STD-019d

LM19

Figure 2-20. Grounding of Overall Cable Shields to Connectors and Penetrating Walls

- a. Cable shields terminated to connectors will be bonded to the connector shell as shown in [Figure 2-20a](#) or [Figure 2-20b](#). The shield will be carefully cleaned to

remove dirt, moisture, and corrosion products. The connector securing clamp will be carefully tightened to ensure a low resistance (5 milliohm or less) bond to the connector shell is achieved completely around the circumference of the cable shield. The bond will be protected against corrosion to conform with Section [2.13.10](#). The panel-mounted part of the connector will be bonded to the mounting surface according to Section [2.13.13](#).

- b.** Where cable continuity is interrupted (e.g., in a junction box), the shield will be carried through and grounded at the box. The length of unshielded conductors will not exceed 1 inch (25 mm). To meet this requirement the length of shield pigtail may be longer than 1 inch, if necessary, to reach ground but will be kept to a minimum.
- c.** Cables penetrating walls or panels of cases or enclosures without the use of connectors will have their shields bonded to the penetrated surface in the manner shown in [Figure 2-20c](#). Overall shields should be terminated to the outer surface of cases.
- d.** Grounding of overall shields to the terminal strips will be grounded as shown in [Figure 2-21](#).
- e.** The shields of the individual pair will be grounded as specified in Section [2.14.1.2](#).

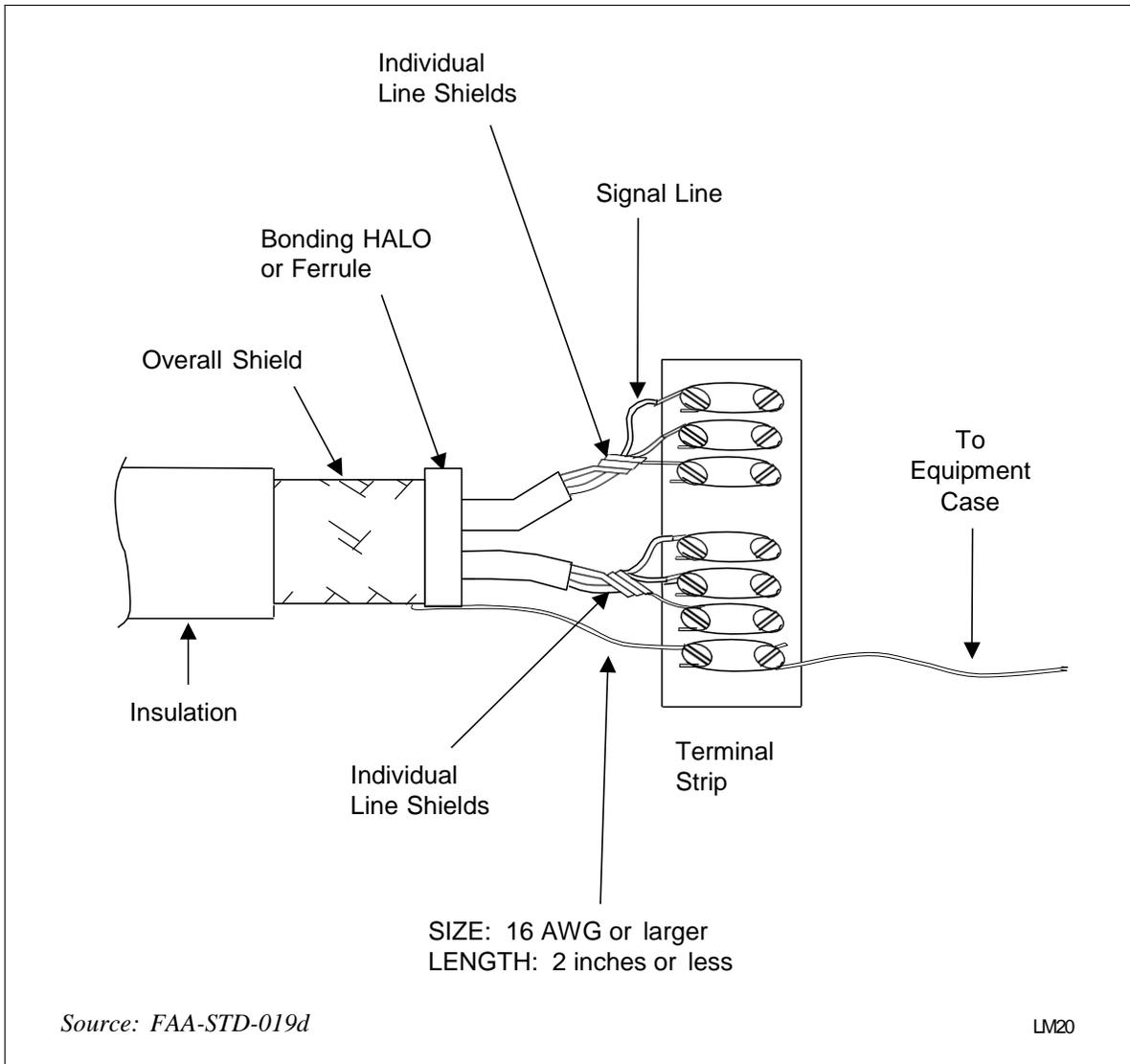


Figure 2-21. Grounding of Overall Cable Shield to Terminal Strip

2.14.1.4 Wire and Cable Routing

Routing and layout of conductors will be performed in a manner that does not jeopardize equipment shield integrity. High-frequency signals should be routed as far as feasible from low-frequency signals. AC power cable and control lines subject to large transients will be routed away from sensitive digital or other susceptible circuits. Shielded cables will be used for either extremely low- or high-frequency signals. Cable shields will be grounded to comply with requirements in Section [2.14.1.2](#) and [2.14.1.3](#) (see [Table 2-9](#)).

2.15 Electrostatic Discharge Minimization, Control, and Prevention

Modern electronic and electronically controlled electrical equipment with high-speed, closely spaced circuitry and miniaturized components is highly susceptible to damage from electrostatic discharge (ESD). This phenomenon is most often related to operator contact with ESD susceptible

items and must be considered when troubleshooting equipment. Some facilities preparation and installation requirements for ESD reduction as related to electrical grounding and bonding are included in this section. A typical ESD meter with an explanation of its use is shown in [Appendix F](#).

- a. **Static Dissipative ESD Control Floor Coverings.** Static dissipative ESD control floor coverings will include static dissipative tile, carpeting, static limiting floor finishes, and floor mats. These floor coverings will be bonded to a ground point (e.g., ESD common point ground) or directly to the MPG system in the area served.
- b. **Relative Humidity Control.** Relative humidity in ESD protection areas will be maintained within the range of 40 to 70 percent.
- c. **Use of Ionization.** Selective use of bench-top or area ionizers may be considered at ESD protected workstations if static generative items (e.g., insulators) are deemed essential and cannot be removed from ESD protected areas or if grounding of mobile personnel would be cumbersome or would create a safety hazard.

Table 2-9. Minimum Separation Distance Between Signal and Power Cables

Condition	<2kVA	2-5 kVA	>5kVA
Unshielded power lines or electrical equipment in proximity to signal conductors in open or nonmetal pathways	5 in. (127 mm)	12 in. (305 mm)	24 in. (610 mm)
Unshielded power lines or electrical equipment in proximity to signal conductors in a grounded metal conduit pathway	2.5 in. (64 mm)	6 in. (152 mm)	12 in. (305 mm)
Power lines enclosed in a grounded metal conduit (or equivalent shielding) in proximity to signal conductors in a grounded metal conduit pathway	–	3 in. (76 mm)	6 in. (152 mm)

Source: FAA-STD-019d

2.15.1 Hard and Soft Grounds

2.15.1.1 Hard Grounds

Any item, material, or product forming a part of the ESD control system and intentionally or unintentionally connecting directly to an ESD ground point (e.g., ESD common point ground reference) or directly bonded to an MPG will be considered to be hard grounded. ESD control work surfaces, cabinets, flooring, test equipment, and other items used for ESD control will be hard grounded to an ESD common point ground reference as specified above.

2.15.1.2 Soft Grounds

A soft ground is the intentional connection to ground through a series resistor limiting current to

1. mA if a person connected to the soft ground were to come into direct contact with a known potential. The soft ground concept will only be used in personnel grounding skin contact devices such as wrist straps, leg and ankle straps, conductive shoes, and heel or toe grounders. All other

2.

elements of the ESD control system will be hard-grounded. The nominal resistance of the resistor used for soft grounding of personnel will not be less than 1 megohm.

2.15.1.3 Panel-to-Understructure Resistance

Panel-to-understructure (metal-to-metal) contact resistances between individual access floor panels and the raised-floor understructure will not exceed 10 ohms.

2.16 Additional Guidelines

- a.** Periodic inspections of electrical components of any LPS installed at any NWS facilities are recommended (see NFPA 780, Appendix K.7).
- b.** New LPSs will be completely inspected immediately after installation. This includes a visual inspection, parts inspection, and ground resistance and ground termination inspection.
- c.** In addition to the above, the LPS should be inspected whenever any alterations or repairs are made to the protected structure, as well as following any known lightning discharge to the system.
- d.** Existing LPSs on any NWS facilities will be visually inspected every 7 months (see NFPA 780, Appendix K.7.2).
- e.** An electrical continuity test will be made on all LPSs from the air terminal to the ground at least every 14 months (see NFPA 780, Appendix K.7.3).
- f.** Inspection will be performed whenever the LPS has been or is suspected to have been struck by lightning.
- g.** For an applied signal difference at the input of electronic equipment, the signal relative to the reference at equivalent points in the two branches must be opposite in polarity and equal in amplitude.
- h.** Another occasional hazard is the location of a site in proximity to an electric substation. It is recommended that no NWS site be located near electric power stations. If this does occur, there is a considerable problem with “ground potential rise” when there is an electric fault. The topic of “ground potential rise” can be found in reference IEEE Standard 367. If consideration of this topic needs evaluation and calculations, the services of a registered Professional Engineer are recommended.

CHAPTER 3

Radial Grounding, Electrical Protection, Equipment Specifications and Installation Guidelines for NWS Facilities



3.1 Purpose

Engineering design guidelines are provided for the grounding and electrical protection of tower sites, equipment buildings, and power and communication locations to minimize damage resulting from lightning strike energy and lightning induced Ground Potential Rise (GPR).

3.2 Applicability

Apply this chapter when installing, operating, maintaining and/or repairing equipment, facilities, and services in order to minimize lightning induced ground potential rise (GPR).

3.2.1 Acronyms and Abbreviations

1. Air Terminals: Lightning Rods
2. Ground Potential Rise (GPR): The product of ground electrode impedance, referenced to remote earth, and the current that flows through that electrode impedance.
3. HALO Ground: A closed loop grounding system that bonds all non-equipment metal frames to ground minimizing the radiation of RF and electromagnetic energy into the equipment room
4. IERG: Interior Equipment Ring Ground is an open loop ring ground that facilitates common bonding of equipment
5. Isolating Transformer: Transformers that provide longitudinal (common mode) isolation of wire-line telecommunication circuits.
6. MGB: Master Ground Bar is an exclusive grounding point for all equipment to one point in the equipment building. See Figure 3-2 for proper bonding to the MGB.
7. MGN: Multi-Grounded Neutral
8. SAD: Silicon Avalanche Diode is solid state protection that shunts transients to ground in less than 5 nanoseconds and required to shunt all lightning surge energy
9. SBTC: Solid Bare Tinned Copper
10. Solid State Protector: A protective device that employs solid state elements that provides a combination of high speed voltage and current sensing. These protectors are shunting devices to ground that are generally a combination of voltage clamps (avalanche diodes) and crowbar devices (multilayer diodes similar to SCR's), and are designed to limit the voltage to a specific value and to reduce current flow to low value of milliamperes within nanoseconds.
11. SPG: Single Point Ground
12. TVSS: Transient Voltage Surge Suppression

3.3 Tower and Equipment Building Installation Recommendations

3.3.1 Grounding System Design and Grounding System Evaluation Method

- 1) Conduct a four (4) probe soil resistivity test to be taken at a tower and equipment building installation site to provide data for an engineering study to design a new grounding system that will minimize (harden) lightning strike damage to equipment.

- 2) To harden against lightning GPR damage requires a specially designed tower and equipment building radial grounding system with impedance not exceeding two (2) ohms each.
- 3) The total overall site ground impedance (tower and building) should not exceed one (1) ohm if possible. Note: This may require significant real-estate space if the site soil resistivity is greater than 200 meter-ohms at the anticipated grounding electrode depth.
 - a. If one (1) ohm is not economically achievable, an attempt should be made to provide the lowest possible ground resistance value, using radial grounding, to minimize lightning induced GPR as much as possible.
- 4) Conduct a site ground resistance test {three (3) probe} to remote earth using the location of the Single Point Ground as the grounding electrode. This test, referred to as a 'fall-of-potential' test will confirm that the site grounding system meets engineering design requirements. A fall-of-potential resistance test must be conducted with the electrical connection (bond) to the power Multi Grounded Neutral (MGN) removed.

Note: all grounding systems of the same resistance to remote earth are not equal. To be equal they must have the same value of impedance to remote earth. Grounding systems using capacitive radials placed horizontally in the earth will have much lower impedance than an inductive ground rods placed vertically in the earth. Lightning current has high frequency components up to 1.0 M HZ, thus a capacitive ground is much better than an inductive ground. At Time 'T' = to Zero a capacitor is a short circuit while an inductor is an open circuit.

3.3.2 Design of Ideal Tower and Equipment Building Earth Grounding

- 1) Tower and Equipment Building grounding system design: See example design of "IDEAL LIGHTNING-DISSIPATING SINGLE-POINT GROUNDING SYSTEM" Figure 3-1.
 - 2) All grounding system wire shall be #2 AWG Solid Bare Tinned Copper (SBTC), diameter =.2576 inches.
 - 3) Use Sankosha Conductive Cement placed over all grounding conductor radials (18 to 24 inches in width) at locations where the soil resistivity is greater than 200 Meter-Ohms at the grounding electrode depth.
 - a. See web site: <http://www.sankosha-usa.com/pdf/san-earth-lateral.pdf> for an example installation of placing dry cement over radial wire.
 - 4) All ground rods shall be galvanized steel, copper clad or stainless steel, and a minimum of 8 ft. in length and 5/8 inch in diameter.
 - 5) All bonds to the grounding system, in contact with earth, shall be by exothermic welding.
 - 6) Tower and equipment building, each require an external ring ground composed of #2 AWG Solid Bare Tinned Copper (SBTC) that is placed below the frost line.
-

- 7) Grounding of a non-self-supporting or a supporting Ice Bridge bonds both ends of the bridge to the tower ground ring and the equipment building ground ring. The tower end of the Ice Bridge is isolated from the tower.
- 8) Guyed towers shall have grounding radials (#2 AWG SBTC) that are a minimum of twenty feet in length for each guy wire and placed out in front of the guyed anchor.
- 9) Ring grounds and radials for tower and equipment building shall each be protected by a 17 lb. or a 32 lb. sacrificial magnesium anode. For grounding systems have more than 500 linear feet of wire use one 32 lb. magnesium anode. Always place the anode two (2) or more feet below the grounding system depth.
- 10) Bond external ring grounds to any metal object or structure within five (5) feet.
- 11) External ring grounds and radials are to be buried at least 30 inches below grade level or below the frost line whichever is deeper and spaced at least two (2) feet from building foundations, tower footings or guyed anchors.
- 12) No bend radii of less than 24 inches throughout the external grounding system.
- 13) A minimum of four (4) ground rods (one at each building corner) spaced a minimum of sixteen feet apart if possible, and bonded to building ring ground.
- 14) A minimum of one ground rod for each tower leg bonded to the tower ring ground.
- 15) Bond each tower leg to ring ground at two points curving in opposite directions on each side of the tower leg ring ground rod.
- 16) Provide four (4) to ten (10) radials off of ring grounds as necessary to obtain the specified grounding impedance desired for each ring ground but not longer than 80 feet each. Space radials equally apart and not closer than 15 feet in separation at the radial ground ring bond points.
- 17) Tower and equipment building ring grounds should be separated by a minimum of 30 feet (to prevent electromagnetic wave damage to equipment building) and bonded together with a single ground wire called the 'ring connecting ground wire'. See Figure 3-1, "Ideal Lightning-Dissipating Single-Point Grounding System".
- 18) The bonding point of this 'ring connecting ground wire' at the building ring ground is known as the Single Point Ground (SPG) location. See Figure 3-1, "Ideal Lightning-Dissipating Single-Point Grounding System".
- 19) Place a tinned Single Point Ground (SPG) Bar at the single point ground location on the building ground ring in a protected hand hole or placed on the equipment building wall and bonded to the SPG on the building ring ground.
- 20) Provide suitable access (a hand hole) for the single point ground (SPG) bar location for future inspection, maintenance, etc. if placing this bar in the earth instead of on the equipment building.
- 21) Tower and equipment building ring grounds separated by less than 30 feet may result in lightning electromagnetic energy damage to equipment within the equipment building.

- 22) Damage may be minimized to equipment in buildings located within 30 feet of towers by providing an elemental Faraday cage in the equipment building's concrete walls utilizing the rebar within the concrete.
- 23) An elemental Faraday cage may be defined as an electrically connected rebar cage, ¼ inch rebar at every rebar intersection, with 8 inch rebar spacing on all four building sides, and bonded to ring ground.
- 24) Radials placed off of tower ring ground should be directed away (opposite direction) from equipment building as well as radials placed off of the equipment building ring ground should be directed away from the tower.

3.3.3 Placing Ground Rods and Bonding to Metallic Objects

- 1) Place all ground rods in undisturbed soil and below the frost line.
- 2) Provide suitable access (a hand hole) for the four ground rods at each corner of the equipment building for future inspection, maintenance, etc.
- 3) If a metal fence is located within twenty (20) feet of the tower ring ground or within five (5) feet from the tower building ring ground:
 - a. Bond the fence to the ring ground
 - b. Bond the fence posts to the ring ground
 - c. Bond openings across the fence

3.3.4 Grounding Conductor Requirements Inside Equipment Building

- 1) Do not use U-shaped grounding conductor runs
 - 2) Place in nonmetallic conduit only
 - 3) If metallic conduit cannot be avoided, bond both ends of the metallic conduit to the grounding conductor, avoid long runs and keep bends to a minimum
 - 4) Minimum bend radius for a #2 AWG wire is 12 inches and 18 inches for #4/0 AWG wire
 - 5) Place grounding conductor through nonmetallic sleeves in floors, walls, ceilings, etc.
 - 6) Consider an Interior Equipment Ring Ground (IERG) to facilitate common bonding of equipment, prevent lightning energy from passing through equipment to get to ground at the floor level, and at the height of the coaxial (bulkhead) entry. The IERG is bonded to the Master Ground Bar (MGB). If an IERG equipment grounding system is not placed, then use home runs (bond ground wires) from each piece of equipment or rack back to a Master Ground Bar (MGB).
 - 7) All equipment racks must be isolated from ground at the floor if the coaxial cable entry at the bulkhead, from the tower ice bridge into the equipment room, is at eight (8) to ten (10) feet above ground level.
-

- 8) The IERG is bonded to the interior Master Ground Bar (MGB) which is then bonded to the bulkhead, which in turn is bonded to the exterior Single Point Ground (SPG) bar or directly to the ground ring at the SPG.
- 9) The IERG should be a #2 AWG or larger solid bare conductor mounted in an open loop (to prevent ground loop currents) around the perimeter of the room at a height of the bulkhead or coaxial entry level above the floor.
- 10) Use #6 AWG or larger conductors to bond equipment to the IERG.
- 11) To provide limited protection against RF interference and electromagnetic radiation from the lightning strike, metal objects such as doorframes, air conditioners, electrical boxes, or cabinets, etc., must be all bonded together in a ring, and then bonded only to the MGB. This ring type ground is called a HALO Ground. Absolutely, do not bond this HALO Ground to fire protection systems or to the IERG. Absolutely, do not bond any equipment to this HALO Ground.
- 12) A HALO Ground may also be grounded externally to the facility ring ground at the four (4) corners of the building.
- 13) The MGB is the only bonding point (connection) between the IERG and the HALO Ground.
- 14) External ground bars must be tinned and all connections shall be bonded using a two (2) hole lug connection for each bolted bond connection.
- 15) Bonding to the MGB should be as shown in Figure 3-2.

3.3.5 AC Power Grounding Electrode and DC Rectifier

- 1) The protective grounding for the AC service must meet the requirements of the National Electrical Code (NEC) and any local codes. Insure that the neutral in the main service panel is bonded to ground (AC ground electrode).
- 2) A bonding conductor must be placed from where the AC power service ground is derived to the metallic water pipe system (if present).
- 3) Bond the AC power service entrance panel neutral to the tower building's Master Ground Bar (MGB).
- 4) Bond the AC grounding electrode (ground rod) at the meter to the SPG bar or to the SPG location on the building ground ring.
- 5) DC Rectifier ground must be bonded to the MGB.

3.3.6 Transient Voltage Surge Suppression (TVSS)

- 1) Service Entry Protection Panel must be UL 1449 listed and tested with ANSI C62.41-1991. Capability shall be bi-directional and treat both positive and negative impulses.
- 2) Effective response time shall be 20 nanoseconds or less.
- 3) Suppression shall be line to neutral, except delta configurations.
- 4) Sub-protection Panels shall operate as a totally coordinated system with the Service Protection Panel and perform equal or better than UL 1449 and be UL listed.

- 5) Unit shall not short circuit power flow that would cause an interruption of power to load.
- 6) Effective response time shall be 5 nanoseconds or less.
- 7) 5 nanoseconds or less is necessary to protect against lightning surges and this requires Silicon Avalanche Diode (SAD) Technology.
- 8) Suppression shall be line to neutral, except delta configurations.
- 9) Transtector APEX IMAX surge suppression equipment or equivalent is recommended.

3.3.7 Coaxial Cable, Waveguide and Bulkhead Panel

- 1) Coaxial antenna cable shield and waveguide shall be bonded, to the tower, at the top and bottom of the tower, and every 50 to 75 feet in between.
- 2) Placement of bottom grounding kit for all coaxial cable shields should be at the bend where coaxial cable transitions from the vertical direction to horizontal direction.
- 3) All antenna coaxial cable, other cable, wire, and waveguide shall be routed, and bonded to ground at the SPG and to the MGB inside the equipment building, through a bulkhead (ground window). The bulkhead is the bonding point for coaxial cable/waveguide entry into the equipment building that prevents lightning strike current from entering the building.
- 4) Coaxial cable (center conductor with voltage powering) solid state transient surge suppression requires the use of PolyPhaser BGXZ or DGXZ technology or equivalent.
- 5) Preferred coaxial cable entrance into an equipment building is at ground level. This design eliminates the need for large copper straps required to bond the bulkhead to earth ground, and intercepts tower magnetic field.
- 6) Any use of CAT5e cables shall be shielded cables and protected at the top of the tower and in the equipment building using Transtector ALPU-POE-90 or 90M or comparable surge protection.

3.3.8 Communication Facility Isolation from a Lightning Induced Ground Potential Rise (GPR)

- 1) All wire-line (copper) communication services, i.e., copper pairs that may enter an equipment building should be isolated from remote ground (the Central Office ground at the other end) by the use of isolation or neutralizing transformer technology if the GPR is more than 1000V-Peak, per IEEE Std. 487.
 - a. Wire-line isolation using transformer technology and fiber optics to protect communication services from a GPR may be a costly solution. However, if the communication services are considered critical Class 'A' Services that cannot be
 - b. allowed go out of service for any length of time, then isolation is the only alternative and Teleline Isolator by Positron Inc. is recommended or equivalent.
 - 2) Standard communication pair shunting protection such as gas tube or carbon type protectors will not protect equipment at GPR locations. They are too slow and will allow the lightning surge to pass by and damage equipment. Also, shunting type
-

protection will fire in reverse, in a GPR location, placing ground potential voltages on the communication pairs with the current flowing away from the GPR to the remote end. See Figure 3-3 and Figure 3-4.

- 3) Solid state surge protection must be used if lightning surges are to be protected against non GPR or low GPR locations. Use ONEAC 5S-Series solid state protector units, i.e., N5-27-TBK or equivalent.
- 4) Communication metallic shields, entering equipment building, shall be grounded to the single point ground location if wire-line isolation is not used.
- 5) If fiber optic cable is provided for communications, it must be all dielectric cable with no metallic strength members or metallic shield and protected by placing it in a PVC conduit (Schedule 80) with a minimum diameter of 2 inches to prevent gopher damage.

3.3.9 Equipment Building Lightning Protection System

- 1) An equipment building does not require air terminals (lightning rods) on the roof if located within thirty (30) feet of the base of a tower that is at least 100 feet in height because of being under the cone of protection (45 degree angle from top of tower).
- 2) Equipment buildings should be protected with a traditional lightning protection system using air terminals, if considered exposed to a direct lightning strike except for metal building with steel thickness, including roof, of greater than 3/16 inch.
- 3) Follow NFPA 780, "Standard for the Installation of Lightning Protection Systems" and/or UL 96A, "Installation Requirements for Lightning Protection Systems" to protect exposed equipment buildings.
- 4) Exposed equipment buildings with perimeters less than 250 feet should have a minimum of two air terminals on a pitched roof and two 'Down Conductors' bonded to ring ground. Structures exceeding 250 feet in perimeter must have a down conductor for every 100 feet of perimeter bonded to ring ground and additional air terminals per NFPA 780. Metal structures shall be bonded to earth ground every 60 feet of perimeter.

3.4 Personnel Safety

- 1) Maintenance personnel shall not work on a tower or in the equipment building during a lightning storm and should wisely leave the area when threatening weather approaches.
- 2) Maintenance personnel shall work while standing on a rubber mat (20kV) and wear rubber gloves (10kV) when working on wire-line communication services or associated communications equipment, in the equipment building, that are connected to a remote ground.
- 3) Any noted damage to TVSS equipment in the equipment building shall be repaired or replaced immediately prior to any other work attempted.

- 4) A minimum of two maintenance personnel working together at tower locations prone to lightning strike activity is recommended and is a legal requirement in some states if conducting an audit.



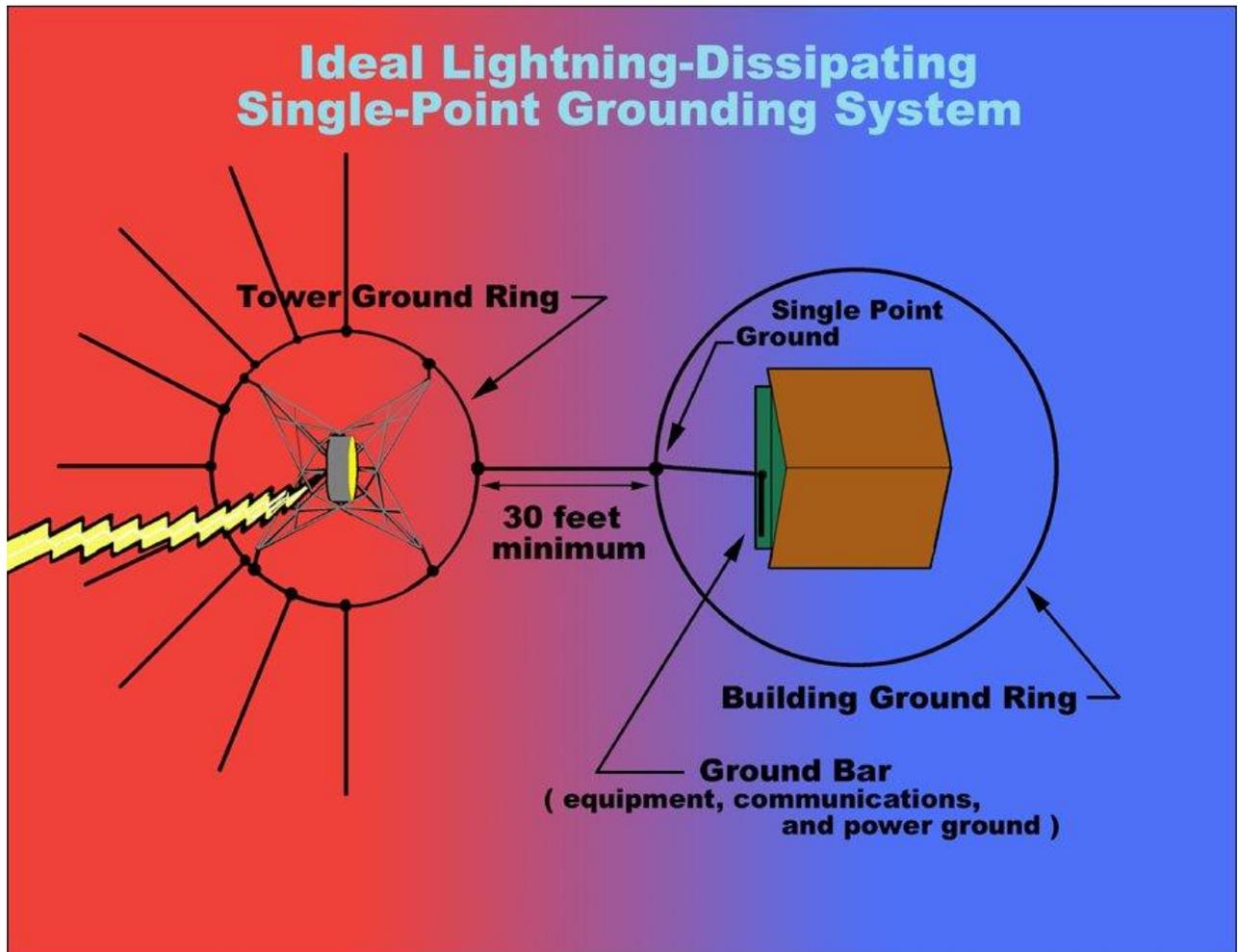


Figure 3-1

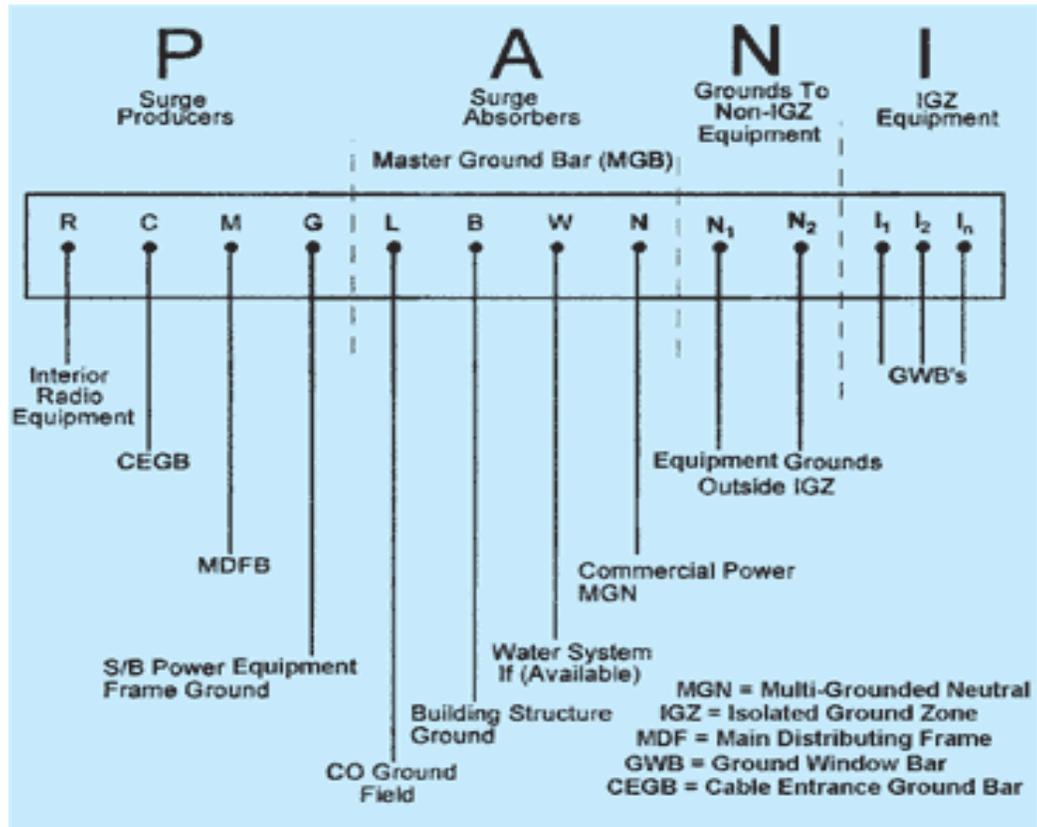


Figure 3-2

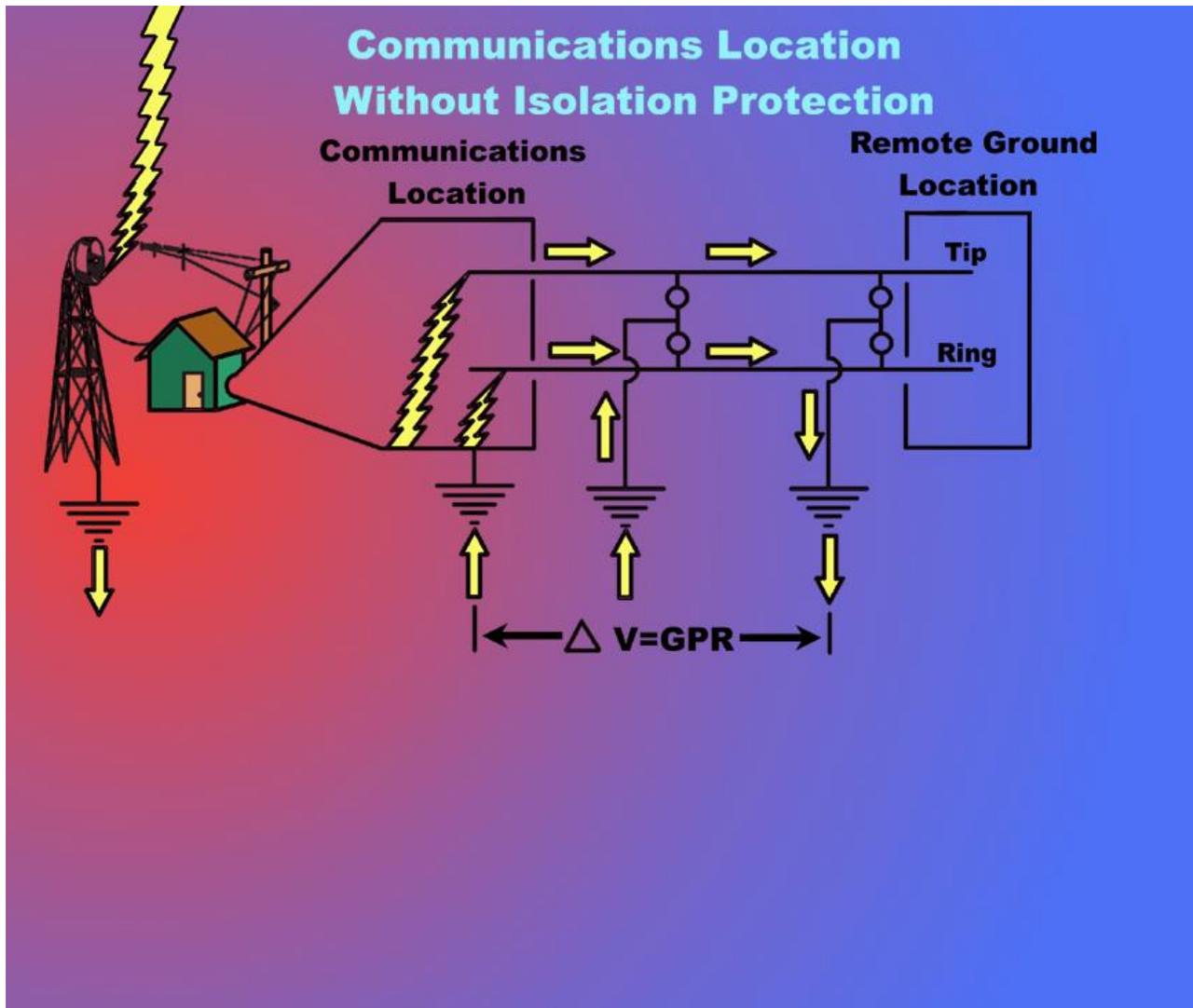


Figure 3-3

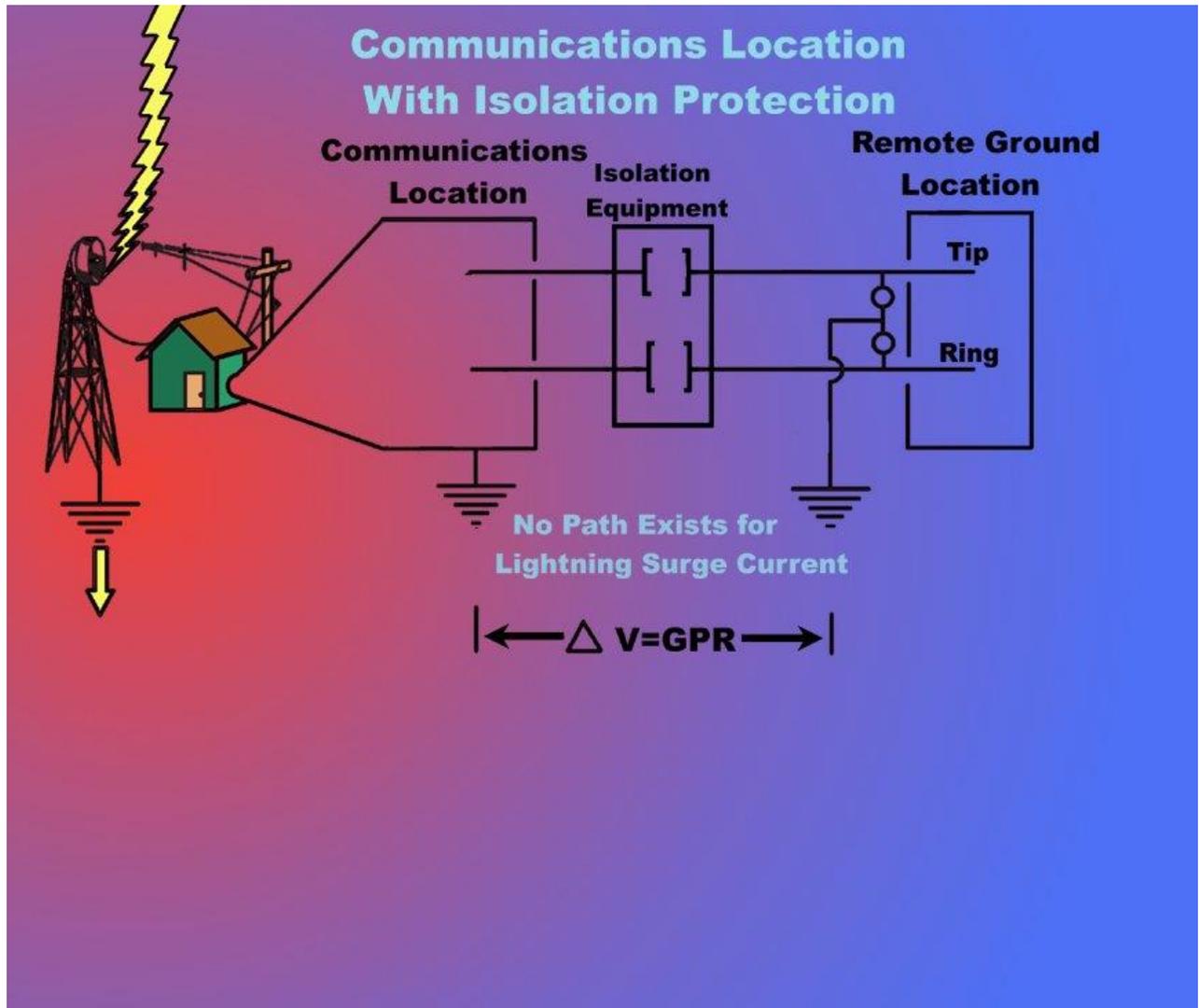


Figure 3-4

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APPENDIX A

Lightning Safety Checklist for NWS Sites



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APPENDIX A

Lightning Safety Checklist for NWS Sites

(Adapted from the National Lightning Safety Institute's Lightning Safety Checklist)

1. Verify air terminals and bases:
 - ☞ Are straight, unbroken, and uncracked.
 - ☞ Are securely fastened to structure.
 - ☞ Are clamped tightly to conductor cable.
 - ☞ Are not more than 20 feet apart on horizontal surfaces.
 - ☞ Are connected to at least two paths to ground.
 2. Verify bonding connections to metal objects:
 - ☞ Are secured tightly to metal equipment.
 - ☞ Are clamped tightly to connector cable.
 - ☞ Are in electrical contact with metal object (measure continuity).
 - ☞ Are reinstalled properly if they have been removed and replaced.
 - ☞ Have aluminum-to-copper connections made with stainless steel separators.
 3. Verify building additions and alterations:
 - ☞ Have no new additions unprotected.
 - ☞ Have no alterations changed and no damaged systems.
 - ☞ Have no new mechanical equipment left unconnected.
 4. Verify cable holders:
 - ☞ Are constructed of high strength silicon bronze bolts, nuts, flat washers and toothpiked lockwashers. Lightning's magnetic forces can "torque" weaker components apart.
 - ☞ Are still tight and secure.
 - ☞ Are still properly spaced at 3 feet O.C.
 - ☞ Are undamaged and have not been removed.
 5. Verify conductors, in general, including bonding straps:
 - ☞ Are unbroken and not frayed.
 - ☞ Have no tight bends. (Radius of bend should be 8 inches or greater and measure not less than 90 degrees from the inside of the bend. This does not apply to "T" or "Y" splices. Bends must be gradual.)
 - ☞ Have all braided cables used on equipment subject to movement.
-

6. If accessible, verify ground connectors:
 - ☞ Are tight and unbroken.
 - ☞ Show no evidence of corrosion. (If so, remove corrosion. Measure for electrical continuity.)
7. Verify service arresters and suppressors:
 - ☞ Are secure and straight, with no bends.
 - ☞ Have leads no longer than recommended by manufacturer. (Minimum length is vital for performance to manufacturer's ratings.)
 - ☞ Have unbroken and uncracked outside case/inside components.
 - ☞ Are free from any burning scent. (Must perform a Sniff Test.)
 - ☞ Have electrical service ground intact.
8. Verify splices and connectors:
 - ☞ Are still tight on conductors.
 - ☞ Have not cracked or appear broken.
 - ☞ They are still secure to proper cables (no loose ends).
 - ☞ Where connectors are employed to fasten down conductor cables to building structural steel, use exothermal weld (not mechanical) connections where possible.
9. Verify through-roof and through-wall connectors:
 - ☞ All are tight and unbroken.
 - ☞ All are watertight.
 - ☞ All leads to roof cable are intact.
 - ☞ All metal conduits entering structures are referenced to ground at both ends.
10. Verify grounding:

CAUTION

Do not perform this test under lightning threat conditions.

- ☞ Resistance measurements are within guidelines.

NOTE: Temporarily disconnect the Lightning Protection System from the ground rod at the Test Well. Use the "Fall of Potential" or other approved test method to measure ground system resistance. Perform this test every fourteen (14) months, as recommended by NFPA 780, Appendix K.7.3, but not during frozen ground or moisture-saturated ground conditions.

11. In inaccessible areas:
 - ☞ Perform bridge continuity testing on bonding straps, cables, conductors, connectors where possible to verify electrical continuity.
12. On main and secondary electrical panels:
 - ☞ Neutral bus is isolated from panel frame and/or ground bar.
 - ☞ Separate neutrals and grounds are employed for each branch circuit.
13. Verify signals lines:
 - ☞ Have used and unused lines equipped with surge suppression/transient protection devices.
 - ☞ Have terminal blocks protected at both ends.
 - ☞ Have all opto-isolators employed, wherever possible on I/O equipment.
 - ☞ In metal conduit, including braided shielding, are grounded only at the end where the circuits derive their zero potential or references point (normally the transmitter end and not the I/O end).
14. Verify grounding of security fences:
 - ☞ Are part of the earth electrode system (EES).
 - ☞ Have gates bonded to the fence at the gate hinge point.
 - ☞ Are not energized before you touch them. (Use a voltmeter.)
15. Verify other metal objects, such as:
 - ☞ Air handling equipment in generator rooms which employ nonconductive vibration dampers have a bonding strap across separated sheet metal.
 - ☞ Large exterior metal objects within 6 feet of the lightning protection down conductor network are bonded to it. (This includes fuel tanks, permanent machinery, stairs, columns, beams, trusses, metal sidings, railroad tracks, “temporary” buildings and trailers, etc.)
16. Verify standby generator building, RDA building, and the radome tower:
 - ☞ From construction documentation (“As-Built”), the original installation and modifications to the earth electrode system are installed per the drawings and specifications.
 - ☞ There is separation of neutral and ground downstream of the main bonding jumper.
 - ☞ The standby generator neutral is isolated at the generator set.

Lightning arresters are installed at the utility AC service transformer.

APPENDIX A₁

Lightning Audit & Safety Checklist for NWS Site Grounding & Electrical Protection Compliance

A. Audit Compliance Evaluation Section in which One Deviation May Compromise the Site to Damage from Lightning

- 1) Inspect to insure that the site AC Power Main Entrance Panel Neutral is bonded to the equipment building's Master Ground Bar (MGB)

DEVIATION	
NO DEVIATION	

- 2) Inspect to insure that the AC Grounding Electrode (ground rod) at the meter (main power panel) is bonded to the Single Point Ground (SPG)

DEVIATION	
NO DEVIATION	

- 3) Inspect to insure that the building has AC Power Surge Protection using Silicon Avalanche Diode (SAD) Technology on the main entrance panel or subpanel supplying power to the equipment room

DEVIATION	
NO DEVIATION	

- 4) Inspect to insure that the MGB is properly (down and out) bonded to the SPG

DEVIATION	
NO DEVIATION	



- 5) Inspect to insure that all coaxial cable and waveguide shields entering the building are bonded to the MGB

DEVIATION	
NO DEVIATION	

- 6) Inspect to insure that all coaxial cable center conductors are protected with SAD

DEVIATION	
NO DEVIATION	

B. Tower & Building Ring Ground (Test Procedure)

(1) Conduct a four (4) probe Wenner Soil Resistivity Test at the depths of the tower and equipment building grounding systems. Several test depths may be required. Use a Megger DET4TD or an equivalent test set. Grounding System Depths are equivalent to probe spacing. Record the meter readings (R) at several different site locations and probe orientations (N-S, E-W, etc.). Use a Soil Resistivity Worksheet to record and average test results. To calculate the soil resistivity, solve the following equation for (ρ) in Ω-M (ohm-meters) with the equation: $\rho = 1.915 \cdot \text{probe spacing in feet} \cdot R \text{ meter reading}$.

(a) These test results can be used to either design new installations or evaluate the existing grounding system installations in order to develop or confirm a grounding system resistance to remote earth. Grounding consultants utilize complex computer equations to design grounding system resistance using these soil resistivity measurements.

(b) Refer to Motorola R56B: “Standards and Guidelines for Communication Sites”, Appendix ‘B’: Soil Resistivity Measurements or other comparable documentation for Test Worksheet examples.

(c) Soil Resistivity (ρ) greater than 200 Ohm-Meters indicates poor soil conductivity and special grounding design techniques using radial grounds and lo-ohm conductive cement are going to be necessary to obtain a grounding system design under one (1) ohm to remote earth or as low as economically acceptable.

AVERAGE SOIL RESISTIVITY	Ω-M
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(2) Conduct a three (3) probe Fall of Potential test of the total grounding system to determine the grounding system resistance to remote earth. The goal is to obtain as low a resistance as possible to one (1) ohm. Use a Megger DET4TD or an equivalent test set. Record test results. **WARNING:** lethal potential may exist between probes during this type of test, if a fault were to occur. Thus insulated rubber gloves are required.

(a) The current probe should be placed at a distance that is out of the zone of

influence of the grounding (electrode) system under test, i.e., a minimum of 5 times the length of the diagonal of the total grounding system area will provide a 90% accurate resistance measurement. The voltage probe placement will be at 61.8% of the distance to the current probe from the electrode under test (usually the SPG).

(b) The AC Power Multi-Ground-Neutral (MGN) must be disconnected from the grounding system while under a ‘fall of potential test’ to obtain a valid reading. Never disconnect the MGN from ground without totally turning off the AC Power to the site.

(c) Refer to Motorola R56B: “Standards and Guidelines for Communication Sites”, Appendix ‘D’: Grounding Electrode Testing/Verification for details on the Fall of Potential Method testing procedure or other comparable document.

SITE RESISTANCE TO REMOTE EARTH	Ω
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(d) If test results indicate a grounding system resistance to remote earth of greater than five (5) ohms then an improved grounding system design using radial grounds and lo-ohm conductive cement may be required. Note: radial grounds provide a better impedance conducting path for lightning surge currents than standard ring grounds using only ground rods. Thus, radial grounding systems provide a better ground even if the resistance test measurement is greater than five (5) ohms to remote earth.

C. Building Lightning Protection (NFPA-780)

- 1) Is equipment building within the cone of protection (45 degree angle from top of tower)? If so, no air terminals are required on roof.

IS BUILDING WITHIN THE CONE OF PROTECTION?	
ARE AIR TERMINALS REQUIRED?	

- 2) If not within the cone of protection, equipment buildings must have air terminals (lightning rods) on the roof, except for metal buildings with steel thickness of greater than 3/16 inch. Air terminal bonds to ground (earth) are known as ‘Down Conductors’.

AIR TERMINALS OBSERVED?	
DOWN CONDUCTORS OBSERVED?	

- 3) Exposed equipment buildings with perimeters less than 250 feet should have a minimum of two (2) air terminals on a pitched roof and two (2) ‘Down Conductors’ bonding air terminals to the ring ground. Structures exceeding 250 feet in perimeter shall have a down conductor for every 100 feet of perimeter bonded to ring ground, and additional
-

roof air terminals per NFPA 780 spaced every 20 feet. Metal structures require that the building frame be bonded to earth ground every 60 feet of building perimeter.

4)

IS BUILDING PERIMETER > 250 FT?	
IS BUILDING A METAL STRUCTURE?	
IS NFPA 780 BEING FOLLOWED?	

D. Grounding Conductor Requirements in Equipment Building

1) No U-shaped grounding conductor runs.

DEVIATION	
NO DEVIATION	

2) No grounding conductors in metallic conduit unless bonded at both ends to earth ground.

DEVIATION	
NO DEVIATION	

3) Minimum bend radius for a #2 AWG wire is 12 inches and 18 inches for #4/0 AWG wire.

DEVIATION	
NO DEVIATION	

4) Grounding conductor must be placed through nonmetallic sleeves in floors, walls, and ceiling.

DEVIATION	
NO DEVIATION	

5) If an Interior Equipment Ring Ground (IERG) is used to facilitate common bonding of the equipment it must be placed at the bulkhead entrance height.

DEVIATION	
NO DEVIATION	

6) Insure that the IERG is bonded to the Master Ground Bar (MGB) or home runs (bond ground wires) from each piece of equipment are bonded to the MGB.

DEVIATION	
NO DEVIATION	

- 7) Inspect all equipment racks to insure their isolation from ground at the floor, if coaxial cable entry from the tower ice bridge into the equipment room is at eight (8) to ten (10) feet above ground level.

DEVIATION	
NO DEVIATION	

- 8) Inspect to insure that the MGB is bonded to the bulkhead (ground window).

DEVIATION	
NO DEVIATION	

- 9) Inspect to insure that the MGB is bonded to the SPG. Repeat of Audit Section A.

DEVIATION	
NO DEVIATION	

- 10) Inspect to insure that the IERG is a #2 AWG or larger conductor mounted in an open loop around the perimeter of the room at a height of 8 to 10 feet above the floor level or at coaxial entry level (bulkhead level) above the floor.

DEVIATION	
NO DEVIATION	

- 11) Inspect to insure that #6 AWG conductors or larger are used to bond equipment to the IERG or used as home runs to bond directly to the MGB.

DEVIATION	
NO DEVIATION	

- 12) Inspect any separate grounding system (HALO) that bonds metal objects such as doorframes, window frames, fans, air conditioners, electrical boxes, or cabinets, to insure that no equipment is grounded to this HALO Ground.

DEVIATION	
NO DEVIATION	

13) Inspect this HALO Ground to insure that it is a closed ring, and then bonded only to the MGB.

DEVIATION	
NO DEVIATION	

14) Inspect to insure that this HALO Ground is not bonded to fire protection systems or to the IERG.

DEVIATION	
NO DEVIATION	

15) A HALO Ground may also be grounded externally to the facility ring ground at the four (4) corners of the building.

IS THE HALO GROUND BONDED TO THE GROUND RING?	
--	--

16) Inspect to insure that the only bond (connection) between the IERG and the HALO Ground is at the MGB.

DEVIATION	
NO DEVIATION	

17) Inspect all internal and external ground bars to insure that bond connections are secure with two (2) hole lug connections for each bolted bond connection.

DEVIATION	
NO DEVIATION	

18) Inspect all external ground bars to insure that tinned ground bars are used.

DEVIATION	
NO DEVIATION	

E. AC Power Grounding Electrode, DC Rectifier, and Voltage Surge Suppression (TVSS)

- 1) Inspect the AC service entrance to insure that it meets or exceeds the National Electrical Code (NEC) and all applicable local codes. Utilities must also adhere to the NEC if non utilities have access.

DEVIATION	
NO DEVIATION	

- 2) Inspect to insure that a bonding conductor has been placed from where the AC power service ground is derived to any metallic water pipe system (if present).

DEVIATION	
NO DEVIATION	

- 3) Inspect to insure that the AC Power Main Entrance Panel Neutral is bonded to the equipment building's MGB. Repeat of Audit Section A.

DEVIATION	
NO DEVIATION	

- 4) Inspect to insure that the AC Grounding Electrode (ground rod) at the meter (main power panel) is bonded to the SPG. Repeat of Audit Section A.

DEVIATION	
NO DEVIATION	

- 5) Inspect to insure that the building has AC Power Surge Protection using SAD on the main entrance panel or subpanel supplying power to the equipment room. Repeat of Audit Section A.

DEVIATION	
NO DEVIATION	

- 6) Inspect to insure that the DC Rectifier Ground is bonded to the MGB.

DEVIATION	
NO DEVIATION	

F. Coaxial Cable, Waveguide, Ice Bridge, and Bulkhead Panel

- 1) Inspect to insure that all coaxial cable shields and waveguide are bonded, to the tower, at the top and bottom of the tower, and every 50 to 75 feet in between.

DEVIATION	
NO DEVIATION	

- 2) Inspect to insure that all coaxial cable shields and waveguide are bonded to the tower as it transitions from the vertical to horizontal.

DEVIATION	
NO DEVIATION	

- 3) Inspect to insure that the ice bridge is bonded to ground at both ends.

DEVIATION	
NO DEVIATION	

- 4) Inspect to insure that the ice bridge is isolated from the tower structure.

DEVIATION	
NO DEVIATION	

- 5) Inspect to insure that all cable shields and waveguide are routed through the bulkhead (ground window), bonded to ground at the SPG, and also bonded to the MGB inside the equipment building. Repeat of Audit Section A.

DEVIATION WITH ROUTING THRU BULKHEAD	
NO DEVIATION	
DEVIATION WITH BOND TO SPG	
NO DEVIATION	
DEVIATION WITH BOND TO MGB	
NO DEVIATION	

- 6) Inspect to insure that the SPG and the MGB are bonded together. Repeat of Audit Section A.

DEVIATION	
NO DEVIATION	

- 7) Inspect to insure that all coaxial cable center conductors are protected with SAD at the bulkhead and bonded to the MGB. Repeat of Audit Section A.

DEVIATION	
NO DEVIATION	

G. Wire Line Communication Facility Isolation from a Lightning Induced Ground Potential Rise (GPR)

- 1) Inspect any wire-line (copper) communication services entering the equipment building to determine if properly isolated from remote ground.

ARE THERE ANY WIRE LINE COMMUNICATIONS?	
ARE THEY PROPERLY ISOLATED FROM REMOTE GROUND?	

- 2) Inspect any wire-line communication services not isolated from remote ground to insure that their metallic shields are bonded to the SPG.

ARE WIRE LINE COMMUNICATIONS NOT ISOLATED?	
ARE THEIR METALLIC SHIELDS BONDED TO THE SPG?	

- 3) Inspect wire-line communication services not using isolation technology to insure that all pairs are protected using SAD.

ARE WIRE-LINE PAIRS PROTECTED WITH SAD?	
--	--

H. Test Equipment

Use a Megger DET4TD or an equivalent test set with an additional special set of long probe leads to conduct a three (3) probe Fall of Potential test of large grounding systems.

Note: probe lead lengths must be long enough to accommodate a required distance that is at least five (5) times the diagonal length of the grounding system under test to be out of the influence of the large electrode under test.

If the grounding system under test has a diagonal length of 100 feet then the current probe 'C' should be placed at 500 feet and the voltage probe 'P' should be placed at approximately 309 feet. The electrode under test 'E' connection is to the SPG location.

J. Routine Audit Intervals

Audit interval for the following may be every five (5) years, provided that there has been no vandalism or theft:

- B. Tower & Building Ring Ground (Test Procedure)
- C. Building Lightning Protection (NFPA-780)

Audit interval for the following may be every three (3) years, provided that no tower or equipment additions or modifications have been made. Note: if additions or modifications have been made then a site audit should follow:

- D. Grounding Conductor Requirements in Equipment Building
- F. Coaxial Cable, Waveguide and Bulkhead Panel

Audit interval should be every two (2) years:

- E. AC Power Grounding Electrode and Voltage Surge Suppression (TVSS)
- G. Wire Line Communication Facility Isolation from a Lightning Induced Ground Potential Rise (GPR)

Audit interval should be every year:

- A. Audit Compliance Evaluation Section in which One Deviation may Compromise the Site

K. Personnel Safety

Maintenance personnel are to not work on a tower or in the equipment building during a lightning storm and should wisely leave the area when threatening weather approaches.

Maintenance personnel are to work while standing on a rubber mat (20kV isolation) and wear rubber gloves (10kV isolation) when working on wire-line communication facilities or associated communications equipment in the equipment building that have a remote ground.

Maintenance personnel are to repair or replace any noted damage to TVSS equipment in the equipment building prior to any other work attempted.

A minimum of two (2) maintenance personnel should be working together at tower locations prone to lightning strike activity, and is a legal requirement in some states if conducting an audit.



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APPENDIX B

Lightning Protection Checklist

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APPENDIX B

Lightning Protection Checklist

1. Earth Electrode System
 - ☞ Has an EES been installed at this facility?
 - ☞ Is original site grounding survey data available at this facility?
 - ☞ Is the present ground EES properly sized and interconnected with the proper sizes and types of cables?
 - ☞ Are all connections to ground rods made by exothermic welding or other approved methods?
 - ☞ If an access well has been provided at this facility, is it properly installed and marked?
 - ☞ Using the 62 percent “Fall of Potential” method, does the EES measure less than 10 ohms (5 ohms in a facility housing operating electronic equipment)?
 - ☞ With the test probes in the same location and using the 62 percent Fall of Potential above, do all other connected grounds to the EES have the same resistance as measured in No. 6 above?

2. Service Entrance Grounding
 - ☞ Is the incoming power neutral conductor grounded at the transformer and the Main Service Disconnect Means (MSDM)?
 - ☞ Is the electrical transformer enclosure and Main Service Disconnect Means housing properly grounded?
 - ☞ Is the service entrance conduit grounded at both ends?
 - ☞ Is the grounding electrode conductor properly sized, installed and terminated at the EES?
 - ☞ Are all ground rods installed properly and interconnected?
 - ☞ Is the grounding electrode conductor properly terminated at the service entrance device neutral bar?
 - ☞ Is the ground bus properly bonded to the neutral bar established in the enclosure of the MSDM?
 - ☞ Is the MSDM ground bus properly installed and bonded?
 - ☞ Are all load side neutral conductors grounded only at the service entrance device? (Neutral must not be grounded at the equipments, raceways, switches, distribution, lighting or branch circuit panelboards, etc.)

3. Surge Protection Equipment Grounding
 - ☞ Verify proper AC surge protection devices are installed at the facility.
 - ☞ Is the AC power surge protector installed at the service entrance line side?

- ☞ Is the AC power surge arrester installed with the shortest lead lengths possible, keeping the number of bends to a minimum, and without any sharp bends or kinks?
 - ☞ Verify the phases, neutral, and ground of the surge protector device are properly installed.
4. Equipment Grounding
- ☞ Are all equipment grounding conductors green insulated?
 - ☞ Are equipment grounding conductors run in the same raceway with the phase conductors and sized properly?
 - ☞ Are all metallic raceways electrically continuous, end to end?
 - ☞ Are all equipment grounding conductors properly terminated?
 - ☞ Are all troughs and electrical enclosures properly grounded?
 - ☞ Where isolated receptacles (orange) are utilized at the facility, are they properly installed per the NEC requirements?
5. Signal Grounding
- ☞ Is the main ground plate connected to the EES with the shortest conductors possible?
 - ☞ Is the main ground plate conductor properly terminated at both ends?
 - ☞ Does the electronic equipment designated for single point grounding have an isolated ground terminated?
 - ☞ Is the feeder ground plate properly installed and marked?
 - ☞ Is the branch ground plate of the single point grounding system properly installed and marked?
 - ☞ Is the signal ground conductor properly color coded?
 - ☞ Is the signal ground conductor properly terminated at the equipment?
 - ☞ Is the single point ground conductor properly terminated at the feeder plate?
 - ☞ Is the Telco ground properly terminated to the facility ground system?
6. Lightning Protection Grounding
- ☞ Are all air terminals UL-approved for lightning protection?
 - ☞ Are all air terminals properly supported?
 - ☞ Are all air terminals at the proper elevation?
 - ☞ Are all the air terminals properly interconnected?
 - ☞ Are all exterior metal objects subject to a direct lightning strike or flash-over properly bonded to the roof or down conductors?
 - ☞ Does each air terminal have a minimum of two paths to the earth ground system?

- ☞ Are all the down conductors installed properly, and are they external to the facility building?
- ☞ Are all metal objects within 6 feet of the down conductors properly bonded to the down conductors?
- ☞ Are all down conductors connected properly to the ground rods?
- ☞ Are all ground rods properly sized, interconnected and installed?

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APPENDIX C

Lightning Protection Rationale

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APPENDIX C

Lightning Protection Rationale

Earth Electrode System

- Where required, an Earth Electrode System (EES) shall be installed capable of dissipating the energy of direct lightning strikes, dissipating DC, AC, RF currents and conducting power system fault currents to earth.
- A site survey should be made for existing facilities if data are not otherwise available. The four-probe method using a Biddle ground-resistance tester model DET62D or equivalent tester should be used.
- The EES shall consist of grounding rods, a counterpoise cable forming a closed loop on the ground rods and approved connections. The ground rods shall be 3/4 inches in diameter by 10 feet in length, copper-clad steel sectionalized type installed with the top of the rod at least 12 inches below finished grade. The ground rods shall be interconnected by the counterpoise cable that is a bare No. 4/0 AWG or larger copper conductor buried at least 2-1/2 feet below the finished grade. Connections to the ground rods shall be exothermic welds or by use of UL-approved connectors. Ground rods shall be outside of the drip line of the building's dripline.
- Structural steel of the building shall be connected to the EES at every other column around the building at intervals that shall not average over 60 feet apart, with No. 2/0 AWG or larger copper conductor. All underground metallic pipes, tanks and telephone grounds shall be connected to the EES by means of a No. 2 AWG copper conductor. All bonding resistances measured shall be one milliohm or less for each bond.
- An access well shall be provided for large facilities. The access well shall have a removable cover that can be locked and should be located at a ground rod as near the central location of the facility as possible. This access well shall be used for connecting the power and electronic grounding systems to the EES and for the connection of any future grounding system to the EES.
- The Grounding Electrode Conductor (GEC) shall be sized in accordance with the NEC, but in no case shall it be smaller than No. 2 AWG copper.
- Use the Fall of Potential method to establish the resistance plot indicating how the EES is performing.

Service Entrance

- Incoming power neutral conductor must be grounded using a Grounding Electrode Conductor (GEC). The case of the transformer must also be bonded to the same neutral point.
- Underground service entrance conduit shall hold only service conductors including the neutral.

- A grounding electrode conductor shall be used to connect the grounded neutral conductor at the service entrance equipment to the grounding electrode. This GEC shall be installed in one continuous length, without a splice or joint. Metal enclosures for the GEC shall be made electrically continuous by bonding each end to the GEC.
- The ground bus at the Main Service Disconnect Means (MSDM) shall be bonded to the neutral bar using the same size conductor as the GEC - Main Bonding Jumper.
- The neutral conductor shall not be connected to any ground other than in the MSDM (e.g., no neutral to ground bonds at sub-panels).

Surge and Transient Protection Devices

- Refer to the manufacturer's installation procedures pertaining to AC surge protection for the proper type and installation procedures.
- The AC power surge protection device shall be installed as close as practicable to the phase, neutral, and ground buses on the load side of the MSDM.
- The leads from the AC surge protection device shall terminate at their respective phase conductors and at the neutral bar. The case of the protector and the conduit nipple between the protection unit and the service shall be bonded to the ground. All leads will be as short as practicable and shall not have any sharp bends or kinks.

Electrical Grounding

- Reference the NEC - Article 250 for equipment to be grounded.
- 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 have low impedance to limit the voltage to ground and facilitate the operation of the protection device in the circuit. The equipment grounding conductor shall run in the same raceway as the power conductors. All power raceways shall be electrically continuous and solidly connected to the equipment at both ends with UL-approved fittings.
- Grounding conductors shall be connected by pressure connectors, clamps or other UL-approved means. Connection devices or fittings depending 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.
- Isolated ground pin receptacles installed in complying with NEC Article 250-146(D) shall only be permitted where approved for the purpose. This type of receptacle requires two equipment grounding conductors. One is run in the raceway with its related circuit conductors from the isolated ground terminal of the receptacle and shall terminate directly at an equipment grounding conductor terminal of its related service. This grounding conductor shall be permitted to pass through one or more panelboards without connection to panelboard grounding terminal. The other is to ground the receptacle box and shall be run in the conduit with its related circuit conductors and shall terminate on the ground bus of the panelboard providing the circuit protection for the receptacle.

Lightning Protection

- A lightning protection system consists of air terminals, roof and down conductors, ground rods, fittings and connections. All items shall have the UL label for use as a lightning protection component. Items that are listed by UL but not approved for lightning protection are not to be used.
- The tip of the air terminal shall be at least 10 inches above the object to be protected. Each terminal that has more than 24 inches total height shall be supported at a point not less than one half its height.
- All air terminals shall be interconnected as required by the “Standard for the installation of lightning protection systems” (NFPA 780) to ensure that each air terminal has at least two paths to ground.
- Not less than two down conductors shall be provided for buildings or structures (except for pole type towers where only one conductor is required). The down conductors shall be as widely separated as practicable.
- A conductor run through ferrous or aluminum material (conduit) shall be bonded to the top and bottom of the conduit.
- Conductors shall be securely attached to the object upon which they are placed. Fasteners shall be spaced not more than 3 feet apart on all conductors and shall be compatible with the structure. Conductors shall maintain a horizontal or downward course. No bend in a conductor shall form an inside angle of less than 90 degrees or have a radius of less than 8 inches. Metal objects that may be subject to a direct lightning strike shall be bonded to the lightning protection system. The bonding plate shall have an area of not less than 3 square inches.
- Metal objects at risk of a direct lightning strike shall be bonded to the system utilizing approved splices, fittings and conductors.
- Approved methods of below grade connections are exothermic.

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APPENDIX D

Ground Requirements for Nonstructural Metal Elements

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APPENDIX D

Grounding Requirements for Nonstructural Metal Elements

Waveguide Grounding, Including Nonstructural Metal Elements

At a minimum, waveguides shall be grounded as described in this appendix.

All waveguides to the antennas shall be grounded at three points:

- Near the antenna.
- At the vertical to horizontal transition near the base of the tower.
- At the waveguide entry port.

Supporting structures for waveguides shall be connected to the exterior earth electrode subsystem at the first and last support columns. Conductor leads shall be as direct as possible.

Waveguides shall be grounded with solid copper straps or conductors at least equal to No. 6 AWG. All bends shall have a radius of 20 cm (8 inches) or greater and no bend shall be less than 90 degrees.

Exterior Nonstructural Metal Elements

All handrails, ladders, stairways, antenna pedestals, antenna elements operating at ground potential and other metallic elements subject to human contact shall be bonded to the lightning protection system with cables no less than a copper No. 6 AWG (see NFPA 780 3.21.3, Isolated [Non-Grounded] Metallic Bodies).

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APPENDIX E

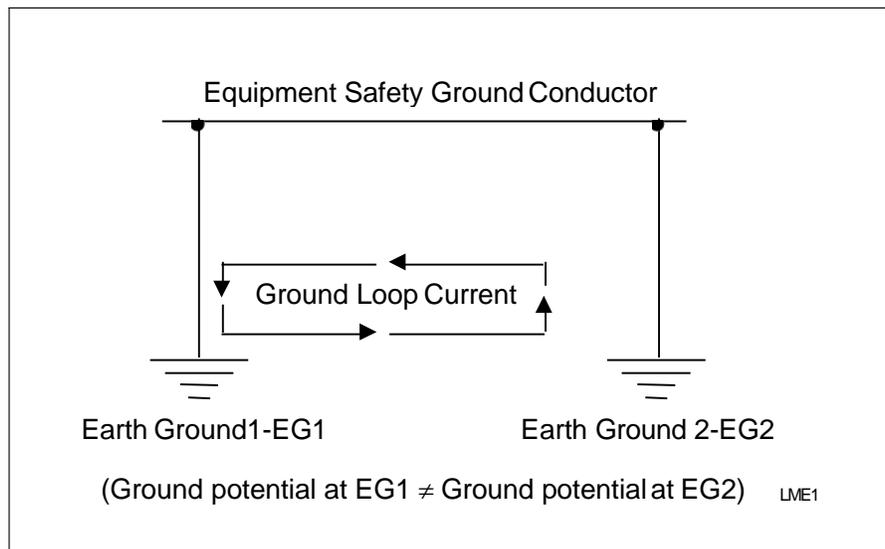
Electrical Ground Loops

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APPENDIX E

Electrical Ground Loops

Ground loops are one of the most significant grounding problems in many commercial and industrial environments. To understand ground loops is to recognize multiple ground paths. If a signal cable is grounded twice, unwanted currents will flow and the signal will be contaminated, which is a common cause of power quality problems. They occur whenever the equipment grounding conductor is connected to ground points, which are not at the same potential as the service ground.



With Earth Ground 1 at a different potential than Earth Ground 2, current flows in the equipment safety ground conductor. This current causes ground noise.

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APPENDIX F

Typical ESD Event and EMI Meter

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APPENDIX F
Typical ESD Event and EMI Meter

The following pages are from the Credence Technologies' Web site at www.credencetech.com.

EM Eye® ESD Event and EMI Meter



EM Eye® is a multifunctional electromagnetic field meter. For full description of all the features of EM Eye® please visit its [web page](#).

As an ESD Audit and Survey tool, EM Eye® performs the following functions:

IJJ Measurement and count of ESD Events
(see [Application Notes](#))

● Measurement of EMI environment

● Ground EMI measurements
(see [Application Notes](#))

Data logging of ESD and EMI Events with time/date stamp for documented ESD Audit and Survey Report. Data can be retrieved with supplied Windows™ -based software.

Specification

Among applications of EM Eye for ESD and EMI/:

- Assessment of effectiveness of ESD preventive measures
- Identifying sources of ESD Events
- fJ Evaluation of danger presented by the ESD Events
- fl Collection of data of ESD Events for the entire work shift with time/date stamp and comparison with the similar data collected during last survey
- Historical records of ESD environment
- Location and evaluation of electromagnetic interference at your plant
- Improving your EMI Environment and your ground
- Calibration and characterization of workbench ESD Event monitors

Verification of grounding from EMI point of view using EM Eye® field strength meter

Application Notes E213

EM Eye Firmware versions 1.0.4.0 and 1.0.5.0

Background

Ground is the most essential component of your ESD/EMI Management. Good ground performs several key functions:

- dissipates static charges from conductive objects
- establishes the common reference at the factory
- provides "disposal" for EMI-related signals
- provides compliance with the safety regulations regarding protection of personnel

Conventional methodology checks the quality of the ground using ohmmeters or multimeters. If the resistance path below the limit, the ground is judged to be good. While this method is adequate for assuring proper dissipation of static charges, it is insufficient for verification of quality of ground for high-frequency signals, i.e. EMI-related signals. The problem is that a typical multimeter is incapable of measuring high-frequency signals (many multimeters go only as high as 3kHz while EMI range extends up to 2GHz and sometimes above that).

What is Different at High Frequencies?

At high frequencies behavior of electric circuits changes. A simple wire which at DC (direct current) and lower frequencies represents a short circuit (0 Ohms) at higher frequencies (Megahertz and Gigahertz range) is an inductor: A coiled wire which at DC and lower frequencies still remains a short circuit, at higher frequencies is an inductor with very high impedance that may block passage of current essentially disconnecting supposedly grounded workbench or a tool from the real ground. As a result, high-frequency EMI-induced signals do not dissipate into the ground and reside on a workbench or on a tool. To make it worse, improperly done ground wires pick up EMI themselves and inject it into the circuits, aggravating the situation. Conventional methodology and tools provide false assurance of "good ground."

The Sources of EMI on the Grounded Objects

In the industrial environment there are abundant sources of EMI. Any electric or electronic equipment generates EMI, ESD Events generate substantial amount of EMI, extraneous sources such as mobile phones used in the vicinity contribute to the problem, EMI generated elsewhere propagates via power and poorly-done ground cables and wires and through the air: If the path to the ground for EMI is poor, a supposedly grounded object may have several volts of high-frequency signal present on its ground.

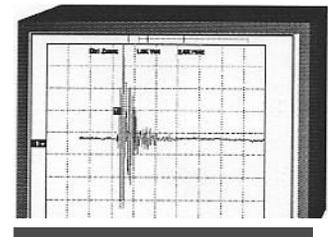
Why EMI is Bad?

To summarize it, EMI causes several significant problems:

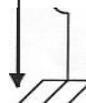
- equipment lock-up
 - equipment and sensor malfunction
 - strong EMI may cause damage of sensitive components
- Any of the above causes losses and downtime.

If equipment is poorly grounded from EMI point of view, it will be much more susceptible to EMI partially due to phenomenon called "ground bounce." At high frequencies voltage drops across such reactive component as long and coiled ground wires can result in ground level shifts or "bounce." The bounce, when added to the device logic level, may be sufficient to erroneously toggle a flip-flop in a neighboring or succeeding logic stage, causing equipment malfunction. If a sensitive component, such as GMR head, is brought to the poorly grounded surface when there is strong "jolt" of EMI, the head will be exposed to electric overstress caused by the worst type of contact -- metal-to-metal.

EMI-related problems are very difficult to diagnose, causing substantial downtime.



○ Ohms at DC
○ Open circuit for EMI



Proper Methodology of Measuring the Ground Quality from EMI Point of View

Verification of ground quality at high frequencies is not as complex as it may sound. Let's examine the basic principle of ground.

Good ground is an "infinite sink." No matter how much energy is provided into it, good ground should have NO voltage on it. If there is a voltage on the ground, its quality is anywhere from poor to unacceptable.

If there is a voltage present on the grounded surface, this voltage would create an electric field. At DC, this field could be measured with the static field meter: If there is a static electric field, the quality of ground from a DC point of view is poor. At high frequencies, the situation is very similar. If the ground quality at high frequencies is poor, there will be high-frequency voltage on the "grounded" surfaces which would create high-frequency electric fields. By measuring these fields one can reliably assess the quality of grounding from an EMI point of view.

Procedure

Set EM Eye to its default screen. If you are not sure where is the default screen, depress Power/(button couple of times) to get to it.

Move EM Eye away from any metal object and measure the background EMI level. If your environment exhibits substantial EMI levels, you may see a bar graph and numbers jump a bit. Please avoid performing these measurements near the mobile phone in use.

Now bring EM Eye's antenna - 1/2" close to the metal grounded surface. If the quality of ground is good, it would have no or very little high-frequency signals sitting on it, therefore, EM Eye should see no substantial increase in emission level. If the emission level goes dramatically up, the quality of EMI ground is very poor.

It also helps to repeat the same test with EM Eye's detector set to PEAK (use DET button from the default screen).



General Guidelines

If the emission level drops when the antenna approaches the grounded surface, it is very good ground for EMI.

If the emission level stays the same or goes up slightly, the EMI quality of ground is adequate.

If the emission level increases more than twice from the background level, the EMI quality of ground is poor and needs to be improved.

Ways to Improve EMI Ground Quality

Though every solution is specific to a particular problem, there are general guidelines to improve ground quality:

- Shorten your ground wires
- Straighten your ground wires
- Use large gauge braided cable
- Connect to known good ground
- Do not chain-link many workstations
- Always verify ground quality for EMI
- Do it on a regular basis

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APPENDIX G

“Fall of Potential” Method for Resistance Measurements

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APPENDIX G

“Fall of Potential” Method for Resistance Measurements

This appendix outlines the most commonly used method to measure electrode resistance to ground (see diagram in [Figure 2-7](#) in Section [2.8.2](#) of this manual).

NOTE: Measurement is generally taken with a Biddle ground resistance tester.

1. Connect the P_1 and C_1 terminals of the test instrument together and to the electrode being tested.
2. Drive reference electrode C_2 into the earth as far away from the electrode under test as is practical.
3. Drive reference P_2 into the ground at 62 percent, along a straight line between the earth electrode being tested and the reference electrode C_2 .
4. The meter reading will show earth ground resistance.

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APPENDIX H

Types of Lightning Protection Systems

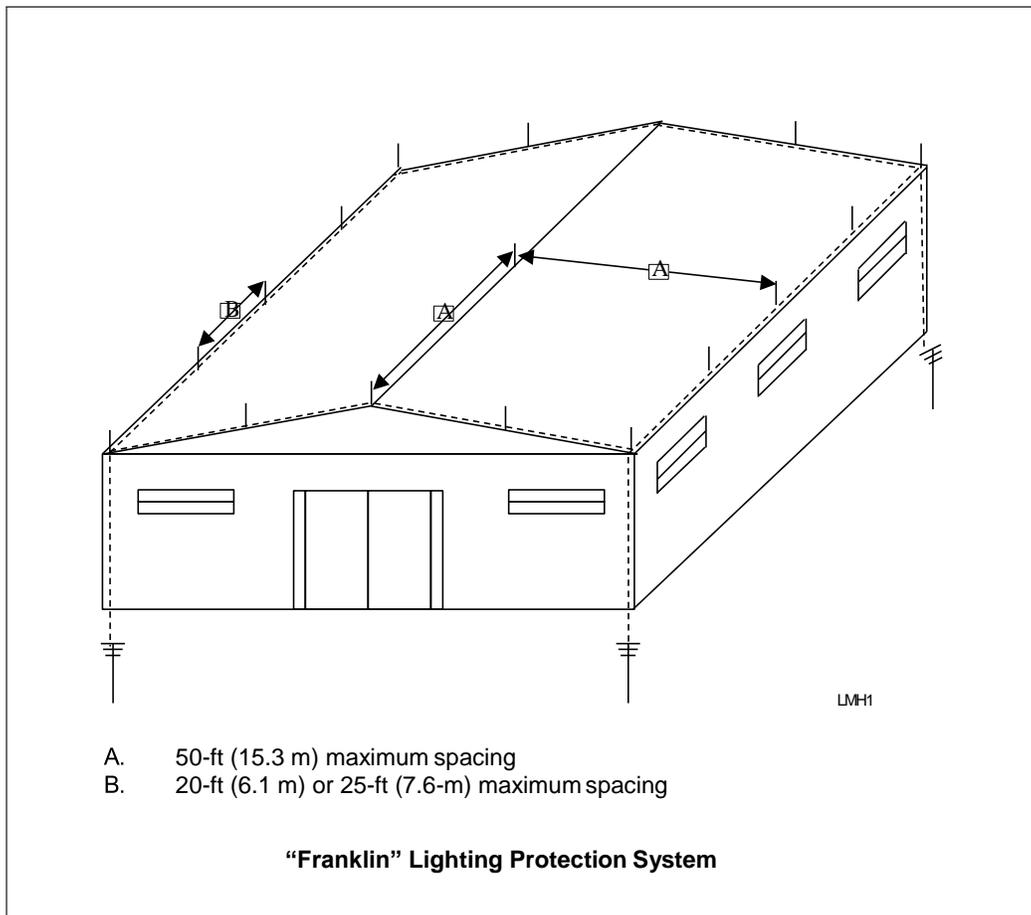
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APPENDIX H

Types of Lightning Protection Systems

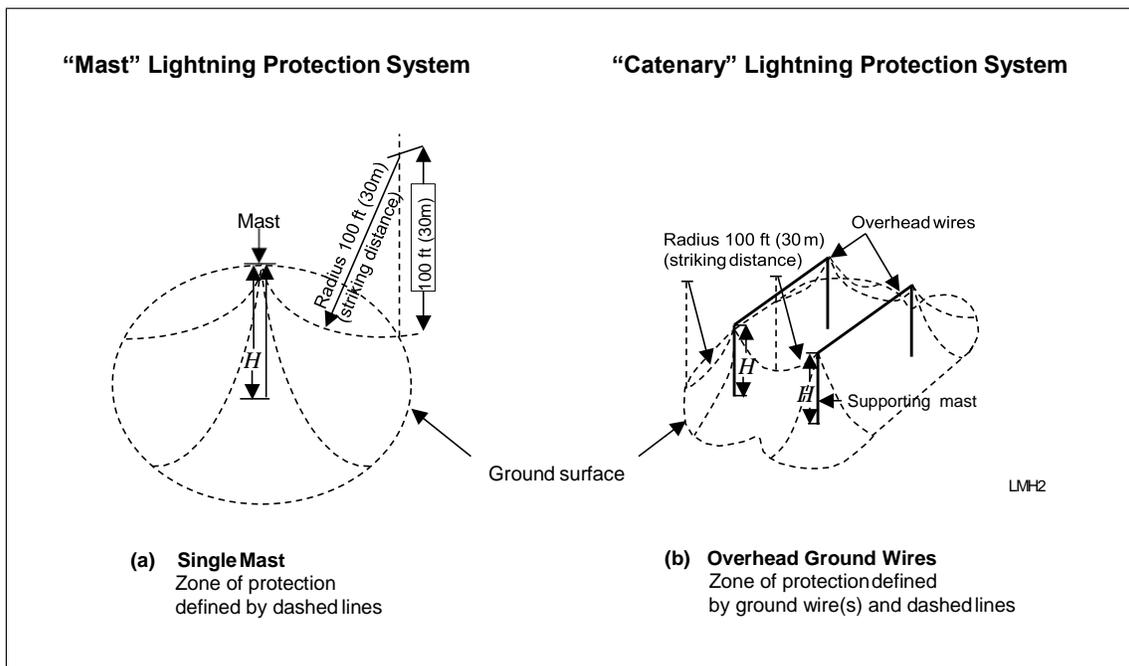
There are three types of lightning protection systems used to determine a “zone of protection.”

- 1. Franklin:** This lightning protection system consists of air terminal strike termination device(s), down conductor(s), and ground (earth) connection(s).



- 2. **Mast:** The lightning protection system consists of a single mast driven into the ground (earth) such that its height above ground will constitute a “zone of protection” for any object located within the lightning striking distance and the mast.

- 3. **Catenary:** This lightning protection system consists of two masts driven into the ground (earth) supporting an overhead ground conductor. The “zone of protection” is defined by a circular arc, concave side upward. The radius of the arc is the striking distance, and the arc passes through the tip of the masts and is tangent to the ground.



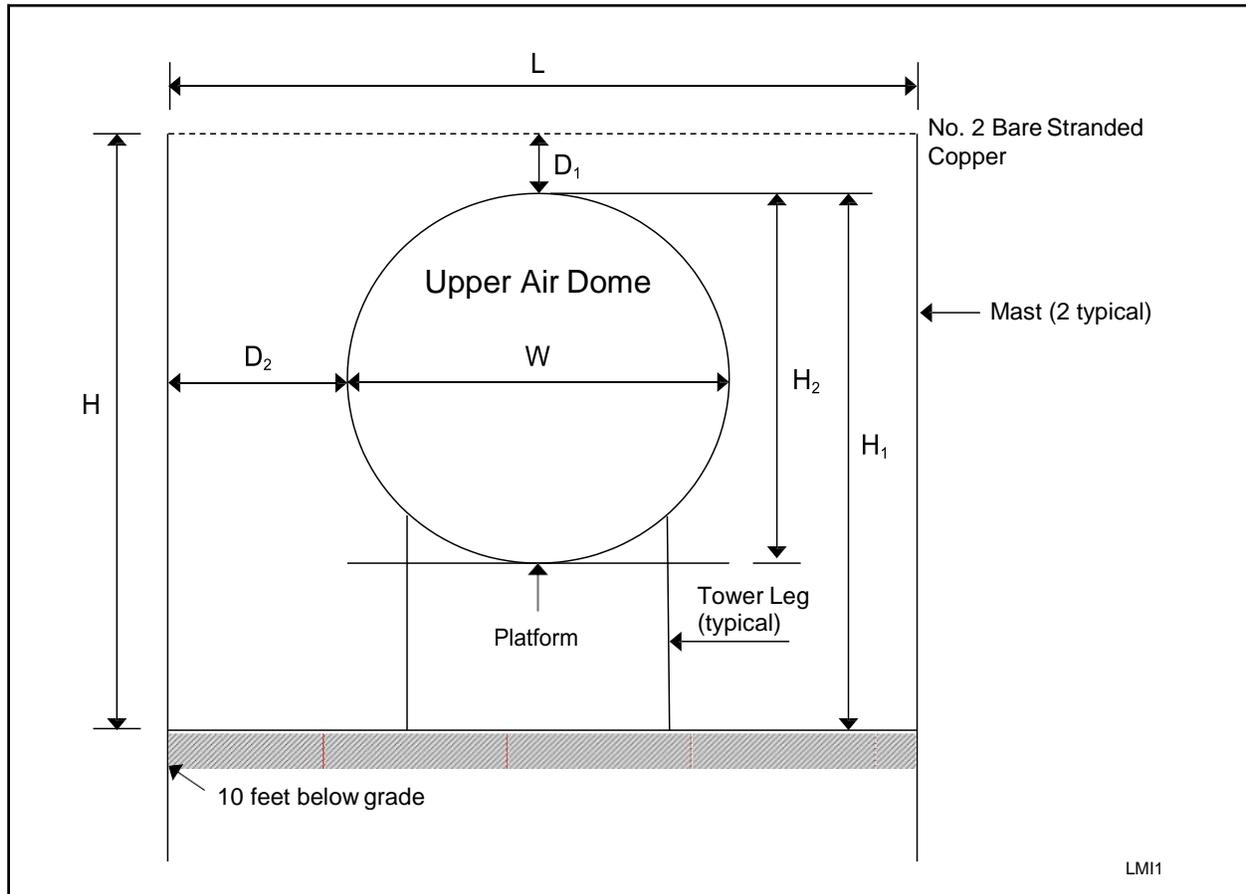
APPENDIX I

Alternative Lightning Protection System for Upper Air Building (Catenary Type)

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APPENDIX I

Alternative Lightning Protection System for Upper Air Building (Catenary Type)



Zone of Protection is established by using a 100-foot arc (concave side upwards)

$$D_1 = L/6N$$

where:

D_1 = Sideflash distance from catenary or distance above dome

L = Lightning protection conductor length

N = 1.5 for single overhead conductor

$$D_2 = H/6$$

where:

H = Upper air dome height above grade

D_2 = Sideflash distance from a mast to dome surface

Example:

Upper air dome height above grade – 55 feet = H

Width of dome – 18 feet = W

Height of Dome from platform – 15 feet = H_2

$$H_1 + D_1 = H$$

Class I size overhead lightning conductor needed (NFPA 780 recommended).

Use No. 2 bare stranded copper conductor.

Length of conductor needed:

$$D_2 + W + D_2$$

$$D_2 = H/6 = 55/6 = 9.2 \approx 10 \text{ feet}$$

$$L = 10 \text{ feet} + 18 \text{ feet} + 10 \text{ feet} \approx 45 \text{ feet of No. 2 lightning conductor:}$$

Distance above dome::

$$D_1 = L/6N \quad (\text{NFPA 780})$$

$$L = 38 \text{ feet}$$

$$N = 1.5$$

$$D_1 = 38/6 \times 9.5 = 8.33 \text{ feet (string conductor 10 feet above dome)}$$

Use rigid conduit for lightning dome conductor (recommended size: 1-1/2 inches).

Rigid conduit should be buried at least 10 feet below grade.

GLOSSARY

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GLOSSARY

(Sources: IEEE STD 100, NFPA 780, and NEC)

Access Well. A small covered opening constructed in the earth made of concrete, clay pipe, or other wall material, providing access to an earth electrode system (EES) connection.

Air Terminal. A component of a lightning protection system specifically designed to intercept lightning strikes.

Alternating Current (AC). An electric current that reverses direction at regularly recurring intervals of time.

Arrester. Components, devices, or circuits used to attenuate, suppress, limit, and/or divert adverse electrical (surge and transient) energy to ground. The terms arrester, suppressor and protector are used interchangeably; the term arrester is used herein for components, devices and circuits at the service disconnecting means.

Bend Radius. The radial distance of any arc formed by a bent cable, measured to the geometric center of the cable.

Bond. The electrical connection between two metallic surfaces used to provide a low resistance path between them.

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

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

Bonding. The joining of metallic parts to form an electrically conductive path, ensuring electrical continuity and the capacity to conduct current imposed between the metallic parts.

Bonding Jumper. A conductor installed to ensure electrical conductivity between metal parts to be electrically connected.

Branch Circuit. Circuit conductors between the final overcurrent device, protecting both the circuit and the outlet.

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 action.

Building. The fixed or transportable structure providing environmental protection; a stand alone structure or one isolated from adjoining structures by fire walls.

Bus, Ground. A bus to which the grounds from individual pieces of equipment are connected, and, in turn, is connected to a main ground at one or more points.

Cabinet. A protective housing or covering for two or more units or pieces of equipment. A cabinet may consist of an enclosed rack with hinged doors.

Cable Tray. A prefabricated metal raceway with or without covers consisting of side rails and bottom support sections.

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

Chassis. The metal structure supporting electrical or electronic components comprising the equipment.

Chemical Enhancement. The chemical treatment of soil around a driven ground rod to reduce its resistance.

Clamp Voltage. The voltage appearing across the surge or transient suppressor terminals when the suppressor is conducting a surge current to ground.

Coke Breeze. A chemically soil resistance enhancement backfill material that is a by-product from burning coke.

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

Conductor, Guard. A grounded wire installed above and in parallel to a current carrying conductor, but not connected to it. Its purpose is to lightning protect the current carrying conductor by enabling nearby high lightning voltages and currents to drain to ground. At least 10 inches should be maintained between the protected cables and the guard conductor (wire).

Conductor, Insulated. A conductor encased within material of composition and thickness recognized by the NEC as electrical insulation.

Conductor, Main. The conductors intended to carry lightning currents between air terminals and ground terminations. These can be the roof conductors interconnecting the air terminals on the roof, the conductor to connect a metal object on or above roof level that is subject to a direct strike to the lightning protection system, or the down conductor.

Cone of Protection (Lightning). The space enclosed by a cone formed with its apex at the highest point of a lightning rod. The diameter of the base of the cone has a definite relation to the height of the rod. The ratio of radius of base to height varies approximately from one to two.

Copper-Clad Steel. Steel with a coating of copper welded to it, as distinguished from copper-plated or copper-sheathed material.

Counterpoise. A system of conductors located below ground to enhance a low impedance path to the earth electrode system.

Critical Load. That part of the load requiring continuous quality electric power for its successful operation.

Earth Electrode System (EES). A network of electrically interconnected rods, plates, mats, piping, incidental electrodes (metallic tanks, etc.) or grids installed below grade to establish a low resistance contact with earth.

Effectively Grounded. Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carry capacity to limit the buildup of voltages to levels below that which may result in undue hazard to persons or to connected equipment.

Electromagnetic Interference (EMI). Any emitted, radiated, conducted, or induced voltage degrading, obstructing, or interrupting performance.

Electronic Multipoint Ground System (MPG). An electrically continuous network consisting of interconnected ground plates, equipment racks, cabinets, conduit, junction boxes, raceways, duct work, pipes, copper grid system, building steel, and other non-current carrying metal elements.

Electronic Single Point Ground System (SPG). A single reference network providing a single-point reference in the facility for equipment requiring single-point grounding. The single-point ground system is designed in a manner to minimize stray currents and magnetic interference. It consists of conductors, plates and equipment terminals, all of which are isolated from any other grounding system except at the main ground plate.

Electrostatic Discharge (ESD). Electrical discharges of static electricity that build up on personnel or equipment, generated by the sudden transfer of charge between bodies of differing electrostatic potentials.

Equipment Grounding Conductor. The conductor with the phase and neutral conductors used to connect non-current carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor and/or to the grounding electrode conductors at the main service disconnecting means or at the point of origin (X_0 bond) of a separately derived system.

Equipment. An item having a complete function apart from being a component of a system.

Exothermic. Characterized by or formed with the release of heat.

Facility Ground System. Consists of the complete ground system at a facility including the earth electrode system (EES), electronic multipoint ground system (MPG), electronic single point ground system (SPG), equipment grounding conductors (EGC), grounding electrode conductor(s) (GEC), and lightning protection system (LPS).

Faraday Cage. A grounded metallic barrier which can be used as a shield.

Feeder. All circuit conductors between the service equipment or the source of a separately derived system and the final branch circuit overcurrent device.

Filter. A circuit that eliminates certain portions of a signal, by frequency, voltage, or some other parameter.

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

Ground Grid. A system of grounding electrodes consisting of interconnected bare conductors buried in the earth to provide a common ground for electrical devices and metallic structures.

Ground Loops. A potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a path such that either or both points are not at the same ground potential.

Grounded Conductor. A system or circuit conductor intentionally grounded at the service disconnecting means or at the source of a separately derived system. This grounded conductor is the neutral conductor for the power system.

Grounded Effectively. Permanently connected to earth through a ground connection of sufficiently low impedance and having sufficient current carrying capacity insuring ground fault current, which may occur, cannot build up to voltages dangerous to personnel or equipment.

Grounding Conductor. A conductor used to connect equipment, or the grounded circuit of a wiring system, to the grounding electrode system.

Grounding Electrode. Copper rod, plate, or wire embedded in the ground for the specific purpose of dissipating electric energy to the earth.

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

Halo. A circular metallic disk (band) surrounding the overall shield of a cable. To be used to ground the shield.

Hertz. One cycle of alternating current.

High Frequency. All electrical signals at frequencies greater than 20 kilohertz (khz). Pulse and digital signals with rise and fall times of less than 10 micro-seconds are classified as high frequency signals.

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

Low Frequency. All electrical signals less than 20 kilohertz (khz).

Major Renovations. Any renovation to the building or any additional alterations that cost more than 50% of the replacement cost of the building.

Material Safety Data Sheet (MSDS). A collection of details about chemicals and their hazards.

Multipoint. Pertaining to grounding bus having several different equipment (green conductor) circuit grounds (used in high frequency regime).

National Electrical Code (NEC). A standard containing provisions considered necessary for safety governing the use of electrical wire, cable, equipment, and fixtures installed in buildings. It is sponsored by the National Fire Protection Association (NFPA) under the auspices of the American National Standards Institute (ANSI).

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

Plate, Ground. A plate of conducting material buried in the earth to serve as a grounding electrode.

Radio Frequency. A frequency useful for radio transmission (usually between 10 khz to 100,000 MHz).

Resonance. A condition in a circuit containing inductance and capacitance in which the capacitive reactance is equal to the inductive reactance. This condition occurs at only one frequency in a circuit with fixed constants, and the circuit is said to be “tuned” to this frequency.

Reverse Standoff or Maximum Continuous Operating Voltage (MCOV). The maximum voltage that can be applied across transient suppressor terminals with the transient suppressor remaining in a non-conducting state.

Rolling Sphere Model [Method of Locating Lightning Protection Air Terminals]. This method establishes the zone of protection from a lightning strike. It is the space below a rolling ball of radius [150 feet (46m)] immune to lightning strikes. When the ball is tangent to earth and resting against a strike termination device (air terminal), all space in the vertical plane between the two points of contact (air terminal point and earth point) are in the zone of protection.

Sacrificial Plate. Reduction or prevention of corrosion of a metal in an environment acting as an electrolyte by coupling it to another metal that is electrochemically more active in that particular electrolyte.

Separately Derived System. A premises wiring system whose power is derived from a battery, a solar photovoltaic system, or from a generator, transformer, or converter windings, and that has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

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

Shielded. A housing, screen, or other object, usually conducting, that substantially reduces the effect of electric or magnetic fields enclosed.

Short Circuit. An overcurrent resulting from a fault of negligible impedance between live conductors having a difference of potential under normal conditions.

Signal Reference Grid. A system of conductive paths among interconnected equipment that reduces noise-induced voltages.

Signal Reference Structure (SRS). A system of conductive paths among interconnected equipment that reduces noise-induced voltages to levels that minimize improper operation. (Also known as high frequency grounding of electronic equipment.)

Single Point. Pertaining to the electronic equipment grounding bus, where the electronic equipment chassis grounds are connected and isolated from any other grounding system; this bus, in turn, is directly connected to the EES (used in low frequency regime).

Steady State. The condition of a specified variable at a time when no transients are present.

Surge. An overvoltage of short duration occurring on a power line. Lightning or switch events may cause surges.

Surge Protection Device. A device intended to either limit transient overvoltages or divert surge currents or both. It contains at least one nonlinear component.

Surge Suppressor. A device operative in conformance with the rate of change of current, voltage, power, etc., to prevent the rise of such quantity above a predetermined value.

Susceptibility Level. The electronic equipment susceptibility level serving as the lesser of the damage, degradation, or upset levels, considering all electronic components potentially affected by conducted or radiated transients.

Transient Suppressor. Components, devices, or circuits designed to attenuate and suppress transient and surge energy by providing a control path to ground to protect facility equipment. At the service disconnecting means, the term “arrester” is generally used instead of transient suppressor. The term surge protective device (SPD) is preferred.

Turn-on Voltage. The voltage required across transient suppressor terminals to cause the suppressor to conduct current.

Utility. Furnished commercial power. It is usually the prime power source.

Varistor. Solid-state voltage regulator.

Waveguide. A system of material boundaries or structures for guiding electromagnetic waves (e.g., the use of a hollow metal pipe or duct work).

Weld. To join by applying heat.

Zone of Protection. The space adjacent to a Lightning Protection System that is substantially immune to direct lightning flashes.

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Boldface indicates extensive discussion of topic in paragraph and subparagraphs.

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