Installation Manual

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# Site Grounding and Lightning Protection Guidelines

TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

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MANUAL REVISION HISTORY

| REV | DATE | REASON FOR CHANGE |
|---|---|---|
| D | Oct/04 | Revised to include updated grounding information and instructions. |
| E | Nov/16 | Updated ground test well, target ground system resistance, conduit grounding and updated AC surge protection recommendations. Added sections on lightning rod height, POE surge suppression and copper theft prevention. |

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# 1. PREFACE

This manual provides guidelines for installing the grounding system at communication sites and applies to all personnel responsible for and involved with preparing Harris communication sites and installing Harris equipment.

The methods recommended are essential to protect personnel, minimize component failure, and optimize performance by reducing electrical "noise." Transient voltages introduced into a system by inadequate site grounding often exceed the operating parameters of electronic components resulting in higher equipment-failure rates. Semiconductor devices are especially susceptible to damage by externally induced transient voltages.

## 1.1 SAFETY CONVENTIONS

The following conventions are used throughout this manual to alert the user to general safety precautions that must be observed during all phases of design, installation, inspection, and testing a site grounding system. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards. Harris assumes no liability for the customer's failure to comply with these standards.

**WARNING**

**The WARNING symbol calls attention to a procedure, practice, or the like, which, if not correctly performed or adhered to, could result in personal injury. Do not proceed beyond a WARNING symbol until the conditions identified are fully understood or met.**

**CAUTION**

The CAUTION symbol calls attention to an operating procedure, practice, or the like, which, if not performed correctly or adhered to, could result in a risk of danger, damage to the equipment, or severely degrade the equipment performance.

**NOTE**

The NOTE symbol calls attention to supplemental information, which may improve system performance or clarify a process or procedure.

The ESD symbol calls attention to procedures, practices, or the like, which could expose equipment to the effects of Electro-Static Discharge. Proper precautions must be taken to prevent ESD when handling circuit modules.

**The electrical hazard symbol is a WARNING indicating there may be an electrical shock hazard present.**

## 1.2 GROUNDING RELATED ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AC** | Alternating Current |
| **AIC** | Amperes Interrupting Capacity |
| **AL** | Aluminum |
| **ANSI** | American National Standards Institute |
| **ATS** | Automatic Transfer Switch |
| **AWG** | American Wire Gage |
| **CCTV** | Closed Circuit Television |
| **CU** | Copper |
| **DC** | Direct Current |
| **EGB** | Exterior Ground Bar |
| **EMI** | Electromagnetic Interference |
| **GPS** | Global Positioning System |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **LAN** | Local Area Network |
| **MCM** | 1000 Circular Mils |
| **MCOV** | Maximum Continuous Operating Voltage |
| **MGB** | Master Ground Bar |
| **MOV** | Metal Oxide Varistor |
| **NEC®** | National Electrical Code® |
| **NEMA®** | National Electrical Manufacturers Association |
| **NFPA** | National Fire Protection Association |
| **PANI** | Surge Producers/Surge Absorbers/Non-Isolated Grounds/Isolated Grounds |
| **POE** | Power Over Ethernet |
| **POTS** | Plain Old Telephone Service |
| **PVC** | Polyvinyl Chloride |
| **RF** | Radio Frequency |
| **RFI** | Radio Frequency Interference |
| **RMS** | Root Mean Square |
| **SAD** | Silicon Avalanche Diode |
| **SGB** | Supplemental Ground Bar |
| **SPD** | Surge Protection Device |
| **TELCO** | Telephone Company |

| | |
|---|---|
| **TGB** | Tower Ground Bar |
| **TIA** | Telecommunications Industry Association |
| **TVSS** | Transient Voltage Surge Suppressor |
| **UL®** | Underwriters Laboratories |
| **UPS** | Uninterruptible Power Supply |
| **VPL** | Voltage Protection Level |
| **VPR** | Voltage Protection Rating |
| **VSWR** | Voltage Standing Wave Ratio |

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# 2. INTRODUCTION

These installation guidelines have been prepared to improve personal safety and to prevent equipment damage. They establish minimum requirements for grounding a Harris radio site providing protection for personnel and equipment. The grounding, bonding, and shielding procedures provide a low impedance "designed contact" between the communications facility and an earth ground.

All site grounding and electrical equipment installations must comply with all applicable NEC codes and applicable local codes. If a conflict exists between this document and any of these applicable codes, then the codes shall take precedence over the guidelines in this manual.

This manual is a guide for the design and installation of protective bonding and grounding of all Harris and dispatch sites. Contact Harris Systems Engineering to resolve any special situations not covered in this manual.

There are references to ground rods and ground connections throughout this manual. In all cases, there must be only one ground system at each site, building, room, or communications shelter. **ALL GROUNDS MUST BE TIED TOGETHER ACCORDING TO NEC CODE.**

## 2.1 GROUND THEORY

All communications facilities connect to ground or earth ground by capacitive coupling, accidental contact, or designed contact. If you provide a conducting path for lightning from the point of contact to a suitable ground apparatus or electrode, damage and shock hazards are minimized.

All conductors and connections have some associated resistance, but the inductive reactance is normally much larger. All grounding and bonding conductors must have low inductance interconnections to minimize the inductive voltage transients. The "impedance" of a conductor is the mathematical correlation of the resistance and the inductive reactance associated with that conductor. This manual refers to low resistance, low inductance connections as "low impedance" connections.

A single point ground system should be maintained inside all Harris site installations. The idea behind this theory is that if all equipment in a shelter is connected to the exterior ground system at a single point, then the voltage potential of all of the equipment will rise and fall together should a lightning strike occur thus reducing the possibility of current flow through the equipment.

## 2.2 LIGHTNING BASICS

The isokeraunic map illustrated in Figure 2-1 shows the mean annual number of days experiencing thunderstorms in different regions of the United States.

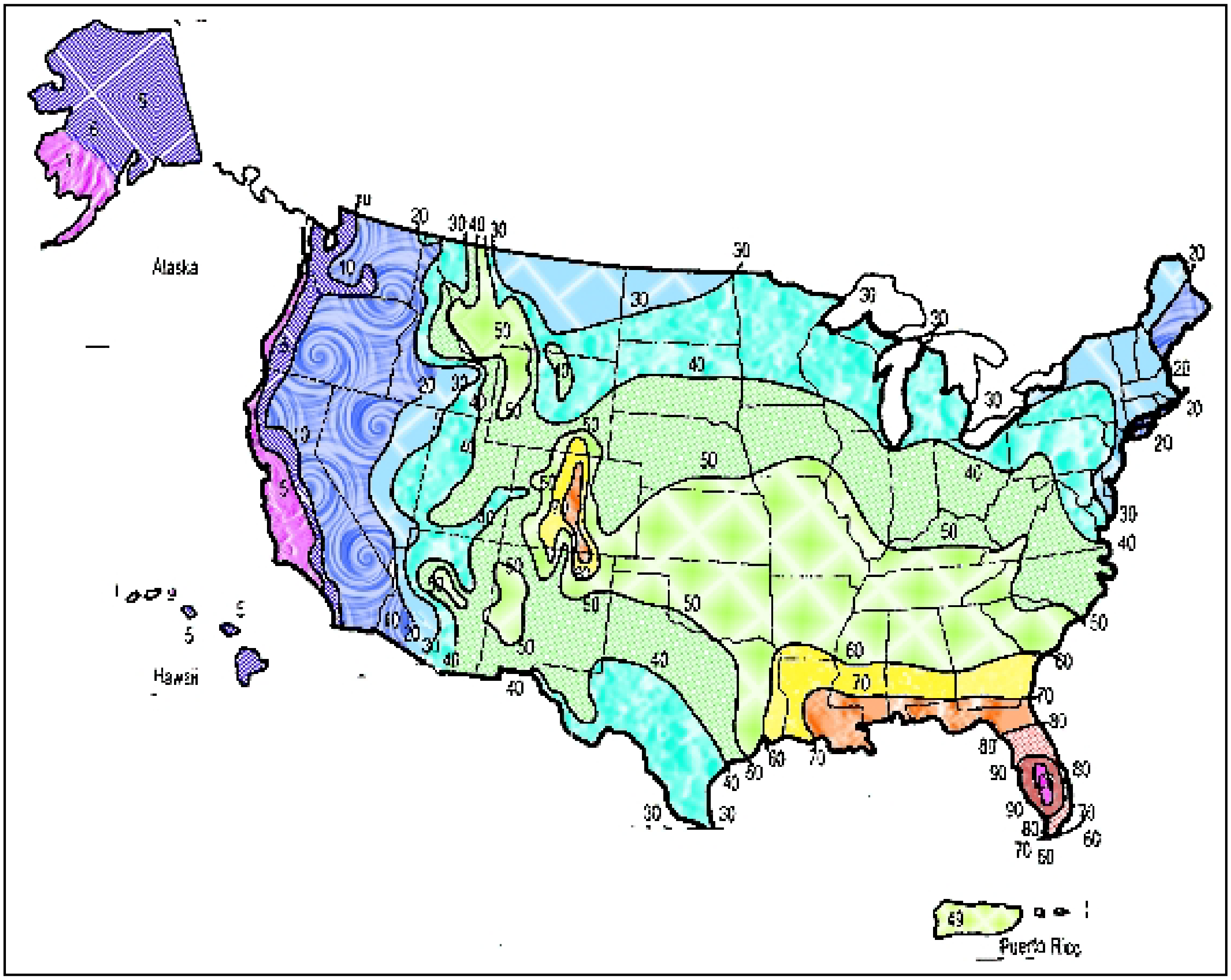


**Figure 2-1: Isokeraunic Map of the United States**

NOTE

The region with the highest thunderstorm frequency is centered on south and central Florida.

Lightning is a constant current source. It will develop any voltage necessary to overcome resistance. A lightning strike has a median current of 18,000 amps, a typical rise time of $2x10^{-6}$ seconds, and duration of $45x10^{-6}$ seconds. The peak voltage that will exist at the strike point depends on the inductance of the path to ground. For a 150 foot self-supported tower with an inductance of $40x10^{-6}$ Henries, the peak voltage that will exist between the top of the tower and its bottom would be 360 kilovolts. If the RF entry port into the shelter were at 7.5 feet, there would be 28 kilovolts present between the RF entry port and ground, as shown in Figure 2-2.

Most lightning hits strike the tallest object in the vicinity. Near a radio site the highest object is usually the tower and its antennas. Proper grounding of the tower and RF transmission cables along with adequate surge suppression on all of the incoming cables minimizes the amount of current that enters the equipment shelter.

NOTE

Low impedance ground connections are necessary to protect critical communications sites and the personnel who may be working there.

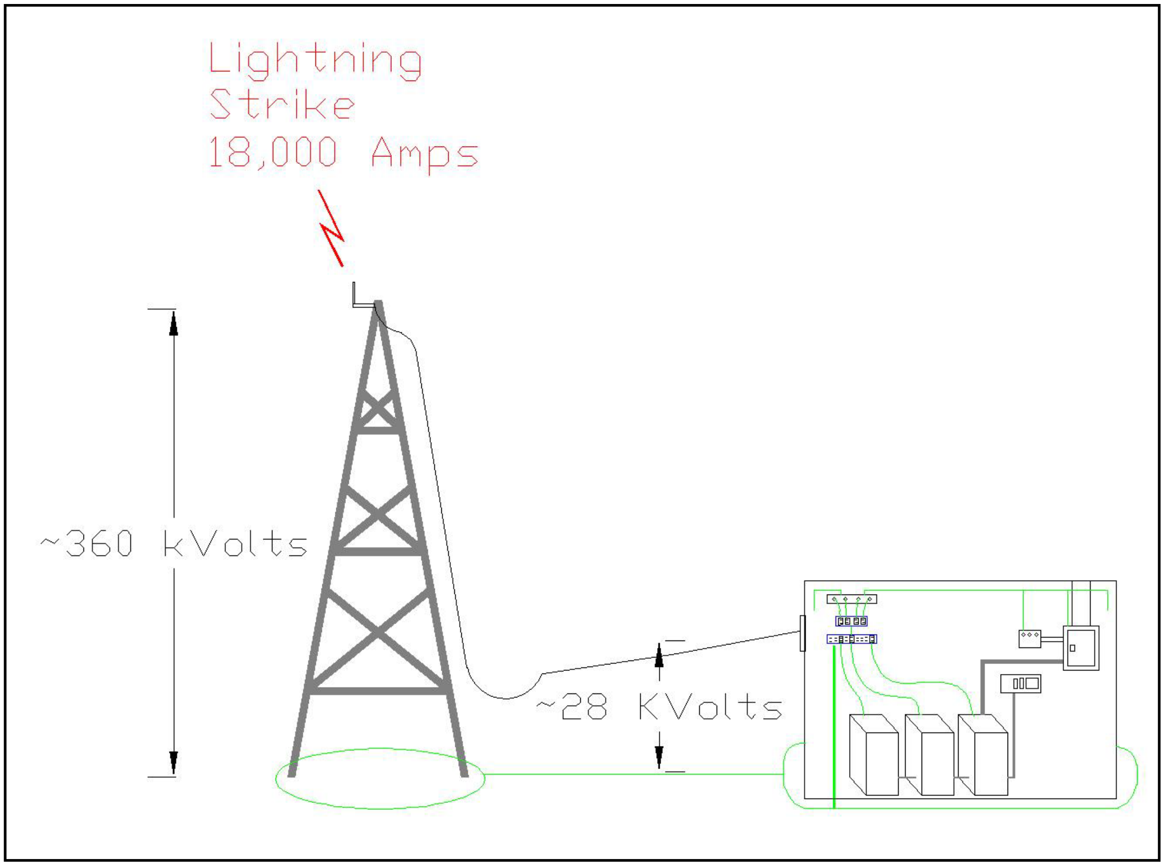


**Figure 2-2: Potential Rise at Site after Lightning Strike**

The illustration in Figure 2-4 explains why maintaining a single point ground connection to the exterior ground system is preferred. Note that the ground voltage potential differs by over 5,000 Volts, from one corner of the shelter to the opposite corner, immediately following a lightning strike to the tower. With a multi-point interior ground system, this large voltage potential could try to equalize through the sensitive electronic equipment and its power supplies. With a single point ground system, described in this manual, the ground potential of all equipment in the shelter would rise and fall together minimizing the risk of equipment damage.

| | |
|---|---|
|  |  |
| New antenna lightning rod tip.<br>(Courtesy of ©2004 Radio Frequency Systems) | Antenna lightning rod tip blunted by a lightning strike. The antenna's lightning rod worked as designed, and the antenna was undamaged. |

**Figure 2-3: Antenna Lightning Rod Tip Before and After a Lightning Strike**

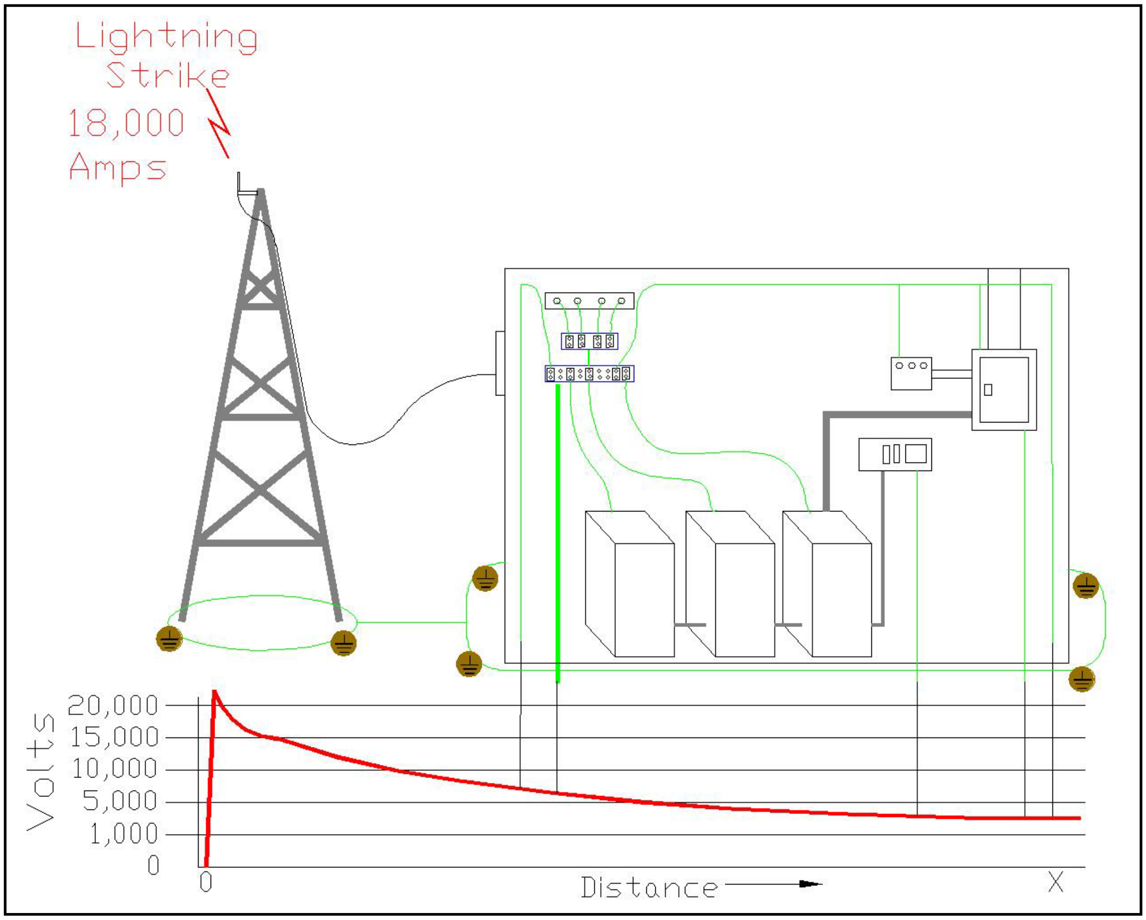


**Figure 2-4: Ground Potential Rise at Site after Lightning Strike**

## 2.3 SITE DESIGN CONSIDERATIONS TO REDUCE POSSIBLE LIGHTNING DAMAGE

Site layout and cable routing can influence a site's susceptibility to lightning damage. The following four concepts can reduce a site's risk to lightning damage:

- Increasing the distance between the shelter and the tower
- Lowering the height of the transmission lines between the shelter and the tower
- Eliminating copper telecommunication and data lines entering the site
- Bringing incoming utility AC power into site underground and locating the transformer as close to site as possible

The following sections describe these concepts.

### 2.3.1 Increasing the Distance Between the Shelter and the Tower

Increasing the distance between the shelter and the tower reduces a site's susceptibility to lightning damage. Locating the shelter at least 30 feet from the tower provides three benefits.

1. It increases the inductance of the RF transmission line path between the tower and shelter. As a surge current travels down the transmission line, this reduces the amount of current that flows toward the shelter as opposed to following the direct path to ground through the ground kit located above the RF transmission line drip loop.

2. It minimizes the magnetic field associated with lightning. This magnetic field can induce currents onto long conductors both outside and inside the shelter. The magnetic field strength drops off as the square of the distance.

3. It keeps the lightning ground potential rise at the tower base from saturating the ground system near the shelter before the majority of it is dissipated.

Obviously increasing distance between the shelter and the tower lengthens the RF transmission line and increases transmission-line loss. It also increases the overall site real estate, which is often at a premium. However, the protection benefits of locating the shelter at least 30 feet from the tower, must be weighed against these two factors.

### 2.3.2 Decreasing the Height of RF Transmission Lines Leaving Tower

Lowering the height, above ground, that the RF transmission line leaves the tower reduces the voltage on the transmission line before it enters the shelter. Ideally, the RF transmission lines would leave the tower below ground level. This may not be practical in some cases, but consideration should be made to minimize the height at which the cables to leave the tower.

Section 7.10 provides examples of RF transmission lines routed underground between a tower and a shelter or equipment room.

### 2.3.3 Eliminating Copper Telecommunication and Data Lines Entering the Site

Another method of increasing lightning protection is to eliminate, if possible, copper telecommunications and data lines entering the shelter. The best solution is to use fiber optic cables where possible. This eliminates possible entry and exit points for lighting surge currents produced by lighting.

### 2.3.4 Routing AC Utility Power Underground to Site

Another possible path for surge currents to damage an RF site is through the AC utility lines that feed power to the site. When possible, power should be run underground to a site. If possible, a pad-mounted AC transformer should be used and located as close to the site as possible.

For maximum protection, the transformer's ground rod should be bonded to the site ground system. This connection should be made with a mechanical clamp (such as an acorn clamp) in a ground access well so it can be disconnected to allow measurement of the site ground system with a clamp-on meter as shown in Figure 2-6.

**Figure 2-5: Preferred Location for Site Incoming AC Utility Transformer**

**Figure 2-6: Disconnect for Transformer Ground's Connection to Site Ground System**

## 2.4 SITE DESIGN CONSIDERATIONS TO REDUCE COPPER THEFT

Copper theft has increasingly become a problem at communications sites. In addition to the cost to replace and repair ground system components that are stolen or damaged, a customer may sustain equipment damage if a lightning surge current is experienced between the theft event and when repairs are made.

Proper site grounding is critical to the protection of communications site, but there are recommendations for deterring theft:

- Use tinned copper ground bars and conductor. Often tinned copper is mistaken for aluminum and left untouched.
- If copper RF entry ports and/or copper straps are used at the site, cover them or paint them to match the shelter.
- Install cameras and signage at the site indicating there are cameras.
- Install motion detectors to alert you to movement inside a fenced compound.

## 2.5 PURPOSE OF GROUND SYSTEM

The purpose of an effective ground system is to:

- Protect personnel by reducing the possibility of electrical shock.
- Provide a non-destructive, low impedance path to ground for lightning strikes and currents.
- Provide a low impedance path to ground for cable shields and other metal encased RF handling devices (antennas, etc.).
- Protect wiring and other electrical components from damage.
- Reduce radio frequency interference (noise) and suppress damaging AC power service spikes.
- Maintain proper performance of the antenna system.
- Control fast-rising electrical surges, which produce high voltage differences between the ends of single conductors such as heavy copper wires and bars.

- Equalize surge potentials through controlled bonding of site ground elements.

These elements include:

- Surge Producers
- Surge Absorbers
- Isolated Equipment Grounds
- Non-Isolated or Integrated Grounds
- Reduce voltage differentials and control surge currents.

**The prime source of danger and damage to equipment is lightning currents that are often conducted to the equipment through RF transmission lines.**

Other sources of surge ingress are through the building's electrical utility service, generator cabling, copper communication lines, and external alarm wiring.

One of the best ways to reduce the chance of damage from lightning is to provide a low impedance path to ground for lightning currents, and preventing them from flowing through the equipment.

## 2.6 MOST IMPORTANT CONCEPTS

The remainder of this manual is dedicated to implementing the following four concepts to achieve the objectives stated above.

- A target measurable 5-ohm or less exterior ground system installed around the tower and shelter
- Single point grounding of the Harris equipment and any ancillary equipment in the shelter
- Low impedance ground connections from all equipment to the single point ground
- Proper surge protection on all incoming connections to the site properly connected to the single point ground connection

## 2.7 GROUND SYSTEM INSTALLATION PROCESS

There are many different types of sites and installation situations. These range from building a completely new tower and site shelter with all of the necessary support equipment to adding one cabinet into an established equipment room. The steps outlined in Table 2-1 are a guide for installing equipment and grounding in the various situations. Each step is explained in more detail later in the manual. Obviously, this manual cannot cover every situation, and in some cases it may be necessary to perform the steps in a different order. However, if there is any doubt as to which steps should be taken to achieve proper grounding at a location, contact Harris Systems Engineering for further guidance.

**Table 2-1: General Ground System Installation Steps**

| Steps | Undeveloped Stand-Alone Tower Site | Existing Multiple Shelter Tower Site | Existing Equipment Room | Rooftop Site | Exterior Cabinet on Pad or Existing Tower |
|---|---|---|---|---|---|
| 1. Measure soil resistivity and pH. | X | X, optional | | | |
| 2. Site specific grounding system design with target of 5-ohms or less. | X | X, optional | X, optional | X, optional | X, optional |
| 3. Check any applicable NEC or local codes. | X | X | X | X | X |
| 4. Have local utility company mark any buried electrical, gas, or telephone lines. | X | X | | | X |
| 5. Install tower ground rods and ground ring. | X | | | | |
| 6. Install shelter ground rods and ground ring. | X | X | | | X |
| 7. Verify all ground rods and rings are bonded together. | X | X | | | X |
| 8. Install and bond Exterior Ground Bar (EGB) and Master Ground Bar (MGB). | X | X | X, MGB only | X | |
| 9. Check all exothermic welds. | X | X | | | X |
| 10. Measure ground resistance and document. | X | X, shelter ring only | X, optional | X, optional | X, optional |
| 11. Ground tower and all exterior metallic objects, such as ice bridges, fences, generators, etc. | X | X | | X | X |
| 12. Install and ground antennas and coax. | X | X | X | X | X |
| 13. Install antenna surge suppressors. | X | X | X | X | X |
| 14. Install and ground all Harris equipment in shelter to MGB | X | X | X | X | X |
| 15. Install and ground surge suppressors on all copper wires coming into the shelter. | X | X | X | X | X |
| 16. Ground all support equipment and metallic objects in shelter, such as cable trays, metallic door frames, fire suppression systems, etc. | X | X | X | X | X |
| 17. Conduct grounding audit to verify completeness. | X | X | X | X | X |

## 2.8 SITE EXPOSURE LEVEL

Understanding a site's exposure level is important in determining how robust the site ground system and surge protection should be. The site's exposure level consists of the site's location with respect to lightning activity and its criticality to the customer's system operation. For example, a site located in Florida has a high likelihood for lightning activity as shown in Figure 2-1, therefore it has a high site exposure level. If a major switching system or control point site is critical to the customer's system operation, it would also be considered to have a high exposure level.

An example of a low exposure level site might be a coverage filler site in a non-critical area.

NOTE

Under no circumstances should personnel safety be compromised at a Harris installation.

## 2.9 AC UTILITY ENTRANCE CONFIGURATION FOR EASIER GROUND RESISTANCE TESTING

Attention to how the site AC utility power entrance and grounding are installed can allow for easier site ground system clamp-on resistance testing.

One location to make a valid clamp-on ground resistance measurement is on the utility power cable entrance on the incoming neutral conductor. At this location on the utility side of the neutral-ground bond, the clamp-on ground resistance meter should measure the entire site ground system.

See Appendix B for details on making site ground system resistance measurements.

The configuration of the AC utility entrance can make access to this measurement location either easy or very difficult as shown in the next two photographs (Figure 2-7 and Figure 2-8).

WARNING

**All site grounding and electrical installation must comply with all applicable National Electrical Codes (NEC) and local codes. If a conflict exists between this document and any of these applicable codes, then those codes take precedence over the guidelines in this document.**

**Shock hazard exists. Entry into the AC Utility Entrance should only be made with permission of the local utility provider. Measurements at the AC Utility Entrance should only be done by qualified personnel using proper safety precautions and wearing approved safety equipment.**

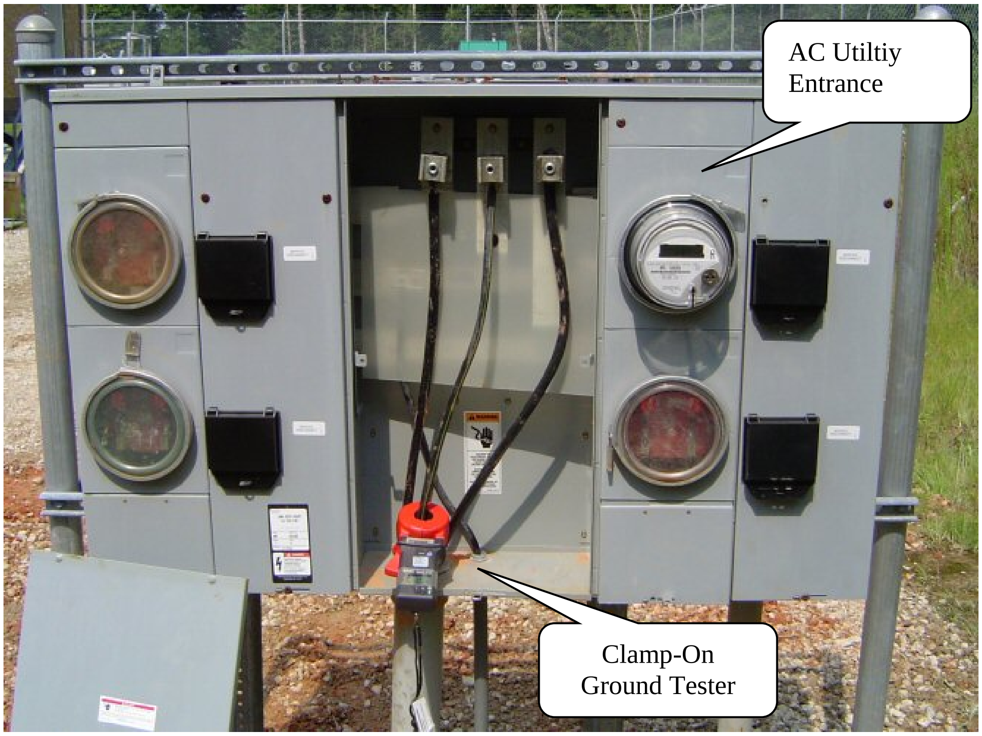


**Figure 2-7: AC Utility Service Entrance Configuration Allowing Easy Access for Clamp-On Ground Resistance Testing (Shown with Clamp-On Ground Tester)**

**Figure 2-8: AC Utility Service Entrance Configuration with Difficult Access for Clamp-On Ground Resistance Testing (Shown with Clamp-On Ground Tester)**

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# 3. GROUND SYSTEM

A complete ground system must provide grounding for the antenna, towers, and buildings. This includes interior and exterior grounding systems for equipment in the communications buildings, the antenna towers and guys, transmission lines, telephone lines, DC power plants, AC power entrance, and the communications facility. All elements of the ground system and conducting elements in near proximity to the system must be connected and bonded together. This ensures all elements of the radio site are at the same ground integrity, as related to true earth ground.

## 3.1 GROUND SYSTEM DESIGN

**The ground system design goal for a Harris site installation should be a measurable five (5) ohms resistance or less** between any connected point on the ground bus and earth ground. This goal assumes that soil conditions local to the RF site are typical, conducive to good grounding systems and the RF site geography can receive a standard grounding system. Where these conditions do not exist, or a 5 ohms resistance cannot be reasonably obtained, then the target ground system resistance should be at least 400% better than the resistance of the site's AC ground rod located at the AC meter.

Other exceptions to this requirement are noted in Sections 4.2.4 Antenna Support Structures on Building Rooftops, 7.5 Tower-Mounted/Pad-Mounted Repeater Equipment, , and 7.6 Radio Control Station.

**All ground rods or systems at a site must by bonded together.** NEC code requires that there be no separately derived ground systems. Any ground rods installed by the electric utility must be bonded to the ground system. At an existing tower site, any grounding installed for a new shelter or equipment must be bonded to the site's existing ground system.

**There should be *no* separately maintained ground rods or ground systems associated with the communications shelter, site, building, or equipment room. Adherence to these requirements is the standard for Harris communications facilities.**

### 3.1.1 Soil Resistivity

Ground system design begins with measuring the soil resistivity where the grounding electrode system will be installed. See Appendix A for details on how to make these measurements and Appendix E for details on how to use the results when developing a grounding system design.

### 3.1.2 Soil pH

The soil's pH (Potential of Hydrogen) should be tested prior to installing the ground system. You can use a soil pH meter or soil pH test kit to measure the soil's pH value. Acidic soil, that is soil with a pH below seven (7), is corrosive to copper and other metals. In areas with highly acidic soil, that is soil with a pH of five (5) or below, additional measures should be taken to preserve the integrity and extend the life of the grounding system. Some options include:

- Encasing the buried grounding system using ground enhancing backfill, see Section 3.2.1.7
- Using electrolytic ground rods encased in ground enhancing backfill

- Using solid copper ground rods instead of copper-clad ground rods
- Using larger buried conductors for connecting the ground rods together
- Consulting a grounding engineering firm

We recommend testing all ground systems annually. However, you must test a grounding system in highly acidic soil at least once a year. Document the results and compare them with previous tests to determine if there is any system degradation.

### 3.1.3 Ground System Design Process

The objective of the ground system design is to develop a site-specific grounding plan detailing the type, diameter, length, and number of ground rods and their locations. Appendix E details how to use the measured soil resistivity to design a grounding electrode system to meet the 5-ohm ground resistance goal.

Take special care when designing a grounding system where difficult site conditions exist, such as limited space, stone mountain tops, sand, coral, limestone environments, or highly resistive soil. Consulting a grounding engineering firm may be advisable in these cases.

### 3.1.4 Ground System Inspection and Testing

Before burying the grounding electrode system and its joining conductors, inspect and test all of the connections and bonding for soundness and take digital pictures. Test and document the grounding electrode system's resistance prior to bonding it to any exterior elements such as the tower, fence, or equipment shelter. See Appendix B for details on how to measure the resistance correctly.

## 3.2 GROUND SYSTEM COMPONENTS

A ground system consists of multiple grounding electrodes bonded together with conductors to form a single reference to earth ground for the site. The location of the grounding electrodes with respect to the various site components such as the tower, equipment shelter, and RF cable entry port are important in maintaining the integrity of the grounding system and providing a non-destructive, low impedance path to ground for lightning strikes and currents.

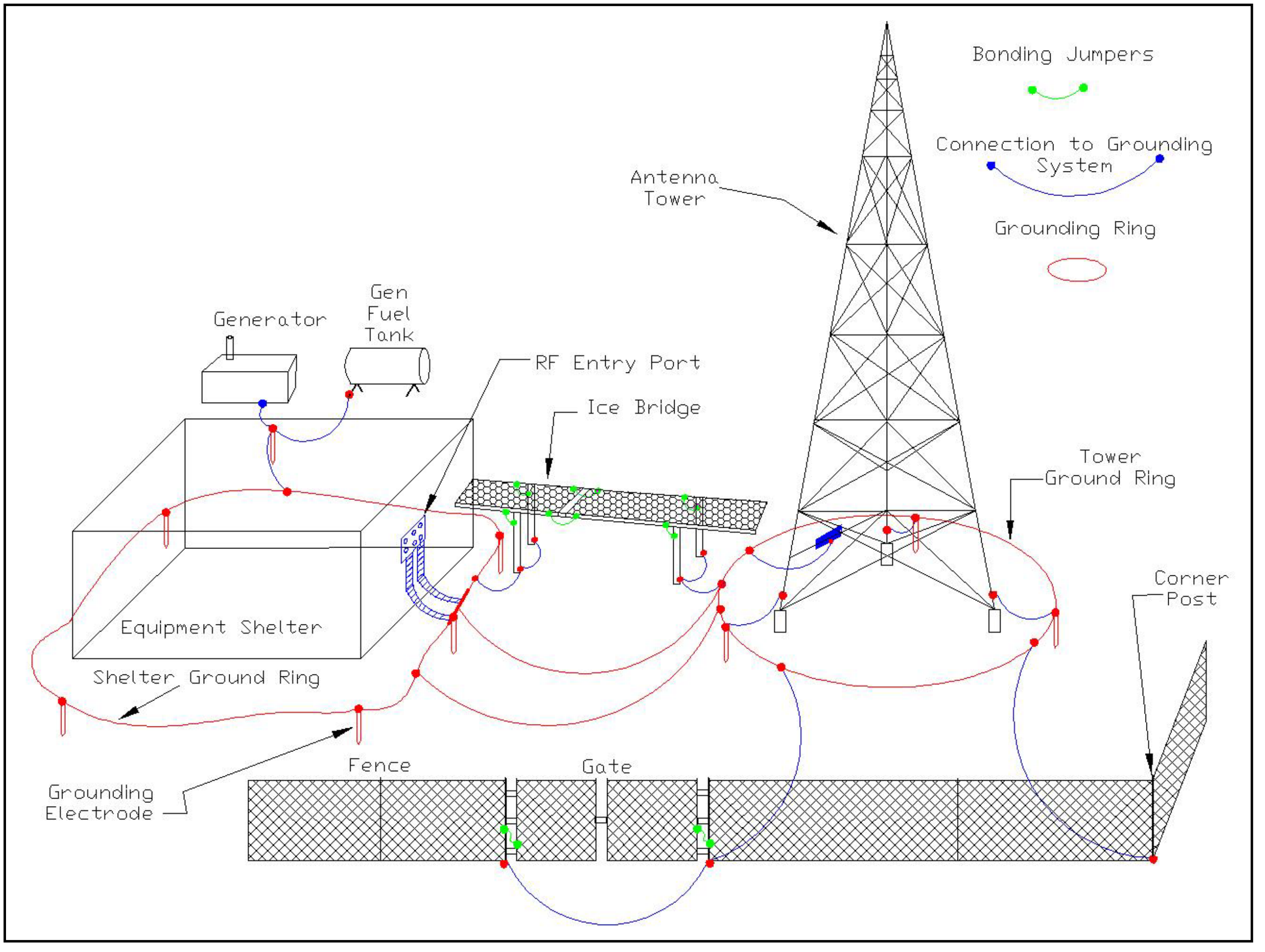



**Figure 3-1: Exterior Site Grounding Overview**

### 3.2.1 Grounding Electrodes

A grounding electrode is any object placed into the earth to provide a conducting path to earth ground. A grounding electrode may be a solid ground rod, electrolytic ground rod, ground plate, concrete-encased electrode, ground ring, or building steel. Although allowed by NEC, metal underground water pipes <u>should not</u> be used as the only grounding electrode for a Harris site. Additionally, NEC forbids using aluminum electrodes or metal underground gas piping systems as grounding electrodes.

### 3.2.1.1 Driven Ground Rods

Harris ground system driven ground rods should be bare ***copper-clad steel***, solid copper, stainless steel, or hot-dipped galvanized steel with a *minimum diameter of 5/8 inch and a minimum length of 8 feet.* The site dimensions and ground system design, based on the soil resistivity of the site, will determine the actual diameter, length, number, and type of ground rods required. See Appendix E for details on ground system design. If the ground system design requires longer ground rods, couple two or three ground rods together using the exothermic weld process.

**Figure 3-2: Driven Ground Rod Installed with Ground Ring Conductor Attached**

If the soil resistivity is below 2,000 ohm-cm, use galvanized steel rods to ground steel towers or galvanized tower guy wires. This will prevent galvanic corrosion of the tower or guy anchor.

### 3.2.1.2 Ground Rod Installation

To maintain the integrity of the ground system, the distance between ground rods should be twice the length of the ground rod (where space permits) or between six (6) feet (minimum) and twice the ground rod's length (maximum), as shown in Figure 3-3. Ground rods should be driven to a depth of at least 30 inches below finished grade, or below the frost line, whichever is deeper. Whenever possible, ground rods should be driven below the permanent moisture level. This ensures a stabilized ground system resistance is maintained even during seasonal or moisture level fluctuations. The ground system resistance increases as the soil temperature or moisture level decreases. Refer to Appendix A for additional details.

Ground rods should be driven vertically whenever possible. Where bedrock is encountered, a ground rod may be driven into the earth at an angle not to exceed 45 degrees from vertical. If multiple angled rods are used, the rods should be arranged so that they are pointed away from each other. If a ground rod must be installed horizontally, then the rod must be buried at least 30 inches below the finished grade.

Only use exothermic welds when connecting a conductor to a ground rod as shown in Figure 3-2.

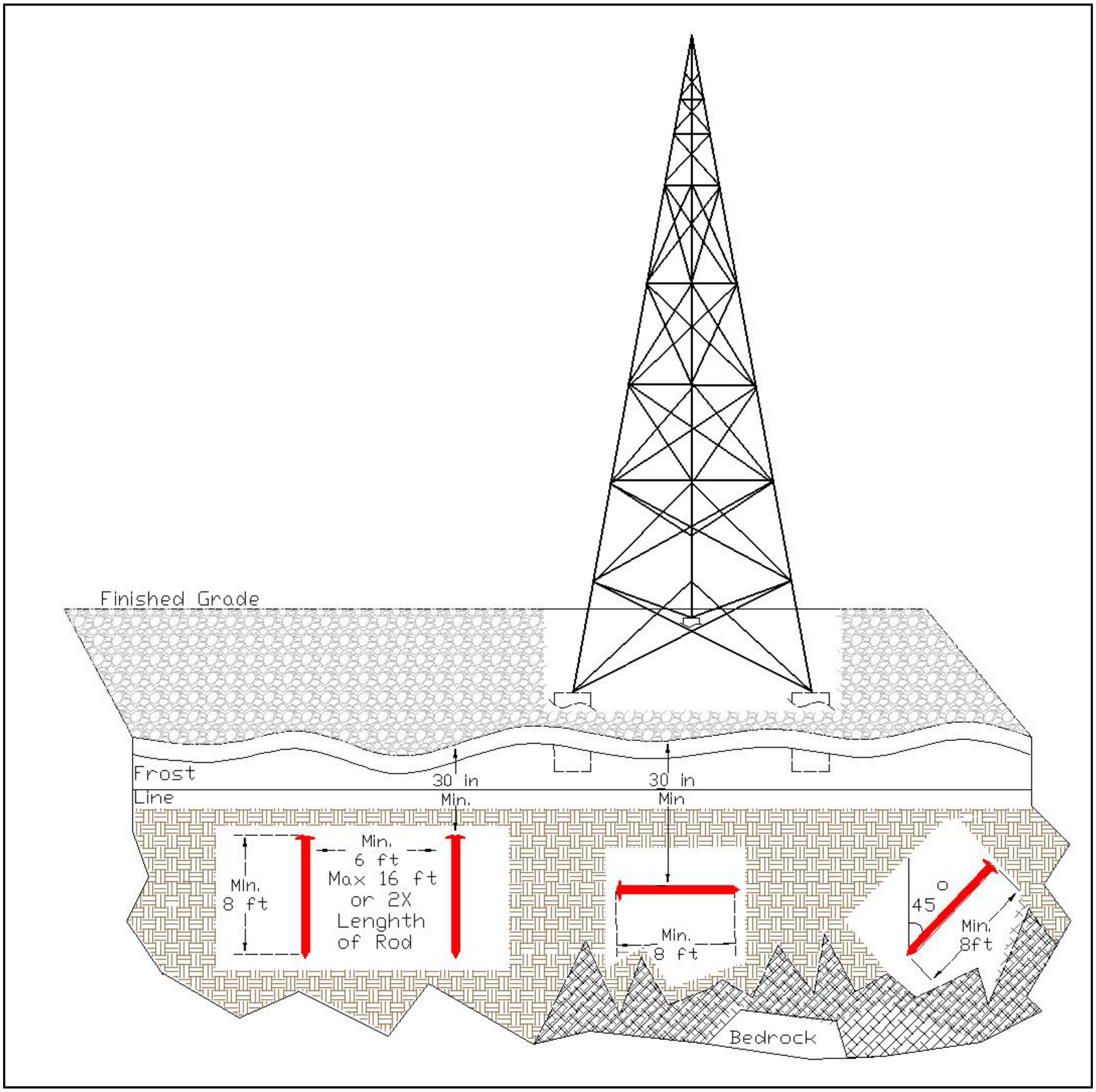



**Figure 3-3: Grounding Electrode Installation Detail**

**Figure 3-4: Ground Rod and Ring with Parallel Exothermic Weld Connections**

### 3.2.1.3 Electrolytic Ground Rods

An electrolytic ground rod is designed to provide a low-impedance and low-resistance ground. Electrolytic ground rods can often provide a more reliable ground than driven copper-clad steel ground rods as temperature and moisture levels fluctuate. This is especially true where soil is shallow and the rock base prevents deep driving copper-clad steel ground rods. Electrolytic ground rods may also last several years longer than copper-clad steel rods.

Usually, electrolytic ground rods are made of hard-drawn copper tubing filled with a mixture of non-hazardous natural earth salts. Changes in atmospheric pressure draw moisture into the rod. Through a process of continuous leaching, small amounts of the environmentally safe compound are released into the soil. This compound enhances the earth ground. The solution slowly leaches into the surrounding earth, creating an ion “root” that has a metallic base. This process continually conditions the soil, reducing soil resistance, enhancing the ground system effectiveness over time. Most electrolytic ground rods provide lower resistance grounds than conventional solid, copper-clad rods, regardless of soil type.

If a ground system is going to be covered by pavement or concrete, then electrolytic ground rods should be considered because of their potential longer life and because they allow moisture to be drawn into the rod improving the effectiveness of the grounding system.

Electrolytic ground rods are available in both straight (Figure 3-5) and L-shaped (Figure 3-6) versions. Any electrolytic ground rod used should be Underwriter’s Laboratory (UL) listed, use environmentally safe compounds, be maintenance free, and should be installed according to the manufacturer’s recommendation. Contact Harris Systems Engineering for guidance in selecting specific products.

NOTE

Electrolytic ground rods using carbon-based backfill materials should not be used in Harris ground system installations. The use of carbon-based ground backfill materials may accelerate the corrosion of the copper ground system due to dissimilar metals contact.

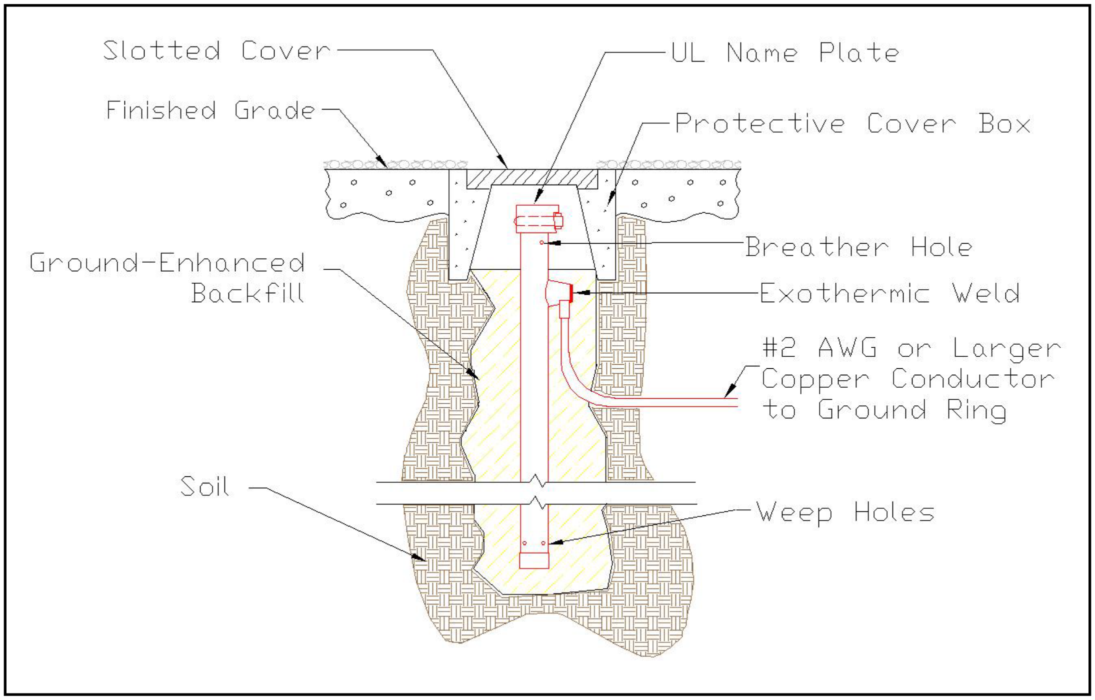



**Figure 3-5: Straight Electrolytic Ground Rod Detail**

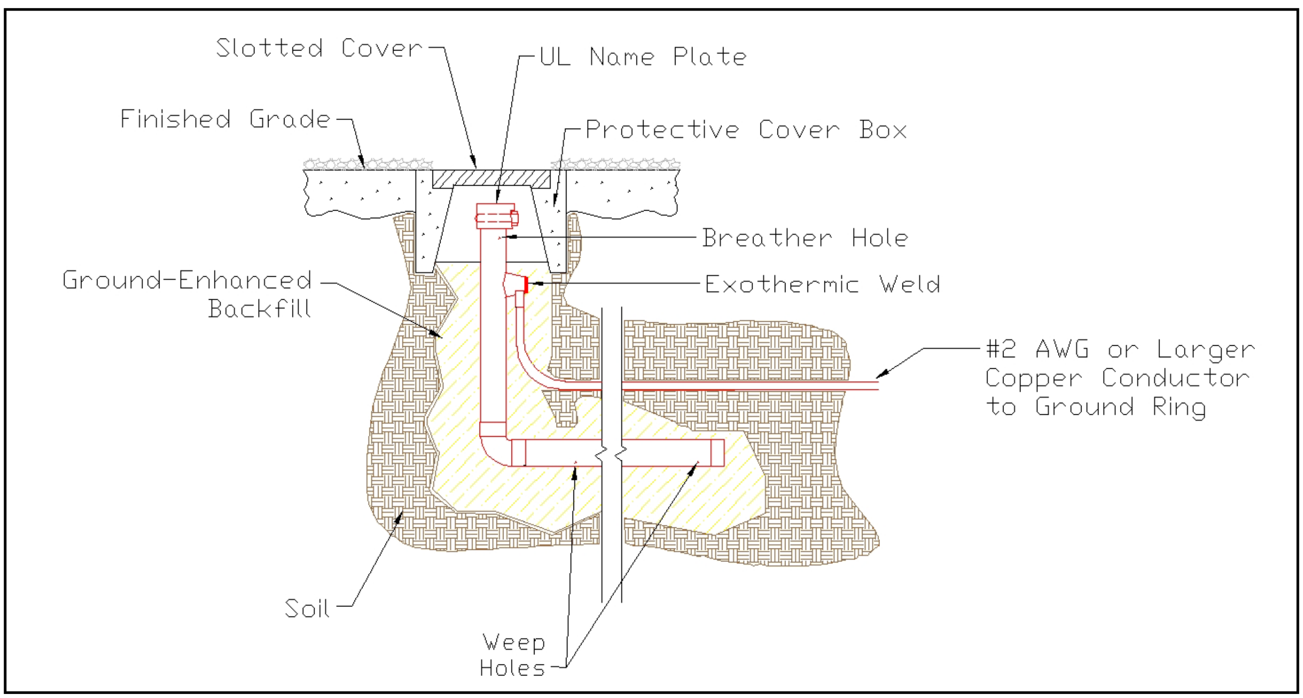



**Figure 3-6: L-Shaped Electrolytic Ground Rod Detail**

**Figure 3-7: Electrolytic Ground Rod Cover and Top Example**

#### 3.2.1.4 Deep-Well Ground

In areas with high soil resistivity, a cost effective solution to obtaining a low ground system resistance may be to use a deep-well ground. A deep-well ground involves drilling a hole down into the water table then inserting a thick-walled 2 to 4 inch copper pipe into this hole. This method, detailed in Figure 3-8, assumes the ground water is more conductive than the surrounding soil.

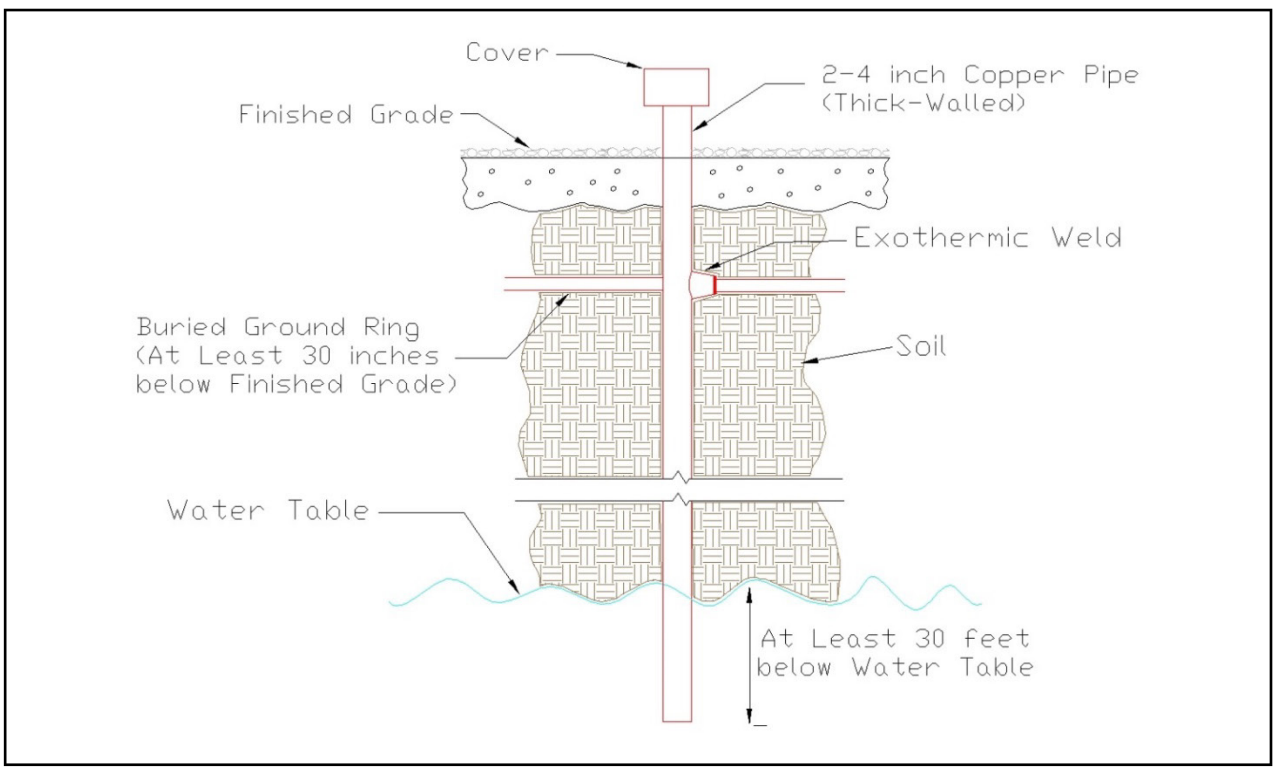



**Figure 3-8: Deep-Well Ground Detail**

The pipe should extend deep enough into the earth so it can reach the water table even during an extended drought. How far past the water table depth depends on the area, but a minimum of 30 feet is recommended.

The ground ring or grounding conductor bonding the deep well ground to the rest of the grounding system should be exothermically welded to the copper pipe at least 30 inches below finished grade. The top of the pipe may be buried or left exposed above grade. If left exposed, the pipe opening should be covered to prevent any object from being accidentally dropped into the pipe.

**Figure 3-9: Deep-Well Grounding Rod Equipment Example**

#### 3.2.1.5 Ground Plates

Special circumstances may require the use of ground plates in the ground system design. A ground plate should be at least ¼ inch thick; have a surface area of at least two (2) square feet; and be buried at least 30 inches under finished grade. Ground plates should only be used in a grounding system design when necessary due to their small sphere of influence and susceptibility to environmental changes.

#### 3.2.1.6 Concrete-Encased Electrodes (Ufer Grounds)

Concrete-encased electrodes, as shown in Figure 3-10, may be used to supplement the grounding system. The concrete-encased ground electrode should never be relied upon as the exclusive or stand-alone site ground system. This is because of the large currents associated with a lightning strike generate heat that can vaporize the moisture in concrete, damaging the concrete and reducing its effectiveness as a grounding electrode. If used, the electrode must be bonded to the rest of the grounding electrode system with at least two connections.

If a tower's concrete footing is used as a concrete-encased electrode, there should be at least one direct connection from the tower to the tower ground ring. This is in addition to the connection from the tower to the concrete-encased electrode.

Concrete-encased electrodes should be at least 20 feet of one or more bare, galvanized, or other conductive-coated steel reinforcing bars at least 0.5 inch diameter or at least 20 feet of #4 AWG or larger bare copper conductor. These bars or conductor should be encased in at least 2 inches of concrete near the bottom of a concrete foundation or footing that is in direct contact with the soil. Typically, a short piece of nonmetallic sleeve is placed around any conductor where it leaves the concrete foundation or footing.

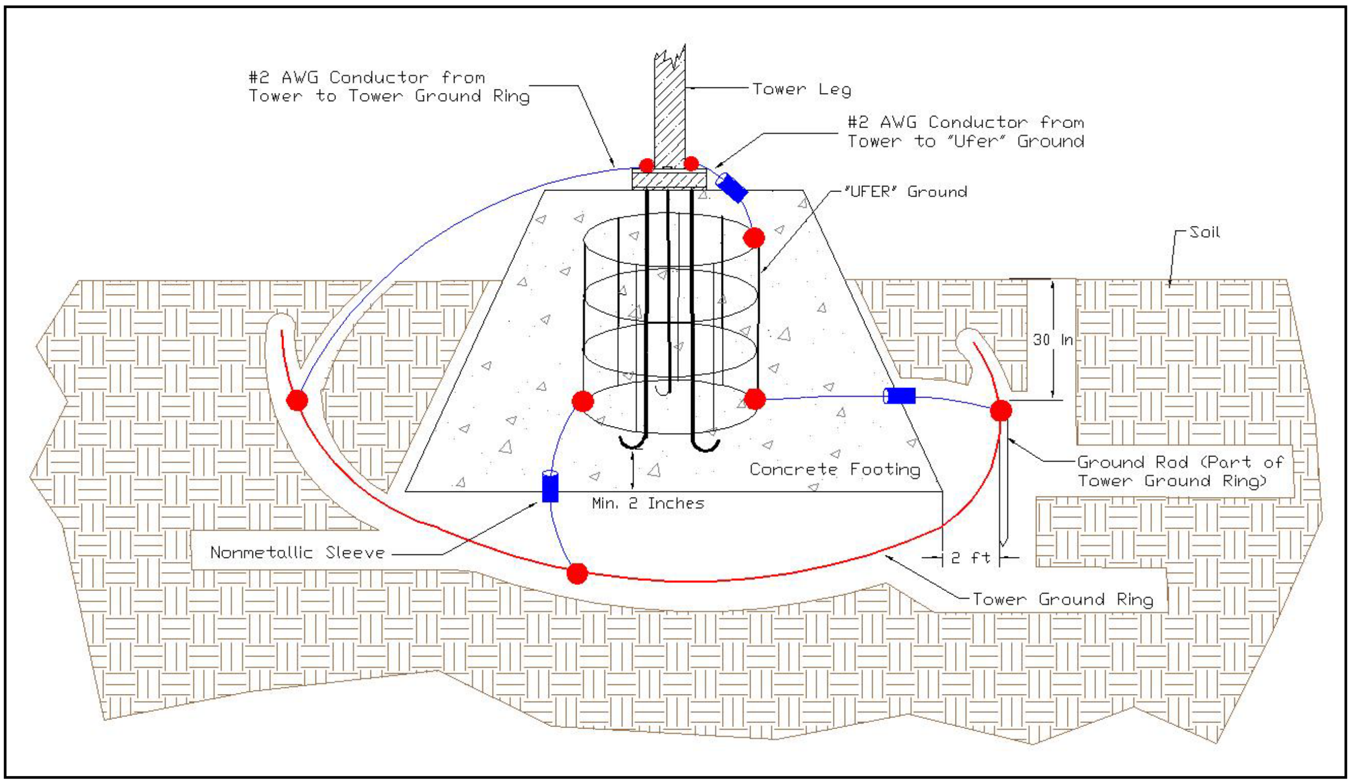



**Figure 3-10: Concrete-Encased Ground Electrode ("Ufer") Detail**

#### 3.2.1.7 Ground Enhancing Backfill

Ground enhancing backfill may be used to lower the grounding system resistance or to protect the grounding electrode system from corrosion, especially in highly acidic soil. If used, the ground enhancing backfill should be environmentally safe, approved by the local authorities, and not have a corrosive effect on the grounding electrode system. Mix and use the ground enhancing backfill according to the manufacturer's recommendation.

Be careful choosing a ground enhancement material. All clay backfill materials must be hydrated to be effective. Unprocessed naturally occuring sodium bentonite clay is usable as a backfill, however, bentonite clay specially processed for grounding applications is preferred.

CAUTION

Never use sand as a backfill material for grounding components.

NOTE

Carbon-based ground enhancement materials should not be used in Harris ground system installations. The use of carbon-based ground enhancement materials, including conductive concrete that has carbon-based material added, may accelerate the corrosion of the copper ground system due to dissimilar metals contact.

**Figure 3-11: Bentonite Clay Used as Ground Enhancing Backfill**

**Figure 3-12: Bentonite Clay Encasement of Ground Ring for Corrosion Resistance**

### 3.2.2 Ground Test Wells

A ground test well allows future inspection of a ground rod or a ground ring. Ground test wells are not required, but should be considered especially in areas with high lightning strike frequency or low pH (acidic) soil. To prevent displacement by frost, the ground test well must be longer than the frost line is deep.

Two different types of ground test well designs may provide value at a tower site. If only one ground test well is installed at a site, then Harris recommends using the design in Figure 3-13. The benefit of this ground test well is that it provides a single ground rod whose resistance can be measured easily with a clamp-on ground tester. This ground test well ground rod is on a stub conductor off the tower ground ring, and the rod should be installed at the same depth as the other tower ground ring rods. The measured resistance of this single ground rod can be recorded and remeasured periodically to watch for changes in its resistance. Increases in this ground test well rod's resistance might indicate that the overall site ground system resistance is increasing due to corrosion or other damage.

NOTE

The measured resistance of the single ground test well rod is not the resistance of the overall site ground system.

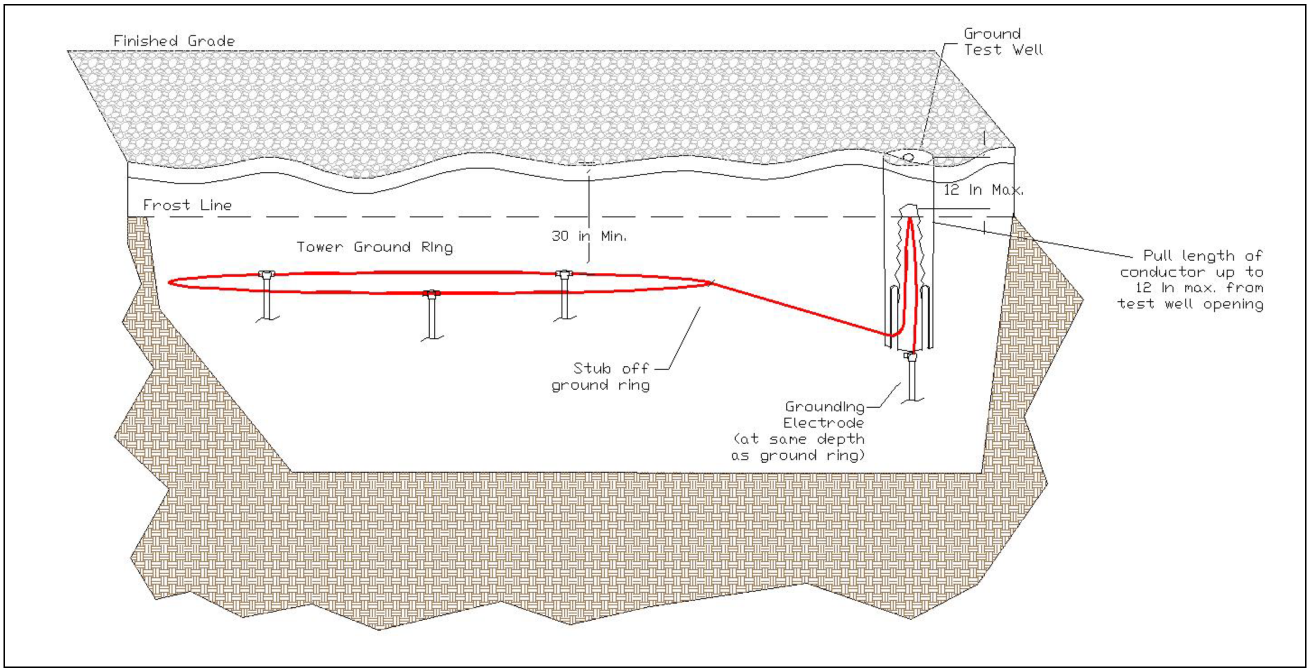



**Figure 3-13: Tower Ground Rod Test Well Detail**

**Figure 3-14: Clamp-on Ground Tester Measurement of a Tower Ground Rod Test Well**

If a second ground test well is required at a site, then Harris recommends the design shown in Figure 3-15. This ground test well is placed on the buried shelter ground ring preferably on the side away from the tower. By pulling a loop of the buried shelter ground ring up into the ground test well, a clamp-on ground tester may be used to verify that the shelter ground ring is still intact forming a complete electrically continuous ring.

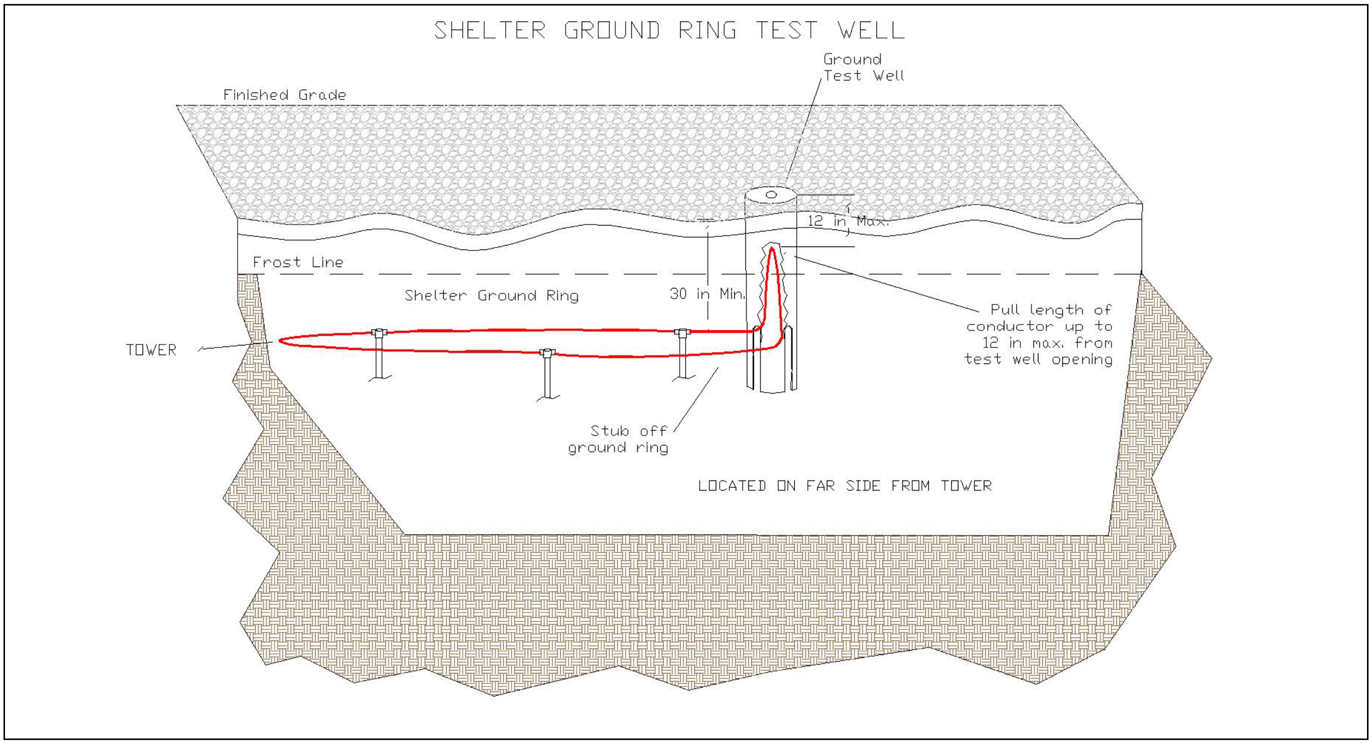



**Figure 3-15: Shelter Ground Ring Test Well Detail**

**Figure 3-16: Clamp-on Ground Tester Measurement of a Shelter Ground Ring Test Well**

For either ground test well design, the housing should be large enough that the loop pulled up into the housing does not contact itself. Ground test wells that consist of a loop of conductor exothermically welded to a buried ground ring provide almost no value since a clamp-on test would only measure the metallic loop inside the ground test well.

**Figure 3-15: Properly Installed Ground Test Well Loop**

A properly installed ground test well loop (less than 12 inches below top of test well) is easily accessed for making clamp-on ground tester measurements.

It is also acceptable to install a ground test well over one of the ground rods along a ground ring as shown in Figure 3-17 and Figure 3-18. The usefulness of this approach is challenging due to the depth of the ground rod making it difficult to reach for making measurements.

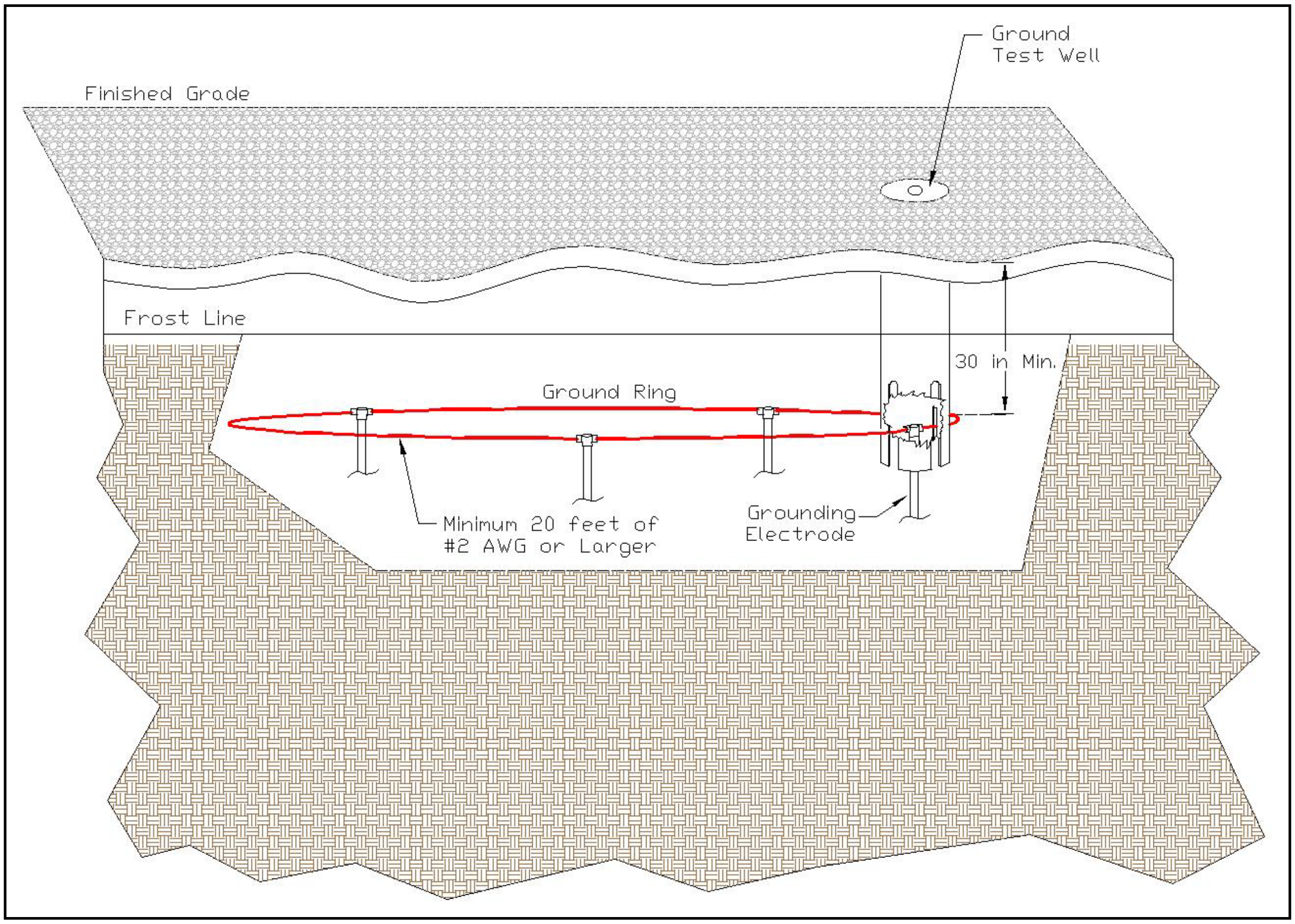



**Figure 3-17: Acceptable Ground Ring and Ground Test Well Detail**

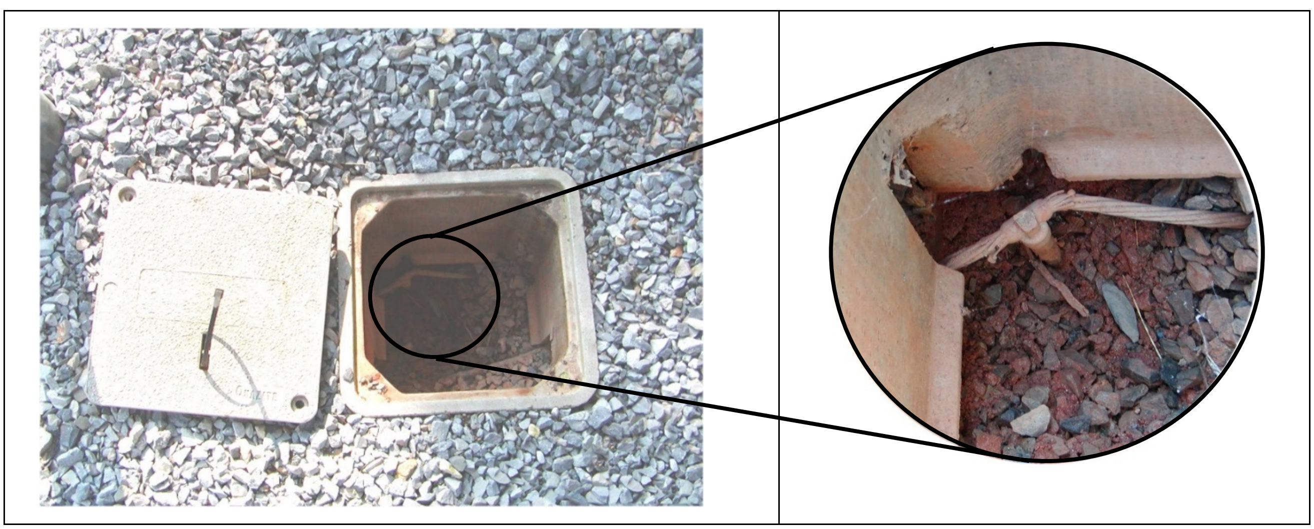


**Figure 3-18: Acceptable Ground Test Well (Allows clamp-on ground test meter to be placed on ground rod below ground ring connection if the rod is not too deep to reach.)**

### 3.2.3 Exterior Grounding Conductors

All exterior conductors should be solid or stranded bare #2 AWG or larger copper wire. Solid wire increases longevity. Using tinned solid copper wire increases corrosion resistance, and it should be used when grounding to a galvanized steel tower or guy anchor. Another method of increasing corrosion resistance is to put a layer of ground enhancing backfill around the conductor before it is buried.

We recommend using larger size conductors for areas with high lightning strike frequency or low pH (acidic) soil. You may use a solid bare copper strap or bars as long as its cross-sectional area is equal to or larger than the #2 AWG wire.

We do not recommend using braided conductors outdoors, since they corrode easily and can then contribute to RF intermodulation.

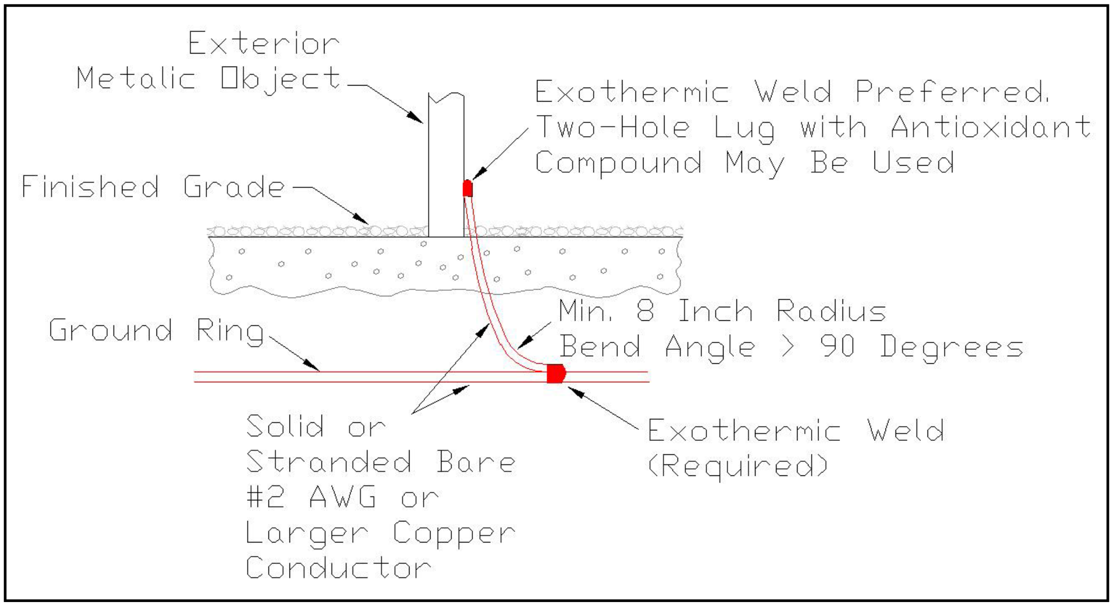



**Figure 3-19: Exterior Grounding Connections**

Grounding conductor runs should be as short and straight as possible, to minimize their impedance. The bending radius should be greater than 8 inches (minimum), and the angles of the bends should not be less than 90 degrees. All bends, curves, and connections should be toward the grounding electrode system. Connecting conductors should always transition in the direction of current flow or toward earth ground, and approach the main ground at an angle of roughly 45 degrees.

You must place the below-grade connecting and interconnecting conductors at the same depth as the tops of the ground rods.

Securely fasten above-grade grounding conductors at least every three (3) feet. Do not run grounding conductors inside metal conduit. This creates a choke, which increases the surge impedance of the grounding cable.

### 3.2.4 Exterior Grounding Connections/Bonding

#### 3.2.4.1 General Requirements

Make all **below-grade grounding connections** with exothermic welds unless site conditions prevent their use. You may use irreversible high-compression connections if exothermic welding would create a hazard.

Make all **above-grade grounding connections** with exothermic welds, irreversible high-compression connections, or UL-listed clamps when necessary. Do not attempt to solder connections.

When making an **exterior grounding connection/bond**, remove any paint or nonconductive coatings. Always place grounding lugs in direct contact with the surface being grounded. Prime and repaint the area after bonding is complete. In the case of a galvanized surface, repaint it using a cold galvanizing spray.

If it is necessary to secure a grounding conductor to the tower structure, secure it using non-conductive materials. Using of a metal clamp creates a choke and increases the impedance of the conductor. You must also exercise care to avoid galvanic corrosion of the tower through the mating of dissimilar metals. Section 3.2.4.3 provides additional information on dissimilar metals.

#### 3.2.4.2 Two-Hole Lug Connections

Observe the following when using two-hole lugs for grounding (see Figure 3-20 and Figure 3-21):

- Only use UL-listed two-hole lugs to make connections.
- Use bolts in both holes, with the lock washers placed on the nut side.
- Do not use self-tapping or sheet metal screws to make connections.
- Use conductive antioxidation compound on all mechanical connections.
- Lug connections to a ground bar should always be in direct contact to the ground bar surface. Lugs should not be “piggy-backed.”
- If you need more connection points than are available on the ground bar, replace the ground bar with a larger ground bar, or add a second ground bar. If you add a second ground bar, the bar should also be connected directly to the buried ground system.
- It is acceptable to add lug connections to the back of the ground bar, if they are in direct contact to the ground bar surface. This is not the preferred practice since lugs placed on the back of the ground bar are difficult to inspect and they are attached using the same bolts as one of the lugs connected on the front of the ground bar.

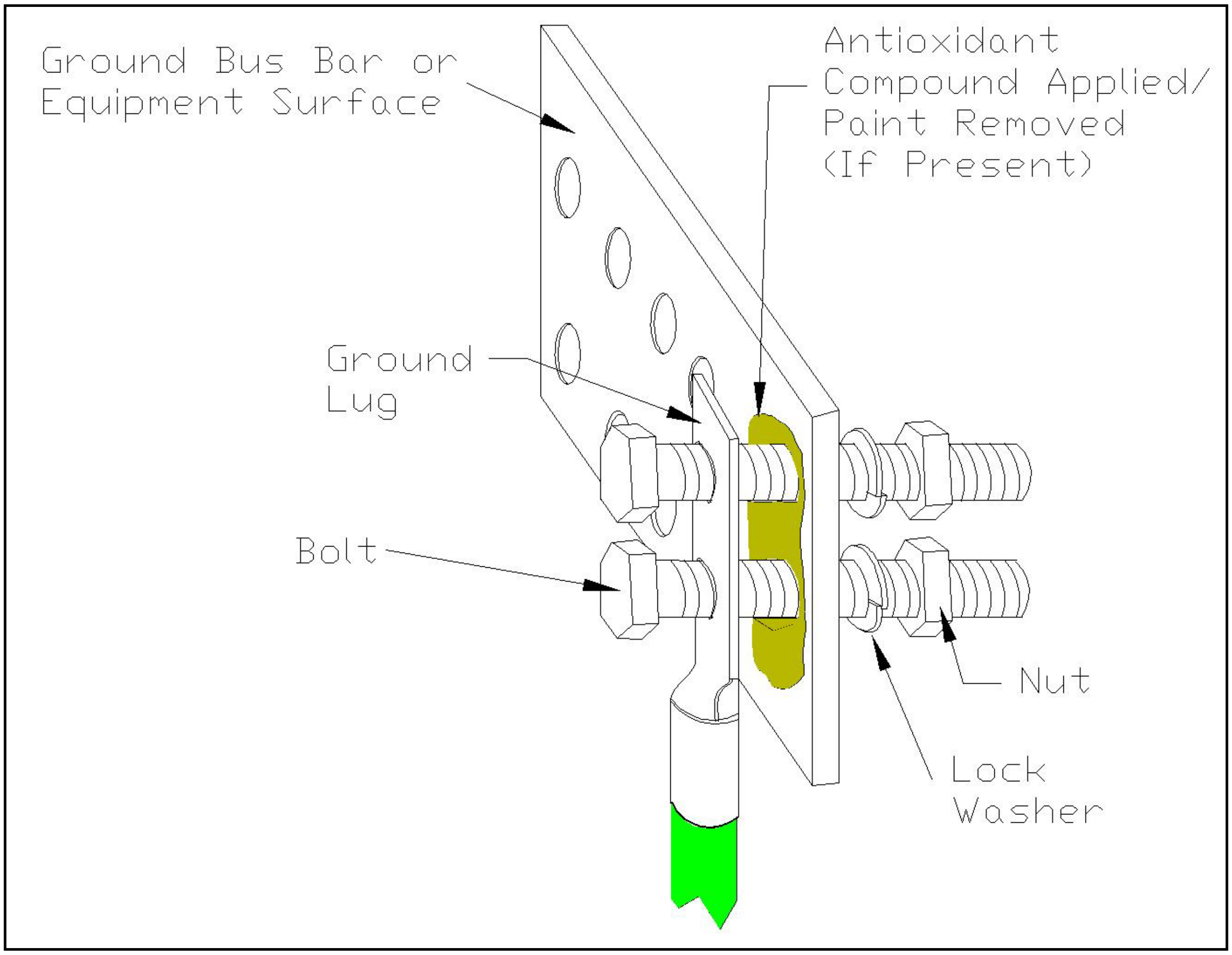



**Figure 3-20: Two-Hole Lug Connection Detail**

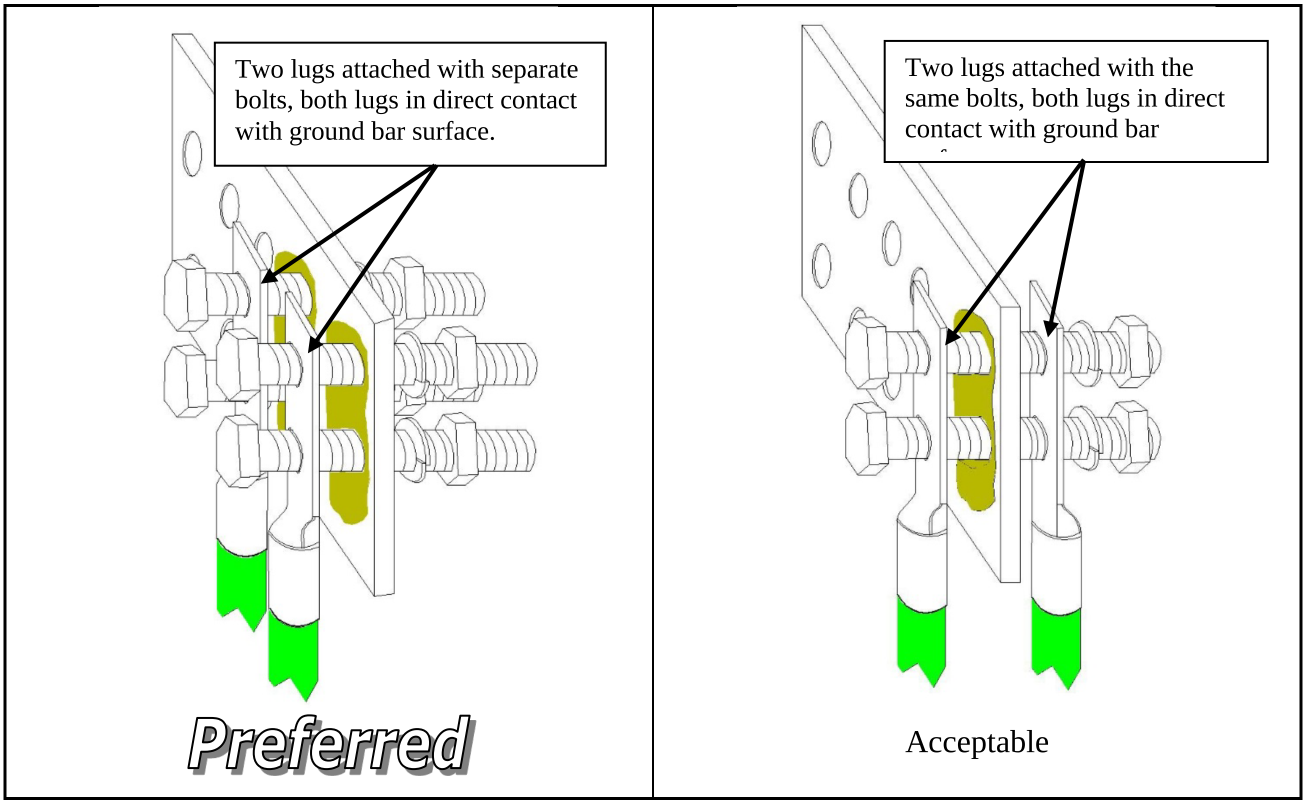



**Figure 3-21: Acceptable Two-Hole Lug Connection Examples**

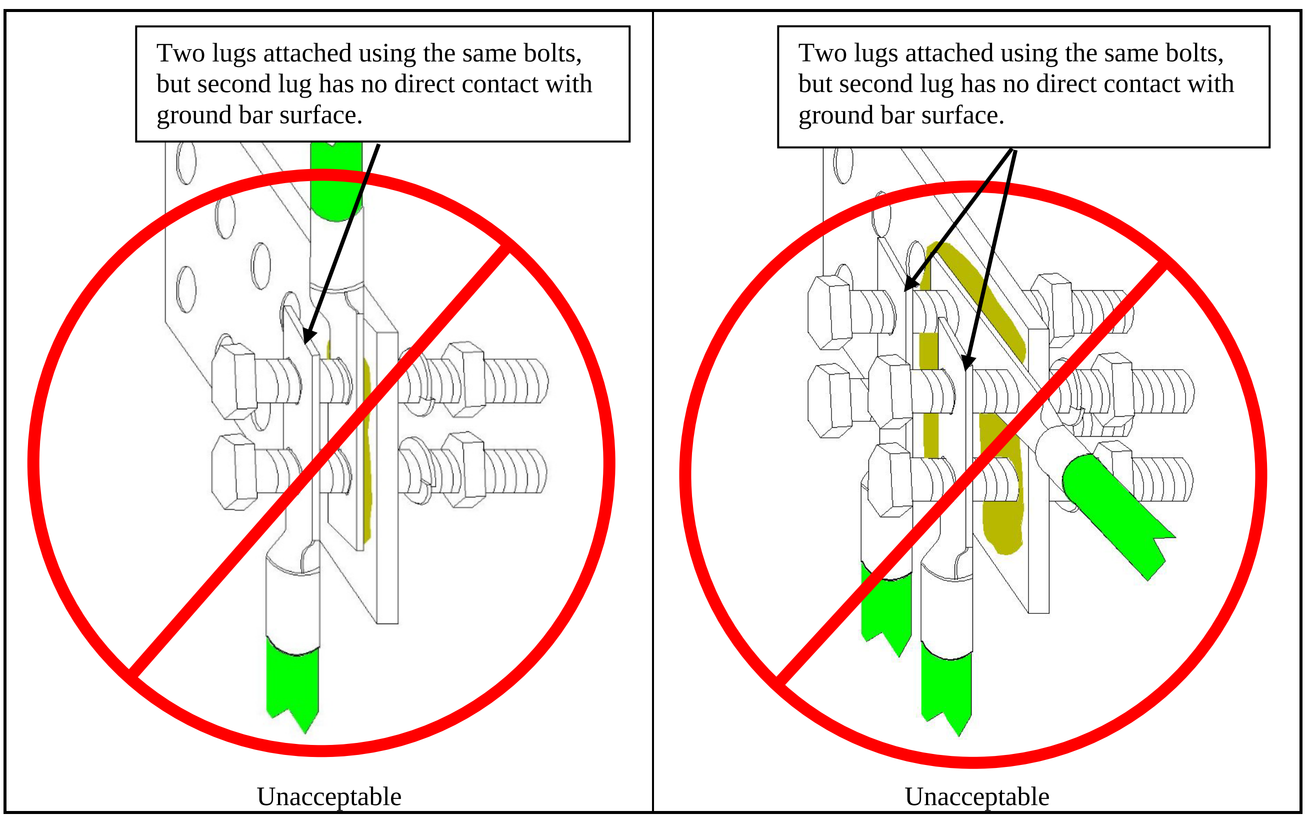



**Figure 3-22: Unacceptable Two-Hole Lug Connection Examples**

### 3.2.4.3 Dissimilar Metals

Connections between two dissimilar metals can cause deterioration of the metallic surfaces through galvanic corrosion if moisture is present. Table 3-1 contains a list of metals that may be safely bonded together with the proper precautions. The metals are listed from the least noble (most likely to corrode) to the most noble (least likely to corrode). Only dissimilar metals with an "A" at their union may be safely bonded together. However, if it is a mechanical connection, they must be coated with a conductive antioxidant compound. The connections may also be bonded with an exothermic weld specifically designed for bonding the two metals.

**Table 3-1: Dissimilar Metals That May be Safely Bonded Together with Antioxidant Compound or Proper Exothermic Weld**

| | Metal | Mag | Alum | Zinc | Iron/ Steel | Cad | Nick | Tin | Stain-less Steel | Lead | Copper | Silver | Pall | Gold |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Less | Magnesium | | | | | | | | | | | | | |
| Noble | Aluminum | | | | | | | | | | See Note | | | |
| ⇩ | Zinc | | | | A | A | A | | | | | | | |
| | Iron/Steel | | | A | | A | A | A | A | A | See Note | | | |
| | Cadmium | | | A | A | | A | A | A | A | | | | |
| | Nickel | | | A | A | A | | A | A | A | A | | | |
| | Tin | | | | A | A | A | | A | A | A | | | |
| | Stainless Steel | | | | A | A | A | A | | A | A | | | |
| | Lead | | | | A | A | A | A | A | | A | | | |
| | Copper | | See Note | | See Note | | A | A | A | A | | A | | |
| | Silver | | | | | | | | | | A | | A | |
| More | Palladium | | | | | | | | | | | A | | A |
| Noble | Gold | | | | | | | | | | | | A | |

CAUTION

The most commonly encountered dissimilar metal connections are copper to galvanized steel and copper to aluminum. Copper should never come in direct contact with galvanized steel such as a tower or guy anchor. Tinned copper wire should be used in these instances. On galvanized steel guy wires, stainless steel pressure connectors are used to connect between the tinned copper down conductor and the guy wire. Copper and aluminum should only be connected with a UL-listed, properly sized stainless steel bimetallic connector marked with "AL/CU" or exothermically welded. As with any dissimilar metal mechanical connection, conductive antioxidation compound should be used.

### 3.2.4.4 Exothermic Welds

Exothermic power and grounding connections must be made with a NEC-approved, pre-engineered system using a controlled exothermic chemical reaction. Exothermic welding is a bonding process that provides a metallic bridge connection that exhibits virtually no resistance. Exothermic connections offer the following advantages over other types of connections:

- The connection permanently welds every strand of the conductor.
- The connection is made with portable equipment that requires no outside source of heat or power.
- Loosening or corrosion of the current path cannot occur since a welded molecular bond is formed.
- The connection is able to withstand repeated high current surges [faults] without damage to the connection or the conductor.
- No special skill and minimum training is required.
- Installation time is the same as with other kinds of connections.

Connections made to ground rods, or to conductors below ground, must be made using an exothermic weld. This attachment procedure ensures firm, electrically conductive, mechanically rigid, and maintenance free connections. Copper grounding conductors spliced with exothermic connections are considered a continuous conductor, as stated in *NEC 250-64*.

When using exothermic welds, be sure to use the proper molds and weld material for the type of conductors or surfaces being welded. Completely clean and dry the objects being welded prior to welding. As always, follow the manufacturer's recommendations, requirements, and safety guidelines.

After welding, inspect each weld for soundness. If you encounter problems making an acceptable exothermic weld, contact to the manufacturer for additional information and technical assistance.

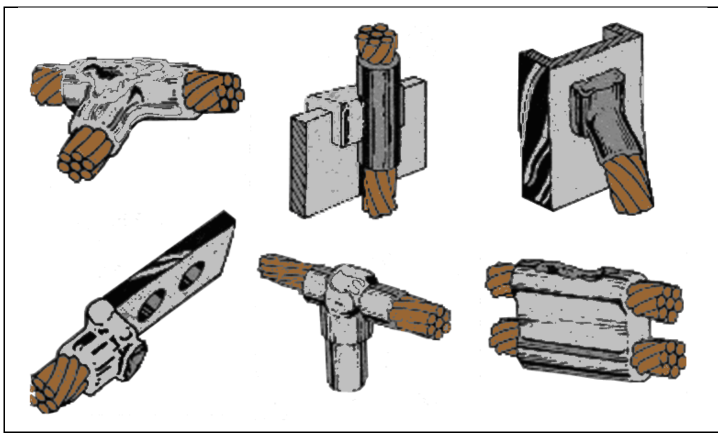


**Figure 3-23: Typical Exothermic Welds**

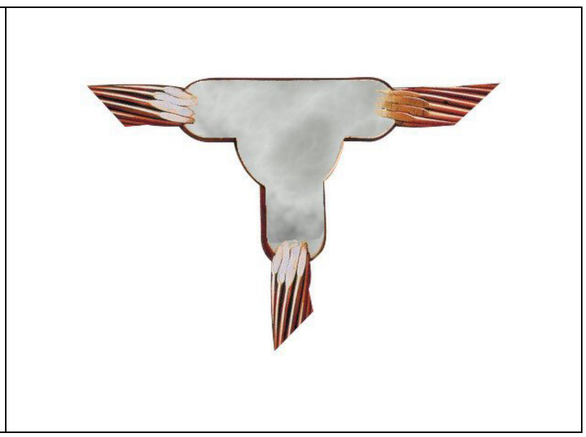
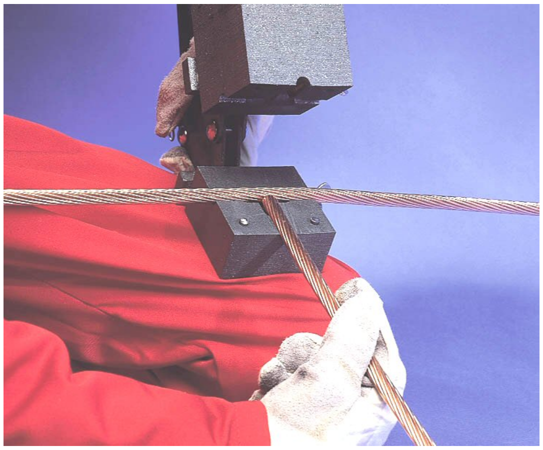
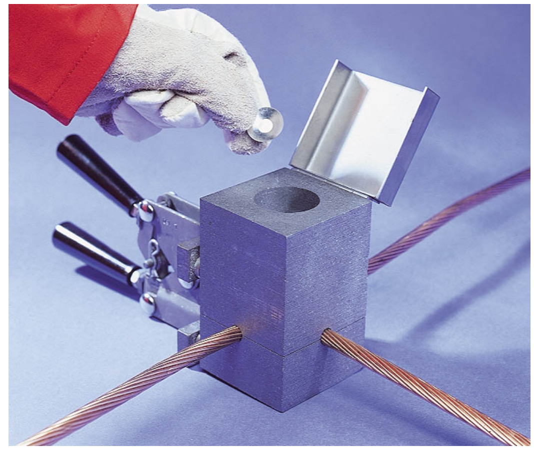


**Figure 3-24: Exothermic Weld Cross-Sectional View**

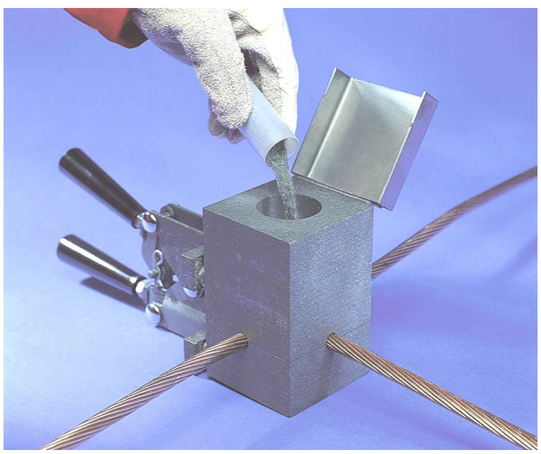
Step 1 – Place conductors in mold.



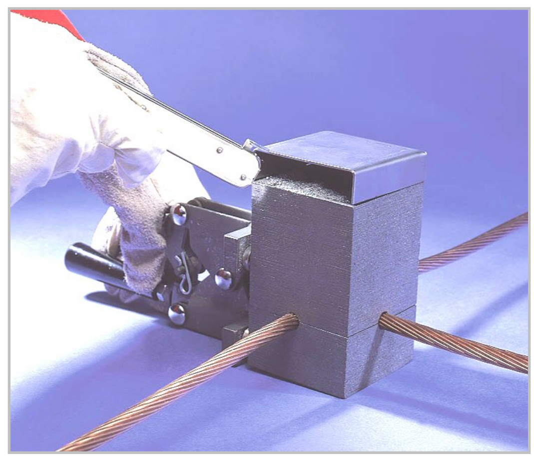
Step 2 – Clamp mold shut, place disk in mold.



Step 3 – Pour weld material into mold.



Step 4 – Sprinkle starting material over lip of mold, and close lid.



Step 5 – Ignite weld material.

Step 6 – Examine finished exothermic bond.

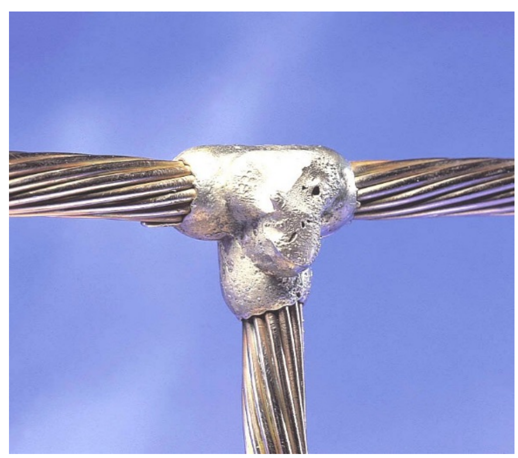


**Figure 3-25: Exothermic Weld Process**
(Courtesy of Thomas & Betts)

**Figure 3-26: Examples of Typical Exothermic Welds**

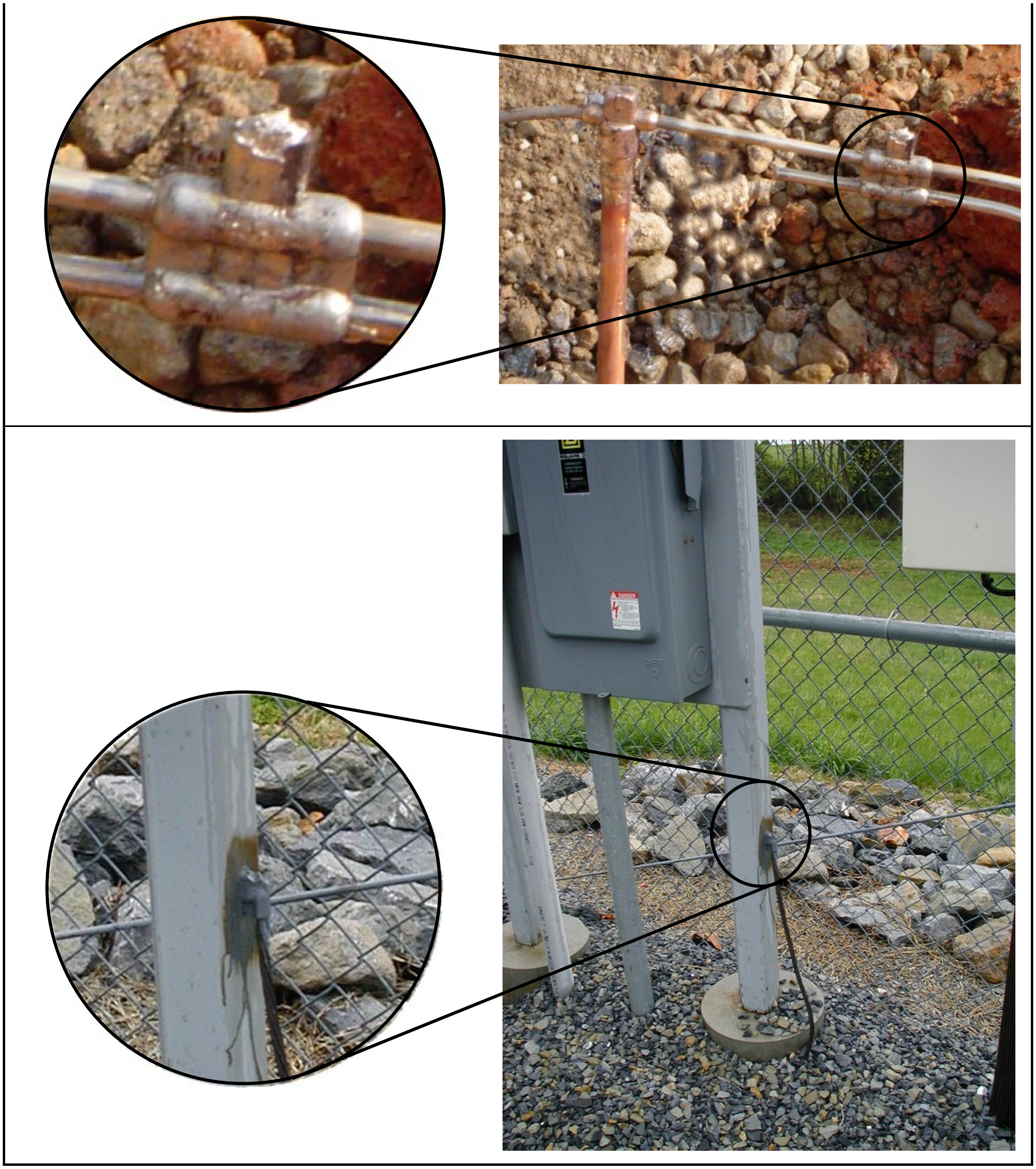


Figure 3-26: Examples of Typical Exothermic Welds … Continued

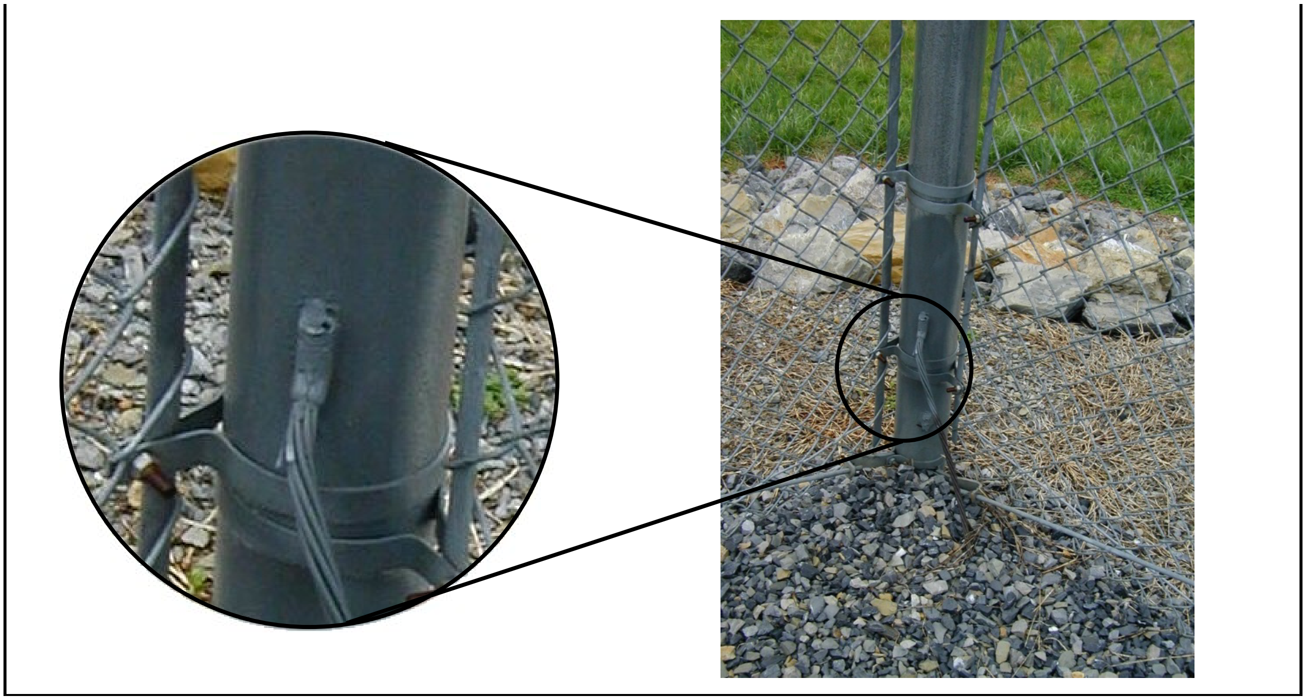


Figure 3-26: Examples of Typical Exothermic Welds … Continued

Figure 3-27: Exothermic Weld Being Made to Bond Conductor to Ground Rod

### 3.2.4.5 Irreversible High-Compression Connectors

Connections made above ground, in areas exposed to weather, should use exothermic welds where possible. If environmental conditions prevent making exothermic welds, an appropriate irreversible high-compression-type connection may be used.

When making above ground pressure-type connections, stranded wire conductors should be used. Ensure connectors are the proper size for the conductor and made of the same material. This will eliminate the effects of galvanic corrosion. Connectors and C-type compression taps should be UL-listed. You should only use the compression tools recommended by the connector manufacturer. Be sure the compression tools and connectors have a minimum 12-ton pressure rating.

Conductors should be dry, cleaned with a wire brush, and coated with a conductive antioxidant compound prior to crimping. Be sure to use the type of antioxidant compound made for the type of metal being connected. The die in most compression tools will leave an imprint on the crimped connector, this imprint allows inspectors to verify that the correct die was used.

We recommend installing heat-shrink over irreversible high-compression type connections used outdoors, especially if the connection is on a jacketed conductor.


**Figure 3-28: Examples of Exterior Irreversible High-Compression Connectors**

(Courtesy of Thomas & Betts)

**Figure 3-29: Examples of Typical Irreversible High-Compression Connections**

### 3.2.4.6 Attaching Copper Straps to Buried Ground Ring

Bonding solid copper straps to the buried grounding ring can be difficult given their thinness. To make exothermic welding of the straps to the grounding ring easier, the straps need to be sandwiched between two thin copper bus bars. The bus bars, with the copper straps bolted between them, can then be exothermically welded to the ground ring. This bus bar assembly with the copper straps "sandwiched" in between is referred to as a sandwiched bus bar assembly.

Be sure to clean all bus bar and copper strap surfaces with a special copper cleaning pad and apply antioxidant compound to all surfaces before bolting the assembly together. Exothermically weld the copper conductors to the sandwiched bus bar assembly and weld the other end of the conductors to the buried ground ring in a parallel manner, as shown in Figure 3-30. You should use at least two #2 AWG, or larger, copper conductors to bond the bus bar assembly to the buried ground ring. Four #2 AWG or two #2/0 AWG conductors are preferred.

In addition to the copper straps from the RF entry port or external ground bar attaching to the buried ground ring, the Master Ground Bar (MGB) conductors will also be attaching to the ground ring. The MGB conductors are routed to the buried ground ring through Polyvinyl Chloride (PVC) conduits, to avoid making direct contact with the sandwich bus bar assembly. Position the copper straps and the MGB conductors (PVC conduits) so the MGB conductors are between two of the copper straps. The MGB conductors should connect to the buried ground ring in the center of the bus bar assembly connecting conductors as shown in Figure 3-30. This is the preferred method; however, the methods shown in Figure 3-31 are also acceptable.

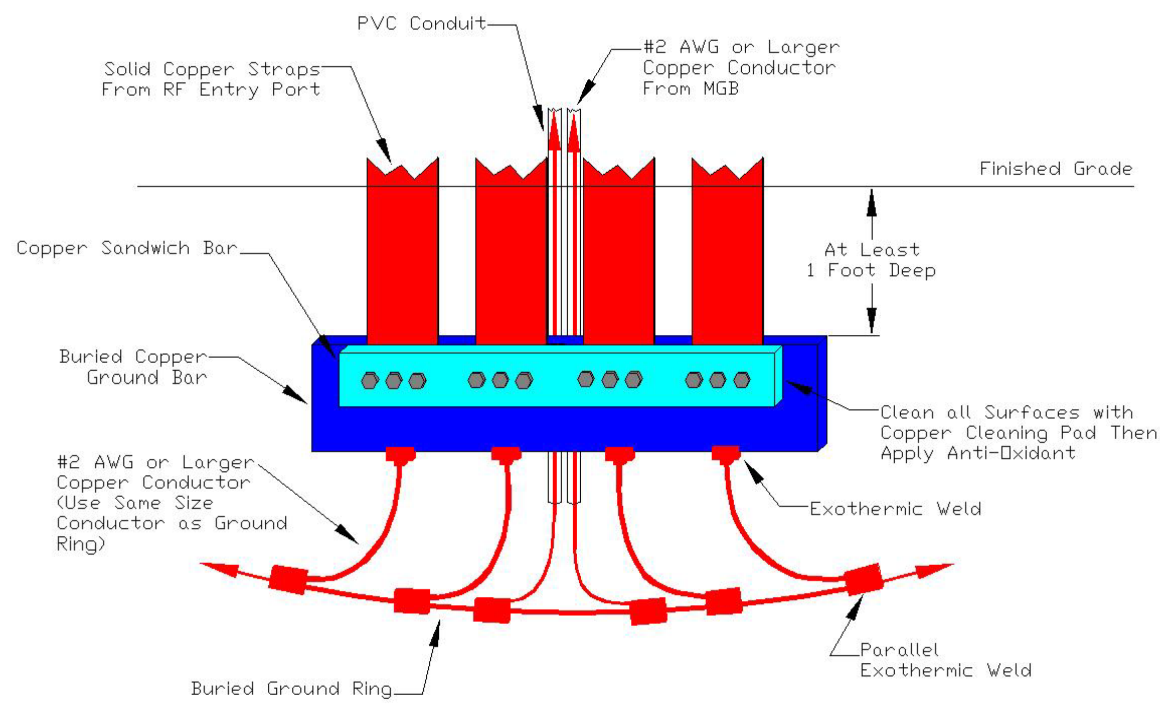



**Figure 3-30: Preferred Method for Attaching Copper Straps to Buried Ground Ring Detail**

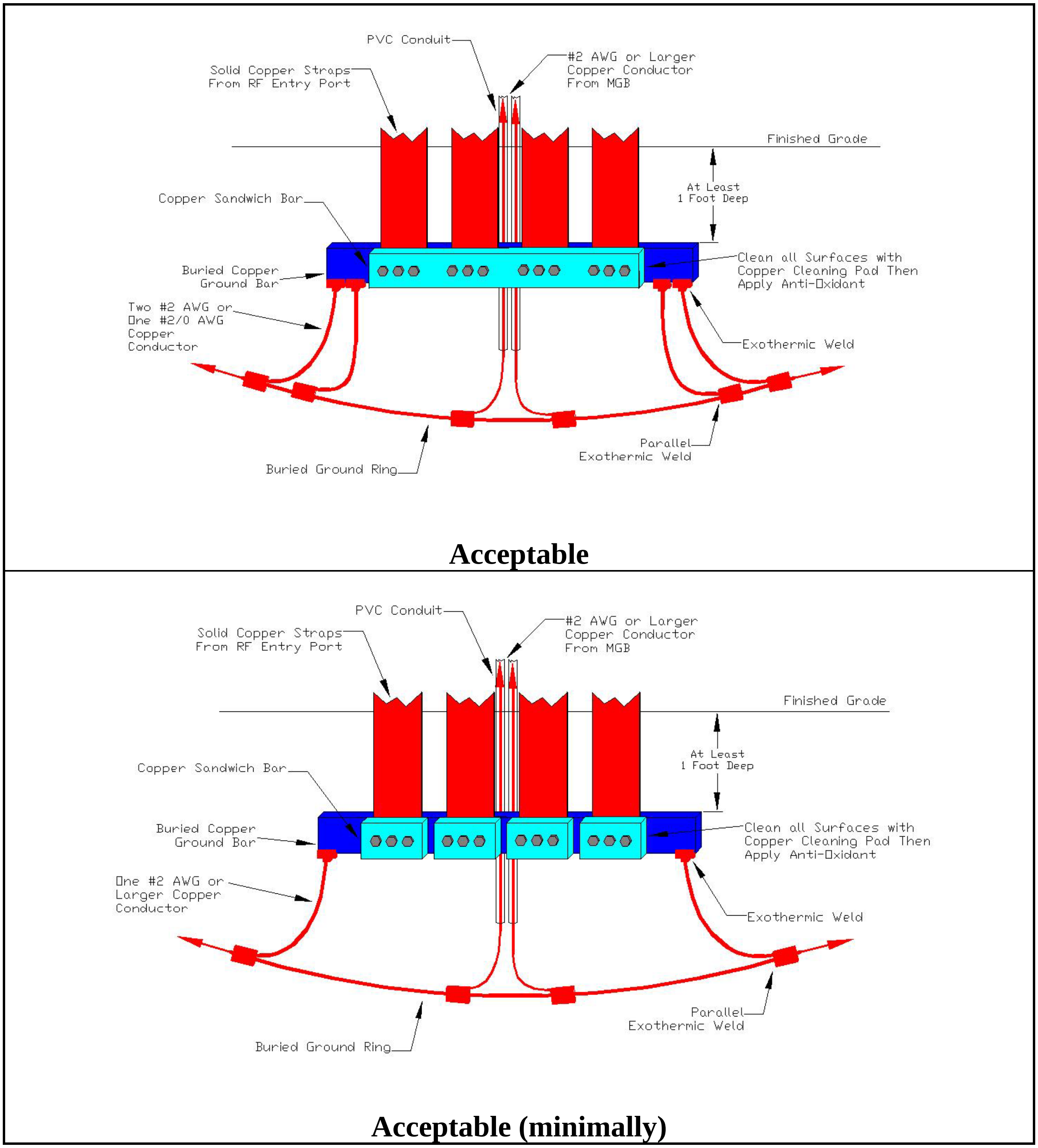



**Figure 3-31: Acceptable Methods for Attaching Copper Straps to Buried Ground Ring Detail**

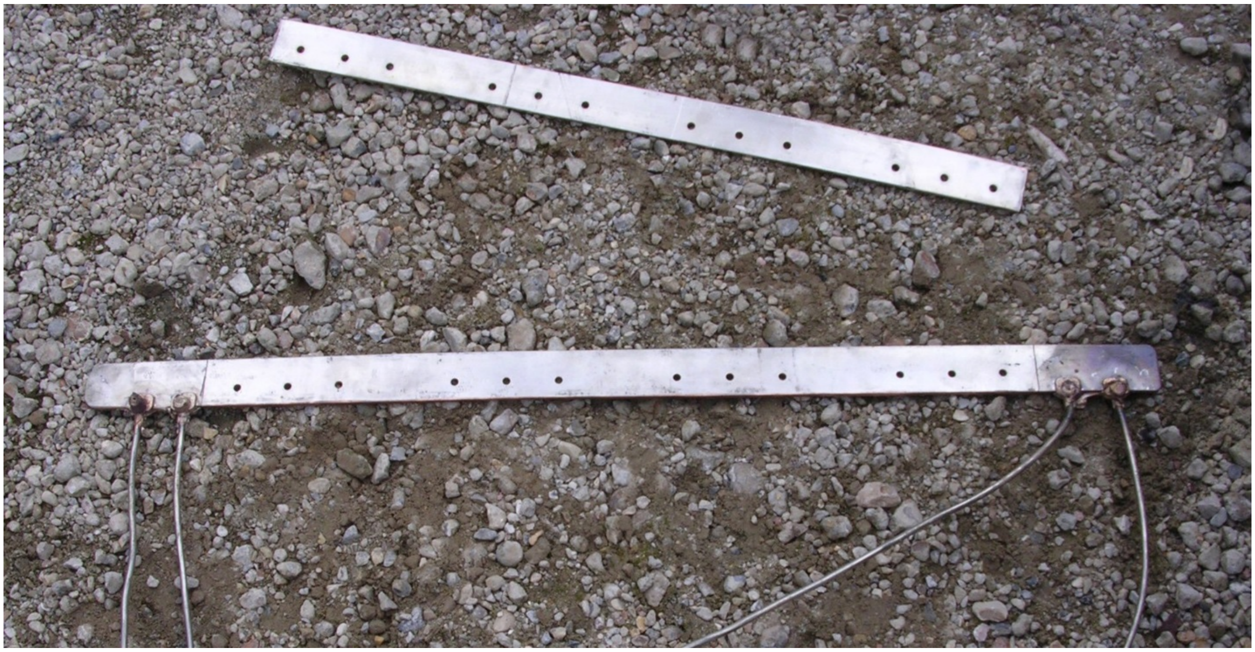


Figure 3-32: Attaching Copper Straps to Buried Ground Ring

Figure 3-33: Copper Strap Attachment Method (Before Attaching to Ground Ring)


**Figure 3-34: Finished Copper Straps Installation Connecting EGB to Buried Ground Ring**

# 4. EXTERIOR SITE GROUNDING

All communication sites must have a complete grounding system. This system includes interior and exterior grounding systems for equipment in the communications buildings, the antenna towers and guys, transmission lines, telephone lines, DC power plants, AC power entrance, and all nearby metallic objects like fences. All elements of the ground system and conducting elements near the system must be connected and bonded together, as shown in Figure 4-1. This ensures all parts of the radio site are at the same ground integrity, as related to true earth ground.

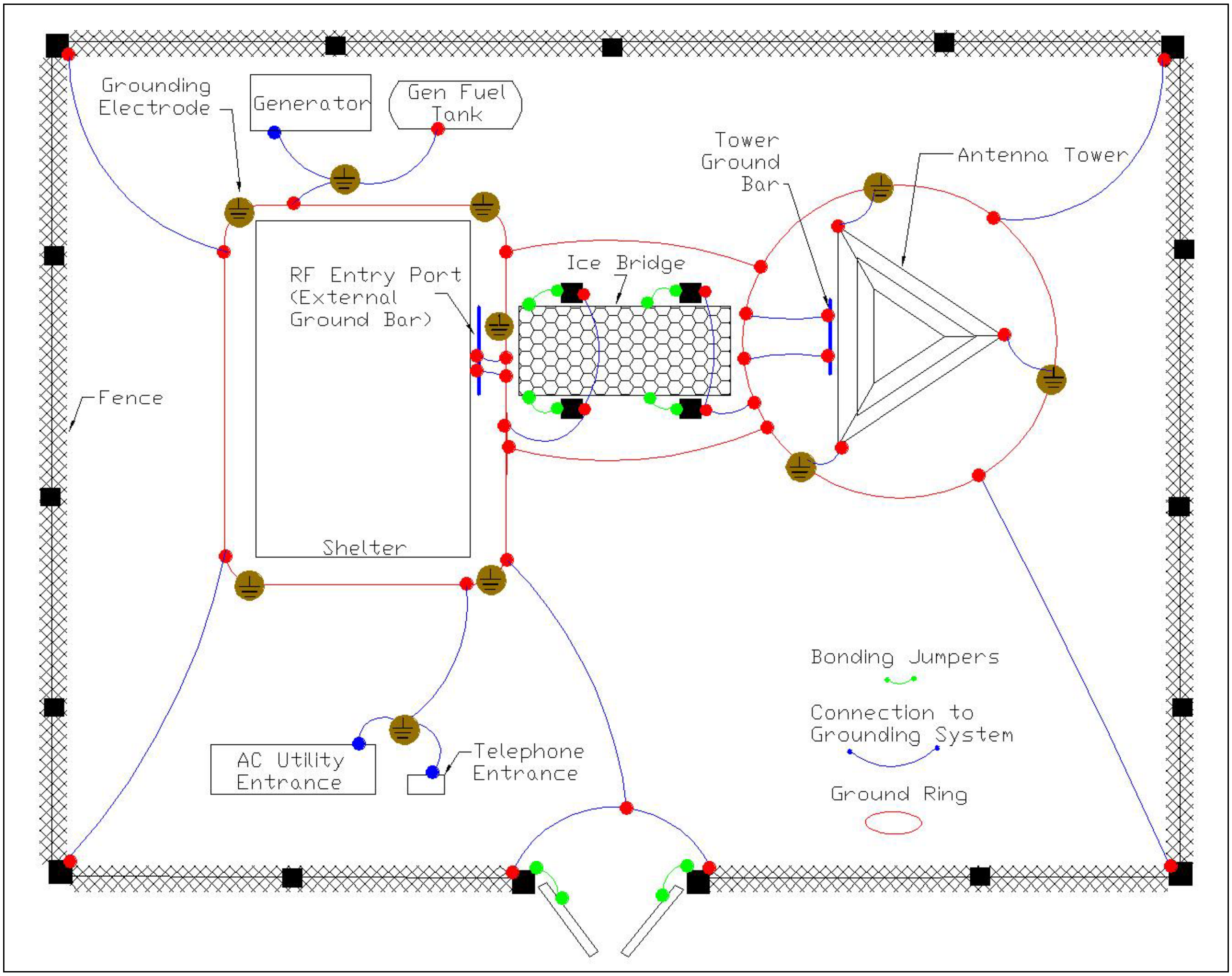



**Figure 4-1: Exterior Grounding Overview of Typical Stand-Alone Shelter Site**

## 4.1 EXTERIOR GROUND RINGS AND RADIALS

Buried exterior ground rings should encircle both the tower and the equipment shelter. These rings bond all of the ground rods together, and you should bond the rings together in at least two places. It is important to note, **there should be *no* separately maintained ground rods or ground systems associated with the communications shelter, site, building, or equipment room.** Adherence to these requirements is the standard for Harris communications facilities.

### 4.1.1 Tower and Shelter Ground Rings

Separate buried exterior ground rings should encircle the equipment shelter and the antenna tower interconnecting their respective ground rods. You should bond the two rings together in at least two places, using exothermic welds. The rings should consist of at least 20 feet of #2 AWG or larger bare copper conductor (See Section 3.2.3). Bury the rings in direct contact with the soil at least 30 inches below finished grade or below the frost line whichever is deeper.

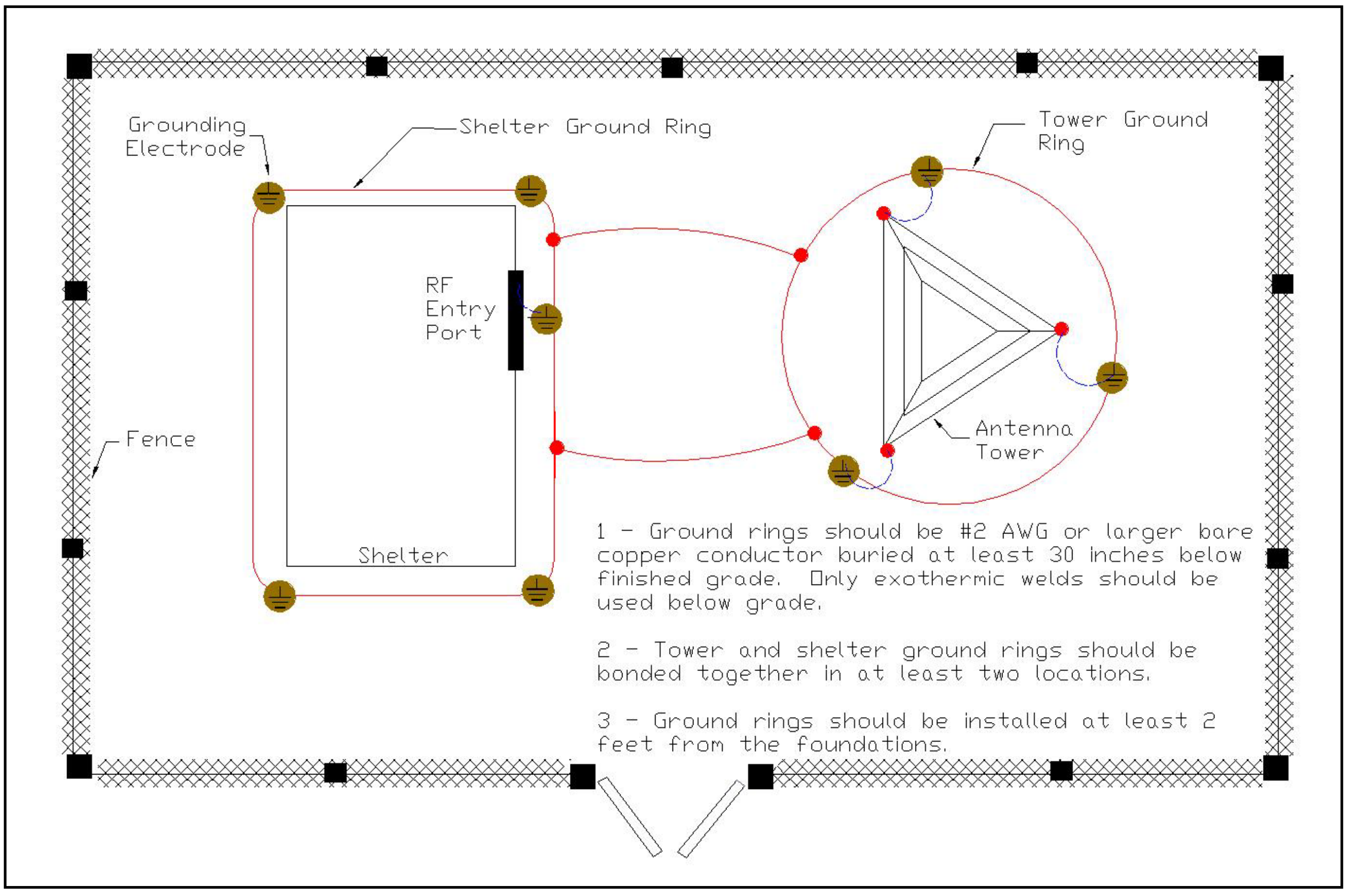



**Figure 4-2: Tower and Shelter Ground Rings**

Install ground rings at least two feet away from the concrete foundation of the equipment shelter or tower. We also recommend locating the building ground ring beyond the drip line of the roof.

Ground rods for stand-alone equipment shelters should be located at each corner of the building. If necessary, additional ground rods can be located along the sides to ensure proper ground rod spacing is adhered to (See Section 3.2.1.2.). Refer to Section 4.2 for more information in determining the number and location of tower ground rods. In areas prone to lightning, place an additional ground rod below the tower ground bar and below the shelter RF cable entry port.

**Figure 4-3: Example of Shelter Ground Ring Installation**

**Figure 4-4: Ground Ring Rods and Conductor**

**Figure 4-5: Example of Tower Ground Ring Installation**

### 4.1.2 Tower Ground Radials

We recommend installing tower ground radials in areas prone to lightning. This provides a low impedance path to ground for lightning strikes and currents. The ground radials also help to minimize temporary saturation of the earth during lightning strikes and increase the effectiveness of the grounding electrode system.

Ground radials are normally 50 and 75 feet long and should radiate out (point away) from the ground rings, as shown in Figure 4-6. The ground radials are made of the same materials as the ground rings and are installed using same installation methods.

NOTE

You should cut ground radials to different lengths [plus or minus five (5) feet] to avoid resonance.

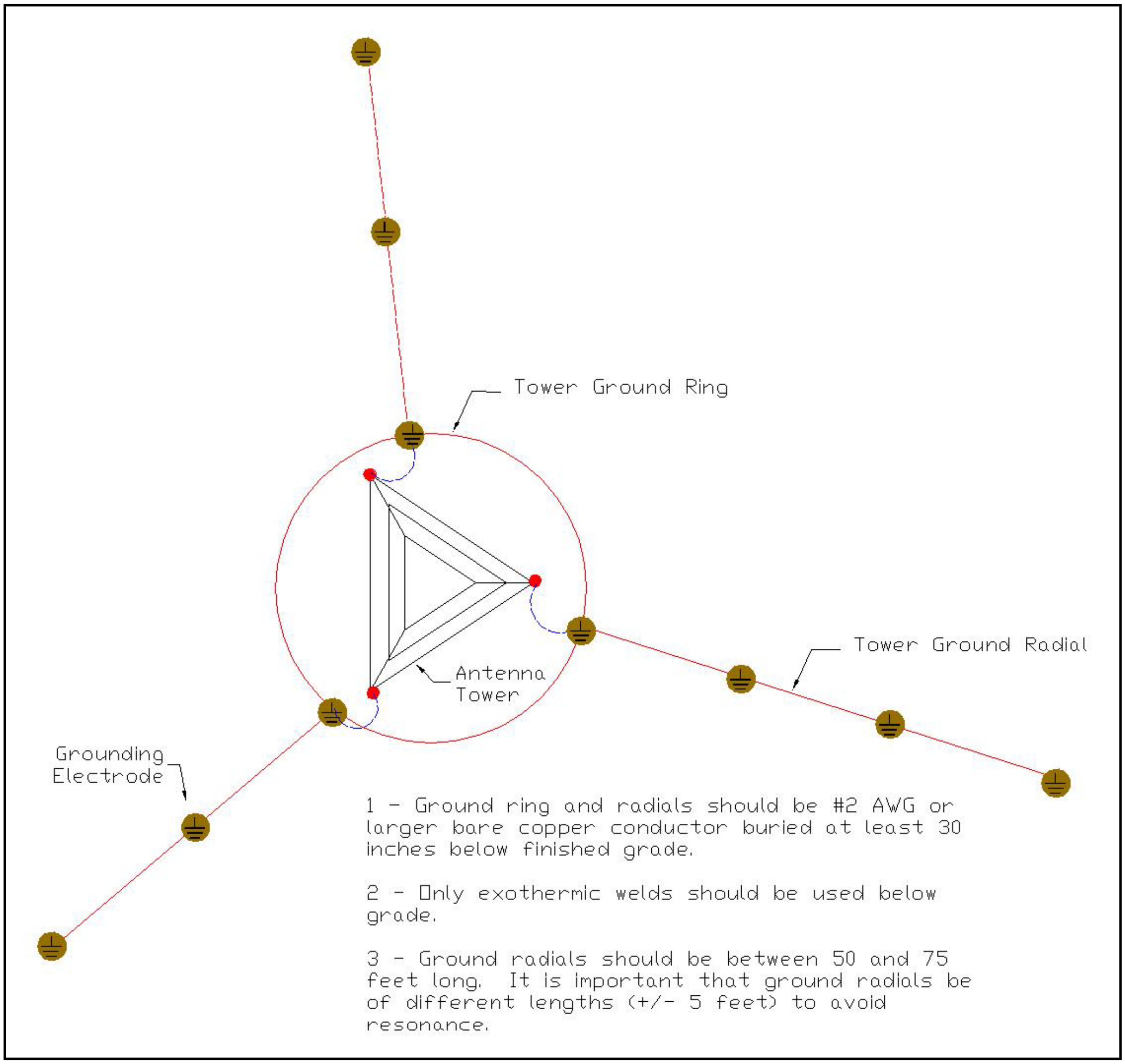
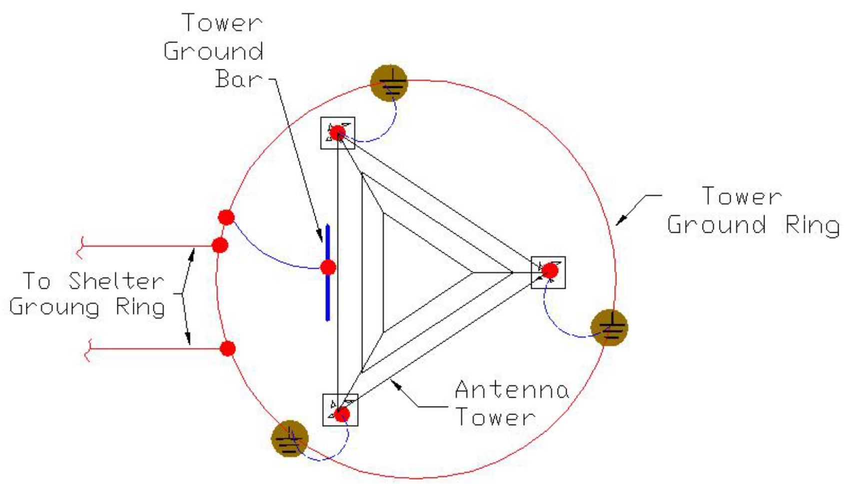



**Figure 4-6: Tower Ground Radials**

## 4.2 ANTENNA TOWER GROUNDING

All antenna towers or support structures should be grounded to the tower ground ring. The type, number, and placement of the ground rods for that ring will vary depending on the tower type or structure being grounded.

When bonding the tower to the tower ground ring you should use a #2 AWG, or larger, solid or stranded bare tinned copper conductor. Exothermically weld all connections to the tower ground ring and connections to the tower itself, if the tower's manufacturer allows and recommends it. Connections to the tower leg must be short and direct. No bends should have a radius of less than 8 inches or an angle less than 90 degrees. Direct all bends and curves toward the tower ground ring. The tower leg ground conductors should approach the ground ring at a 45 degree angle, in the direction of the nearest grounding electrode.




1 - Minimum number of ground rods equals the number of tower legs.

2 - Each tower leg must be connected to the tower ground ring with #2 AWG or larger tinned bare copper conductor.

3 - Connections below ground should be exothermically welded to the closest ground rod.

4 - Connections to the tower itself should be exothermically welded if possible.

5 - Conductors should be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.

**Figure 4-7: Typical Self-Supporting Tower Grounding**

If the tower's concrete foundation was designed as a supplemental concrete-encased electrode (Ufer ground), then it must also be bonded to the tower ground ring with a #2 AWG or larger solid or stranded bare tinned copper conductor.

**NOTE**

A supplemental concrete-encased electrode (Ufer ground) does not remove the requirement to bond the tower itself to the tower ground ring.

In areas highly prone to lightning, larger size conductors and tower ground radials, if space allows, are highly recommended.

## 4.2.1 Self-Supporting Towers

A self-supporting tower grounding system consists of a ground rod at each tower leg (at least three). You may install additional ground rods to decrease ground resistance or to reduce the distance between rods, as described in Section 3.2.1.2. The ground rods are then bonded together to form the tower ground ring. (See Section 3.2.3 and Section 4.1.1.)

You must connect each tower leg to the grounding system using #2 AWG, or larger, solid or stranded bare tinned copper wire. All connections to the tower ground ring should go to the closest ground rod and be exothermically welded. Exothermically weld connections to the tower itself if the tower's manufacturer allows and recommends this. Connections to the tower leg must be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.

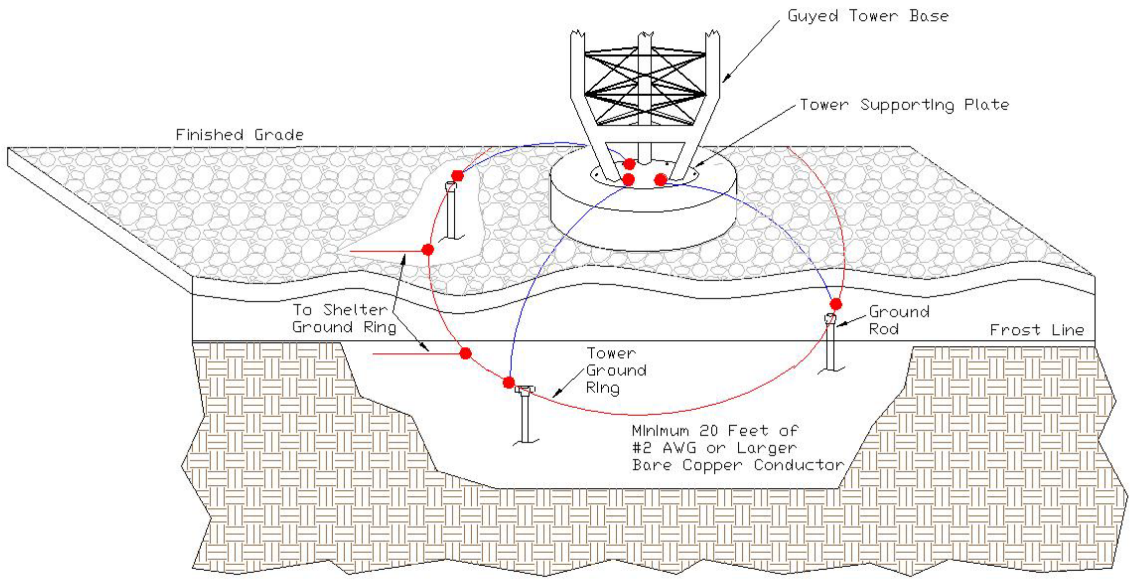
**Figure 4-8: Self-Supporting Tower Leg Ground Connection**

## 4.2.2 Guyed Towers and Guy Wire Anchors

A guyed tower grounding system consists of at least three equally spaced ground rods at the tower base. The ground rods are bonded together to form the tower ground ring. (See Section 3.2.3 and Section 4.1.1.)

### 4.2.2.1 Guyed Tower Grounding

Three equally spaced grounding conductors connect the bottom plate of the tower to the tower ground ring. The conductors should be #2 AWG, or larger, solid or stranded bare tinned copper wire. Conductors should be exothermically welded to the tower ground ring near the closest ground rod. Exothermically weld connections to the tower supporting plate if the tower's manufacturer allows and recommends this. Connections to the tower leg must be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.




1 - Three equally-spaced ground rods are bonded together to form the tower ground ring.

2 - Three connections to the tower ground ring with #2 AWG or larger tinned bare copper conductor.

3 - Connections below ground should be exothermically welded to the closest ground rod.

4 - Connections to the tower base itself should be exothermically welded if possible.

5 - Conductors should be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.

**Figure 4-9: Guyed Tower Base Grounding Detail**

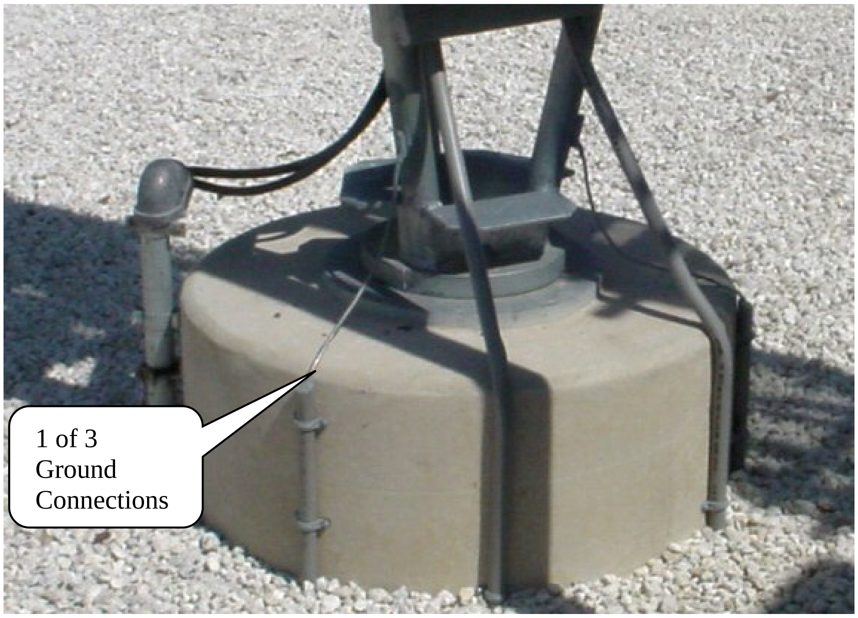



**Figure 4-10: Guyed Tower Base Ground Connections (Only 2 of 3 Shown)**

### 4.2.2.2 Guy Wire Grounding

You must install supplemental ground rods at each guy wire anchor point. The rods must be located at least 2 feet (minimum) away from the concrete anchor footing and should be buried at least 30 inches (minimum) below finished grade, or below the frost line, whichever is deeper (see Figure 4-11). Additionally, the bottom of the ground rod must extend below the lowest point of the anchor footing. (See Section 3.2.1.2.) In areas prone to lightning, you should install additional ground rods and bond them together to better dissipate lightning energy.

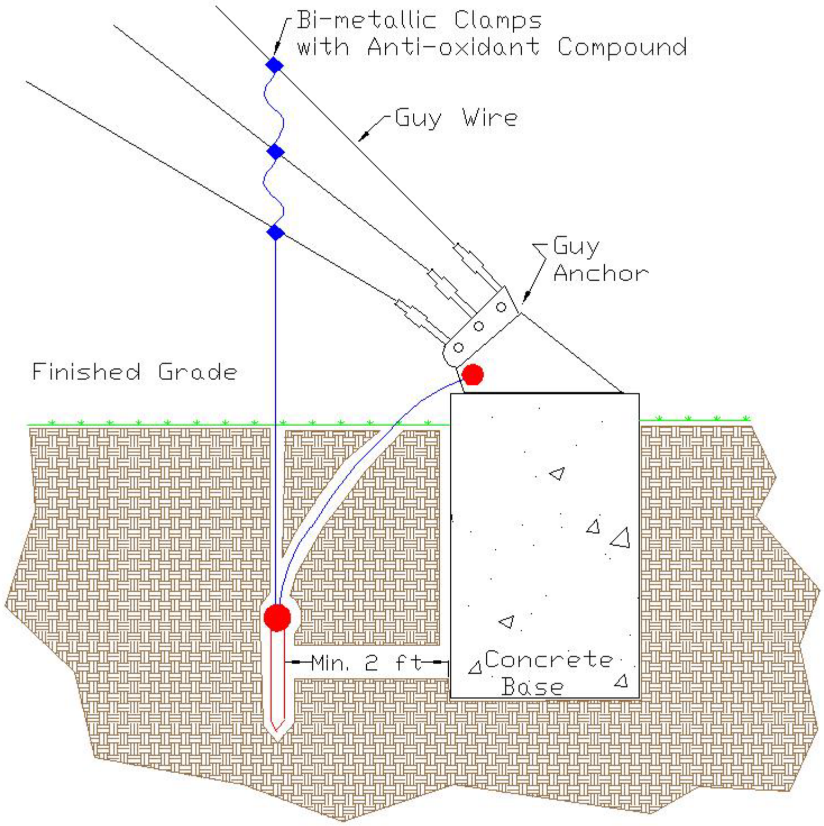
At the guy anchor, you must bond each guy wire to the ground rod using a #2 AWG, or larger, solid or stranded bare **tinned copper** wire conductor. The conductor is connected to each guy wire ahead of the anchor and turnbuckle using a stainless steel or galvanized clamp coated in conductive antioxidant compound. The ground conductor should maintain a continuous vertical drop toward the ground rod. Care should be taken to avoid galvanic corrosion of the guy wires and anchors.

WARNING

**Under no circumstances should an exothermic weld be attempted on a tower guy wire.**

NOTE

In areas where the possibility of tower icing exists, guy wire ice guards, “ice breakers,” may be placed on the guy wire above the ground clamps for protection of both the guy wire grounding and the guy anchor itself.




1 – Two connections to the guy anchor ground rod with #2 AWG or larger tinned bare copper conductor.

2 – One connection from the guy anchor and a separate connection to the guy wires.

3 – Connections below ground should be exothermically welded to the closest ground rod.

4 – Connections to the guy anchor base itself should be exothermically welded if possible.

5 – Connections to the guy wires should only be made with bi-metallic clamps and antioxidant compound, never exothermic welds.

6 – Conductors should be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.

**Figure 4-11: Guy Anchor Ground Detail**

**Figure 4-12: Guy Wire Ground Connections**

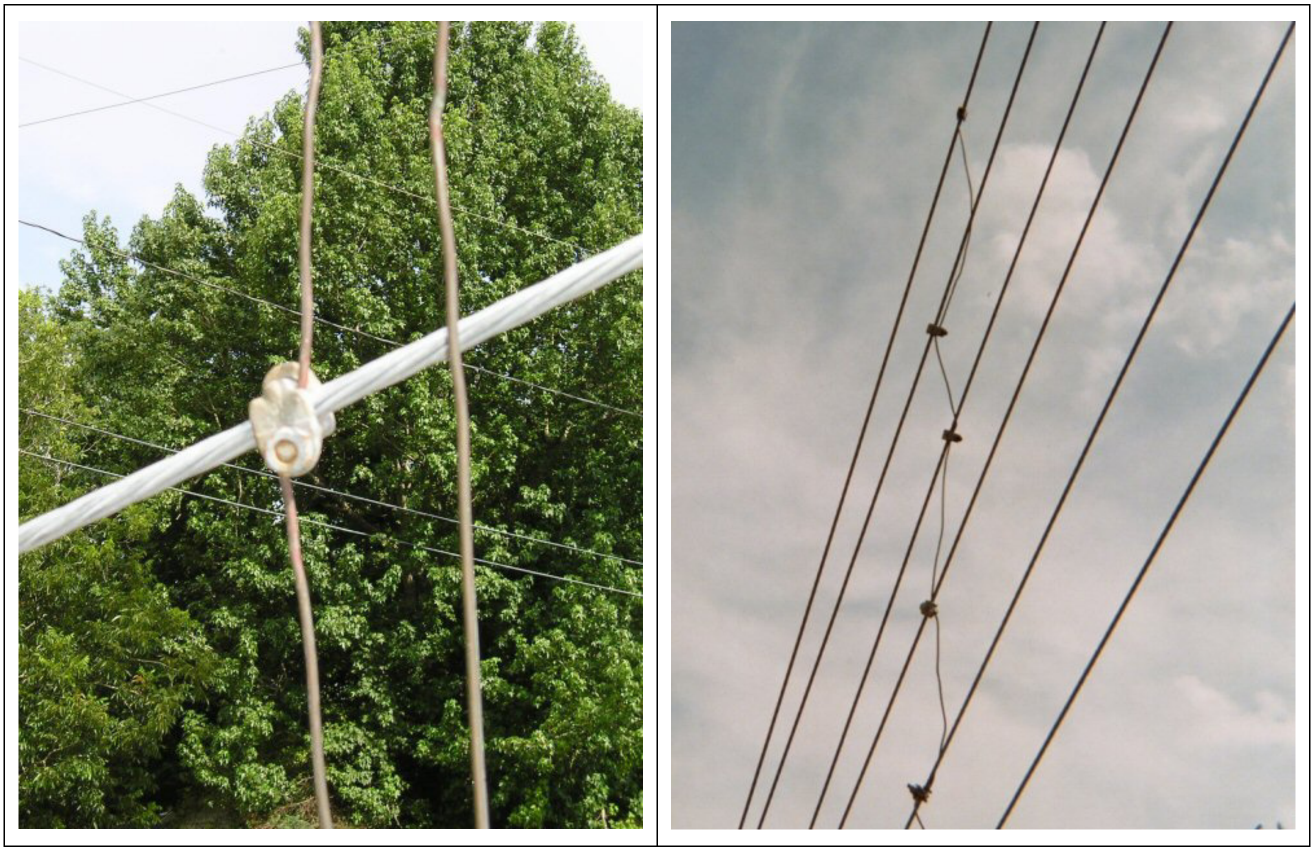


**Figure 4-13: Guy Wire Grounding Connections**

#### 4.2.2.3 Guy Anchor Grounding

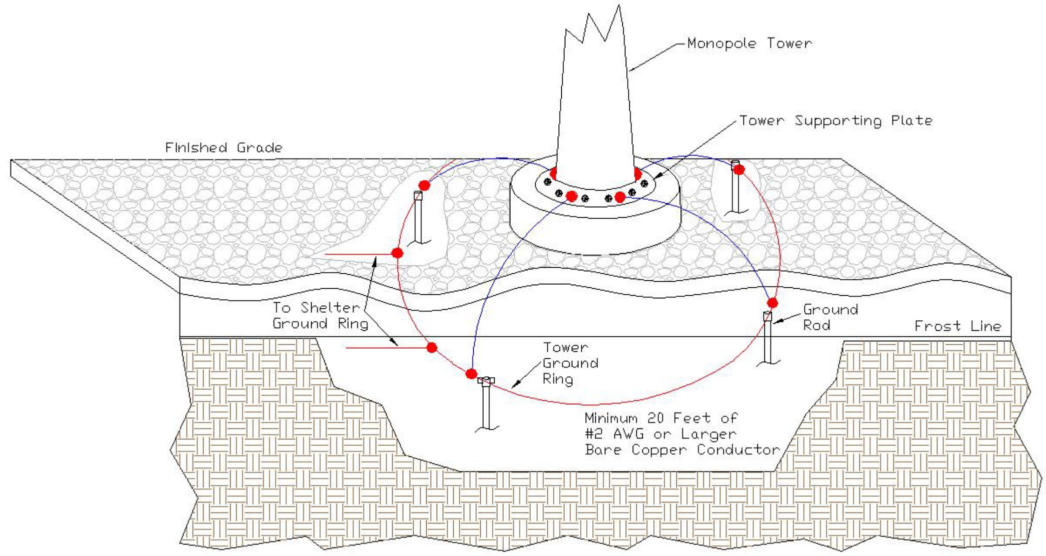
The guy anchor itself should be bonded to the same ground rod as the guy wires attached to the guy anchor. This connection should be made using a #2 AWG, or larger, solid or stranded bare **tinned copper** wire conductor. The connection to the guy anchor should be exothermically welded if allowed by the manufacturer. Otherwise, an irreversible high-compression connection should be made using antioxidant compound. As always, the buried connection to the ground rod should be exothermically welded.

To avoid possible galvanic corrosion, it is not recommended that the guy anchor be in direct contact with the surrounding soil (see Figure 4-11).

### 4.2.3 Monopole Towers

A monopole tower grounding system consists of at least four equally spaced ground rods at the tower base. The ground rods are bonded together to form the tower ground ring. (See Section 3.2.3 and Section 4.1.1.)

Four equally spaced grounding conductors of #2 AWG, or larger, solid or stranded bare tinned copper wire should connect the bottom of the tower to the tower ground ring. All connections to the tower ground ring should go to the closest ground rod and be exothermically welded. Exothermically weld connections to the tower itself if the tower's manufacturer allows and recommends this. Connections to the tower leg must be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.




1 - Four equally-spaced ground rods are bonded together to form the tower ground ring.

2 - Four connections to the tower ground ring with #2 AWG or larger tinned bare copper conductor.

3 - Connections below ground should be exothermically welded to the closest ground rod.

4 - Connections to the tower base itself should be exothermically welded if possible.

5 - Conductors should be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.

**Figure 4-14: Monopole Tower Grounding Detail**

**Figure 4-15: Monopole Tower Ground Connections (Only 2 of 4 Connections Shown)**

### 4.2.4 Antenna Support Structures on Building Rooftops

Rooftop antenna support structures must have a properly designed lightning protection system that meets the National Fire Protection Association, NFPA 780 standards. All bonding conductors should be at least a #2 AWG, or larger, solid or stranded bare tinned copper wire. (See Section 3.2.3 and Section 3.2.4.)

Each antenna support structure leg should be interconnected to form a rooftop tower ring. You should bond the ring on opposite sides to the rooftop ground ring, at a point within two feet of the lightning protection system air terminal grounding down conductor, to a properly grounded building steel, or to another main ground conductor.

In the case of a guyed antenna support structure, the guyed antenna support base should be bonded on opposite sides to the rooftop ground ring within two feet of a lightning protection system air terminal grounding down conductor, to a properly grounded building steel, or to another main ground conductor. The roof-mounted guy anchors should be bonded to the lightning protection ring. (See Section 4.2.2.)

Non-penetrating rooftop sled antenna mounting platforms should be grounded in the same way that a permanent rooftop antenna is grounded.

Radio antenna installations on the tops of buildings must have the tower, down conductors, transmission line shields, and other conducting objects within six feet of the tower or antenna base securely bonded together.

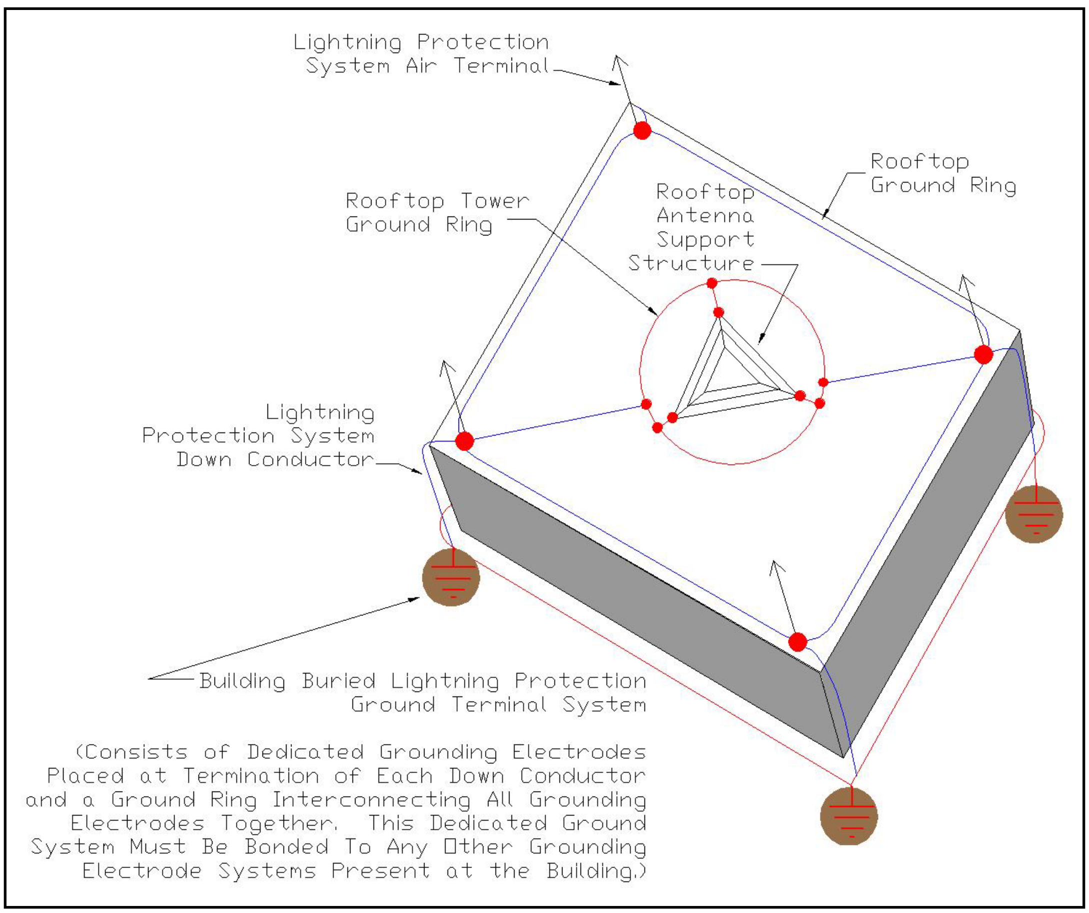



**Figure 4-16: Rooftop Mounted Antenna Structure Grounding**

**Figure 4-17: Example of Antenna Support Structure on Building Rooftop**

### 4.2.5 Wooden Antenna Poles

The proper grounding system for wooden antenna poles consists of two ground rods (minimum) bonded together. (See Section 3.2.1.2 and Section 3.2.3.) You may install additional ground rods to decrease ground resistance. You should bond these ground rods to any ground rods associated with an incoming utility AC service located near the pole or any other ground system present at the site.

A conductor of #2 AWG, or larger, bare solid or stranded copper wire should be run up the pole, away from any other conductors (to avoid possible flashover). You must make connections to the antenna or antenna mast at the top of the pole according to the manufacturer's recommendations. All RF transmission line ground kits installed at the antenna and at the equipment should be connected to the antenna grounding conductor. If a lightning protection air terminal is installed on top of the wooden pole, above the antennas, it should have a separate grounding down conductor that is bonded to the ground rods below finished grade.

We recommend using tower ground bars if more than one antenna is installed on the pole. You should also ground any equipment located near the pole directly to the ground rods using a separate grounding conductor.

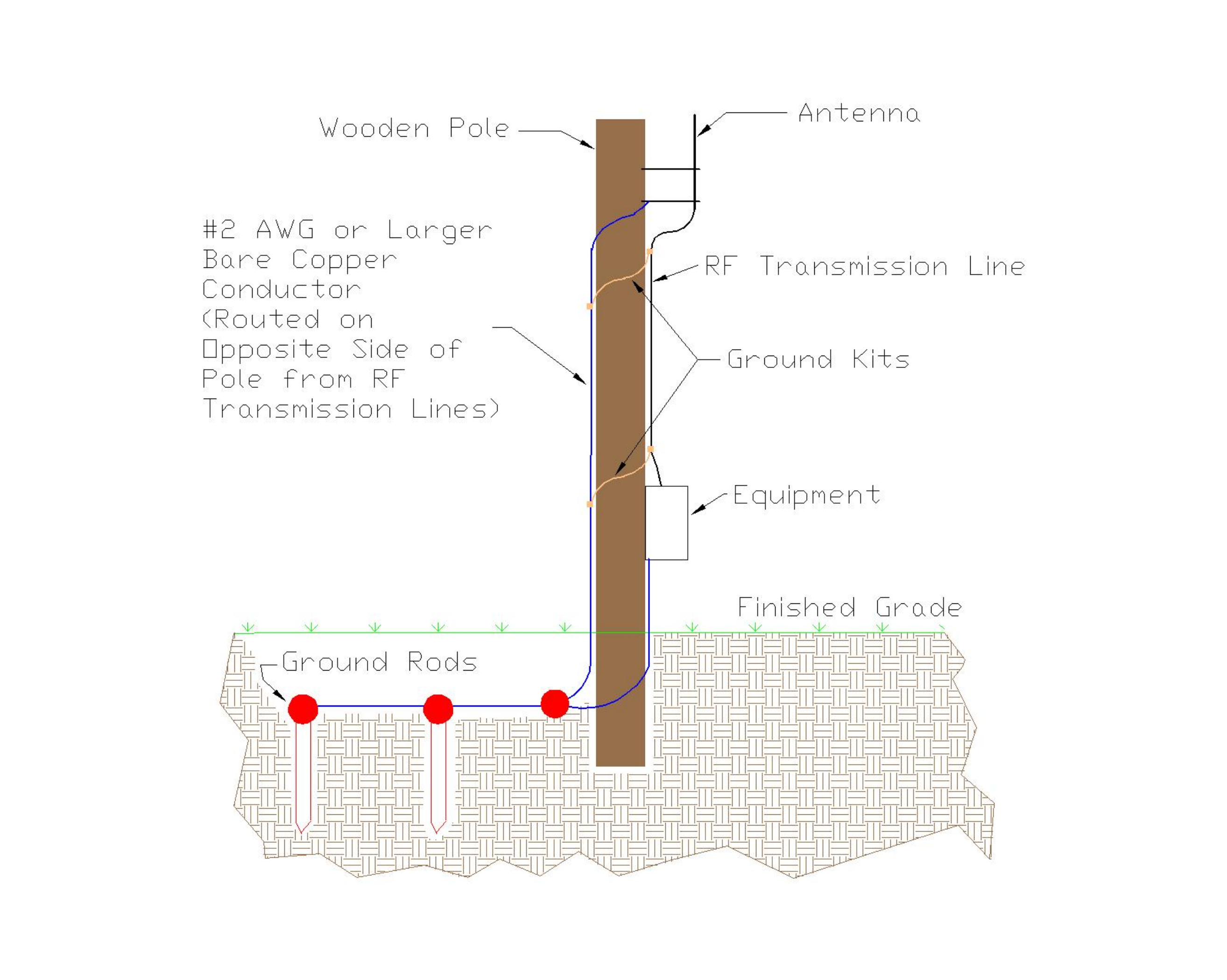
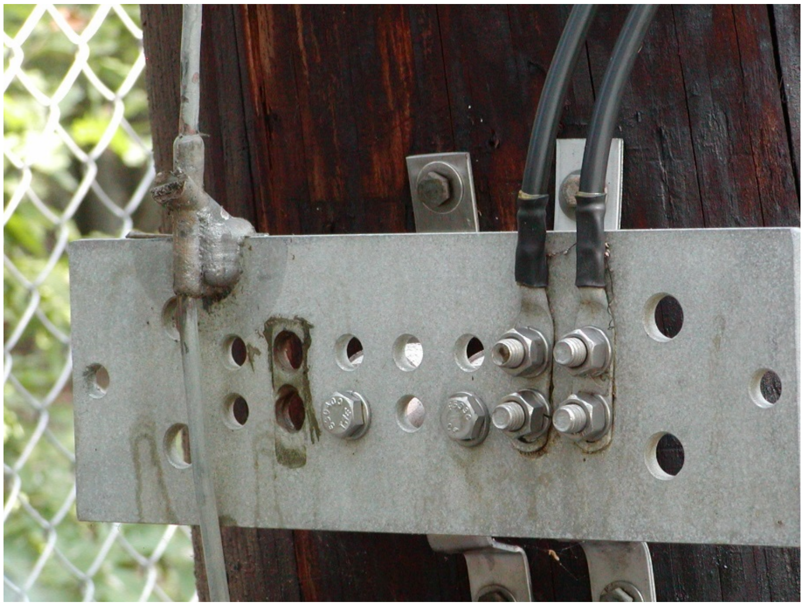
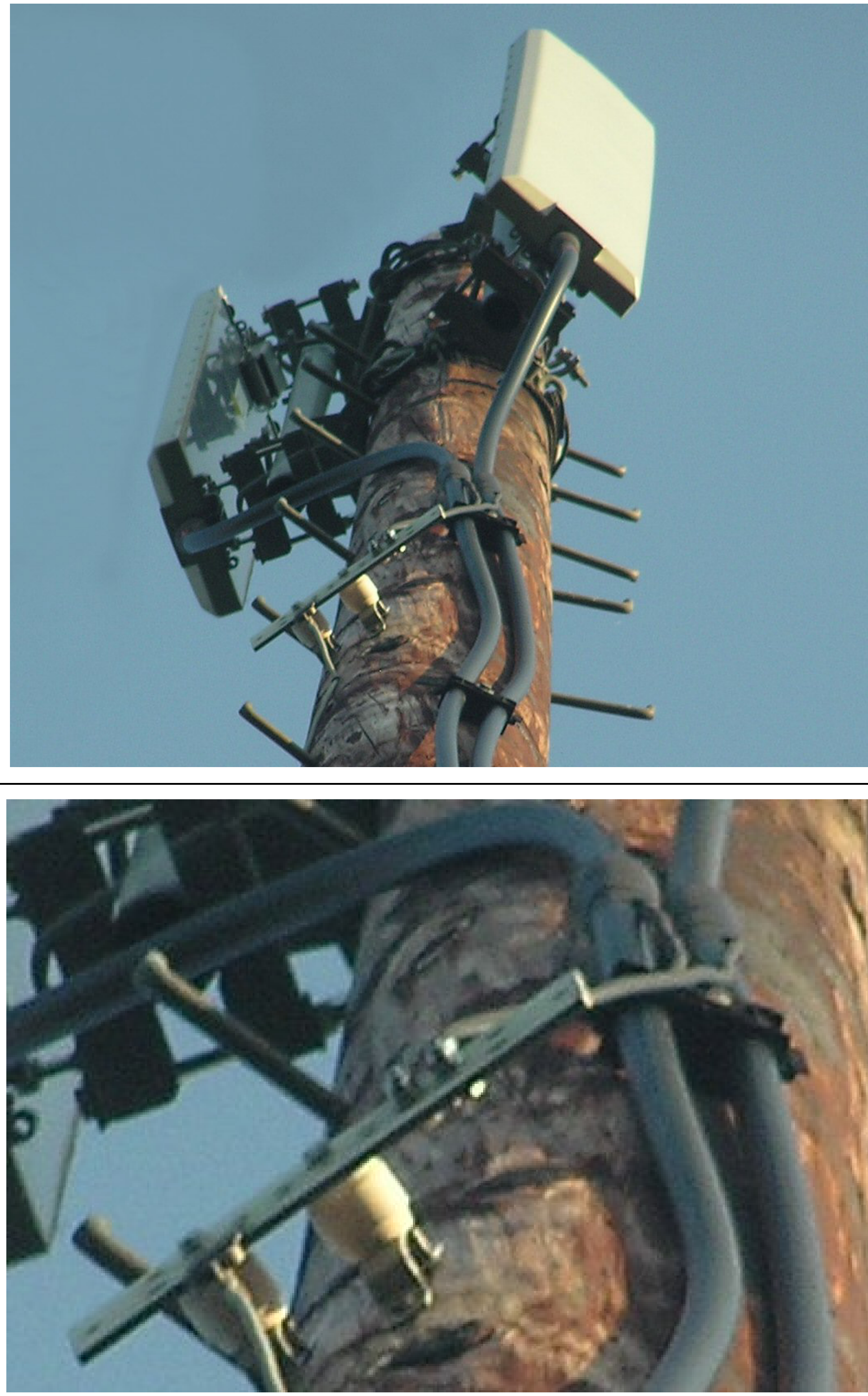



**Figure 4-18: Wooden Pole Grounding Detail**



Detail of wooden pole ground conductor routing and connection to tower ground bar.

**Figure 4-19: Wooden Pole Grounding Example**



Detail of wooden pole tower top ground bar.

**Figure 4-20: Wooden Pole Tower Top Ground Bar Example**

### 4.2.6 Antenna Tower Lightning Protection

All antenna towers or structures should have lightning protection, usually an air terminal. It should be installed at the highest point, ensuring it is higher than the top of any antenna. This reduces the possibility of the antennas being damaged by direct lightning strikes. Any lightning protection installed on a metal tower should be bonded directly to the tower structure. Antennas with a built-in lightning rod may also be used, if the antenna is properly grounded.

The height of the air terminal above the tallest antenna should be greater than the horizontal distance from the top of the tallest antenna to the lightning rod. See Figure 4-21.

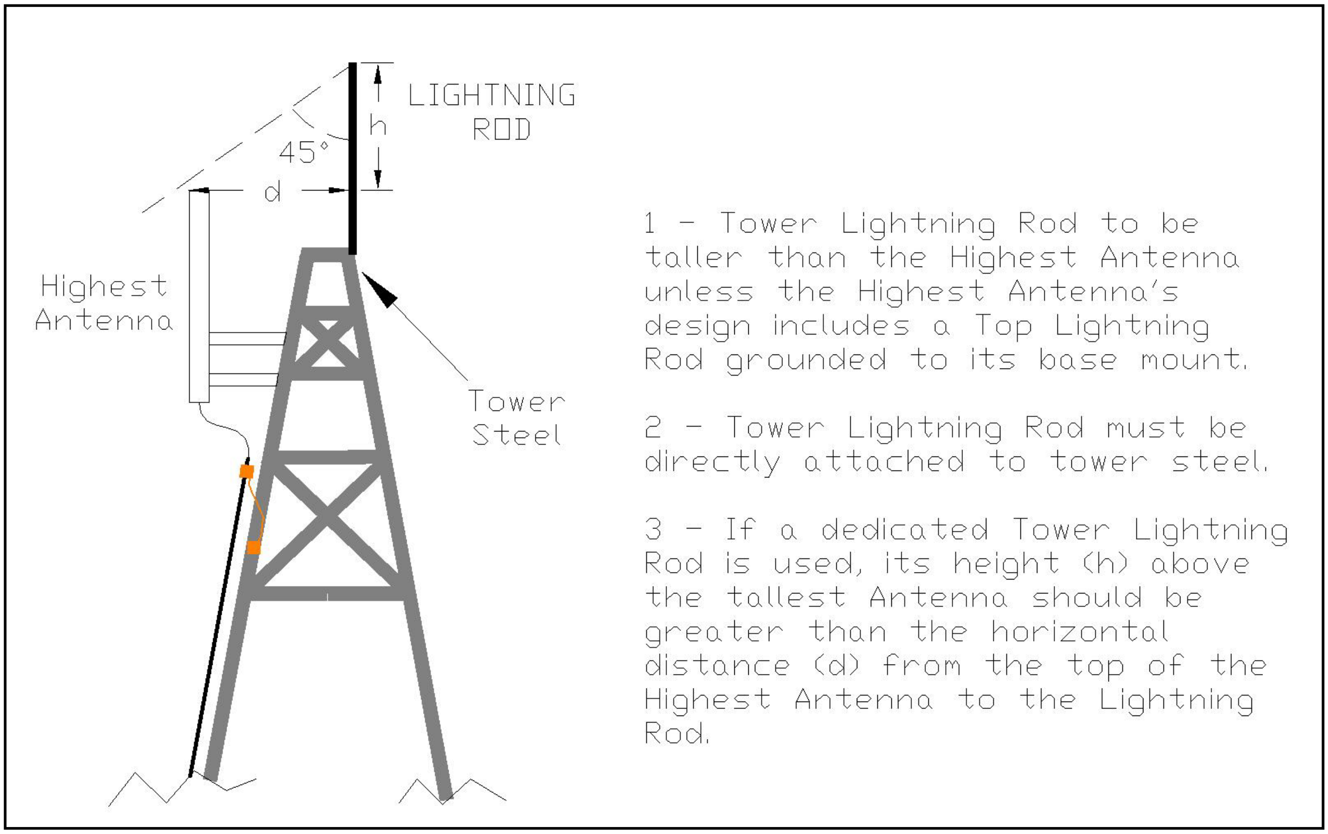



**Figure 4-21: Tower Lightning Rod Height Detail**

On metal towers, a separate down conductor should not be installed from the lightning protection to the ground system. Installing a down conductor the height of the tower would have a higher impedance than the metallic tower structure itself. This could result in damaging the conductor because of arcing between the conductor and the tower in the event of a lightning strike.

However, you must install a down conductor on any non-metallic or non-conductive tower structures, such as wooden poles.

## 4.3 EXTERIOR GROUND BUS BARS

Exterior ground bus bars provide convenient collecting points for RF transmission line grounding kit connections. Ensure the ground bus bars are the proper size with factory pre-drilled holes to accommodate all available grounding conductors. You should connect the bonding conductors using dedicated two-hole lugs and bolts as described in Section 3.2.4.1. You should avoid making multiple connections to the same bolt, if possible.

Exterior ground bus bars should be UL-listed bare copper or electro-tin plated copper at least ¼ inch thick and 2 inches wide. The number of holes (length and width of bar) depends on the number of grounding conductors to be connected. The holes should be properly sized and spaced to accept the two-holed lugs and bolts being used.

NOTE

Harris recommends using tin-plated copper exterior ground bus bars to reduce the risk of copper theft.

Exterior ground bus bars (unless above the base of the tower) should be bonded to the exterior ground ring with at least one exothermically welded #2 AWG, or larger, solid or stranded bare tinned copper conductor. Two conductors are preferred. This conductor should be as straight as possible. The conductor may be routed through a PVC conduit that extends at least 16 inches below grade, this protects the conductor and reduces the step potential on the ground near the conductor.

Exterior ground bars should be bonded to the buried ground ring with the lowest impedance path possible. How low an impedance connection is required between the ground bar and the buried ground ring may be determined by the number of ground connections made to a ground bar and the site's exposure level (that is, the likelihood of a lightning hit and criticality of the site). Bonding an exterior ground bus bar using two conductors bonded to the exterior ground ring is preferred, for both redundancy and lower inductance. The external ground bar conductors should approach the ground ring at a 45 degree angle and in the direction of the nearest grounding electrode.

An even lower impedance connection can be achieved by using 1.5 inch wide solid copper straps. Lightning has many high frequency components that cause current to flow along the "skin" of the conductor. Copper straps are preferred since they have a larger surface area.

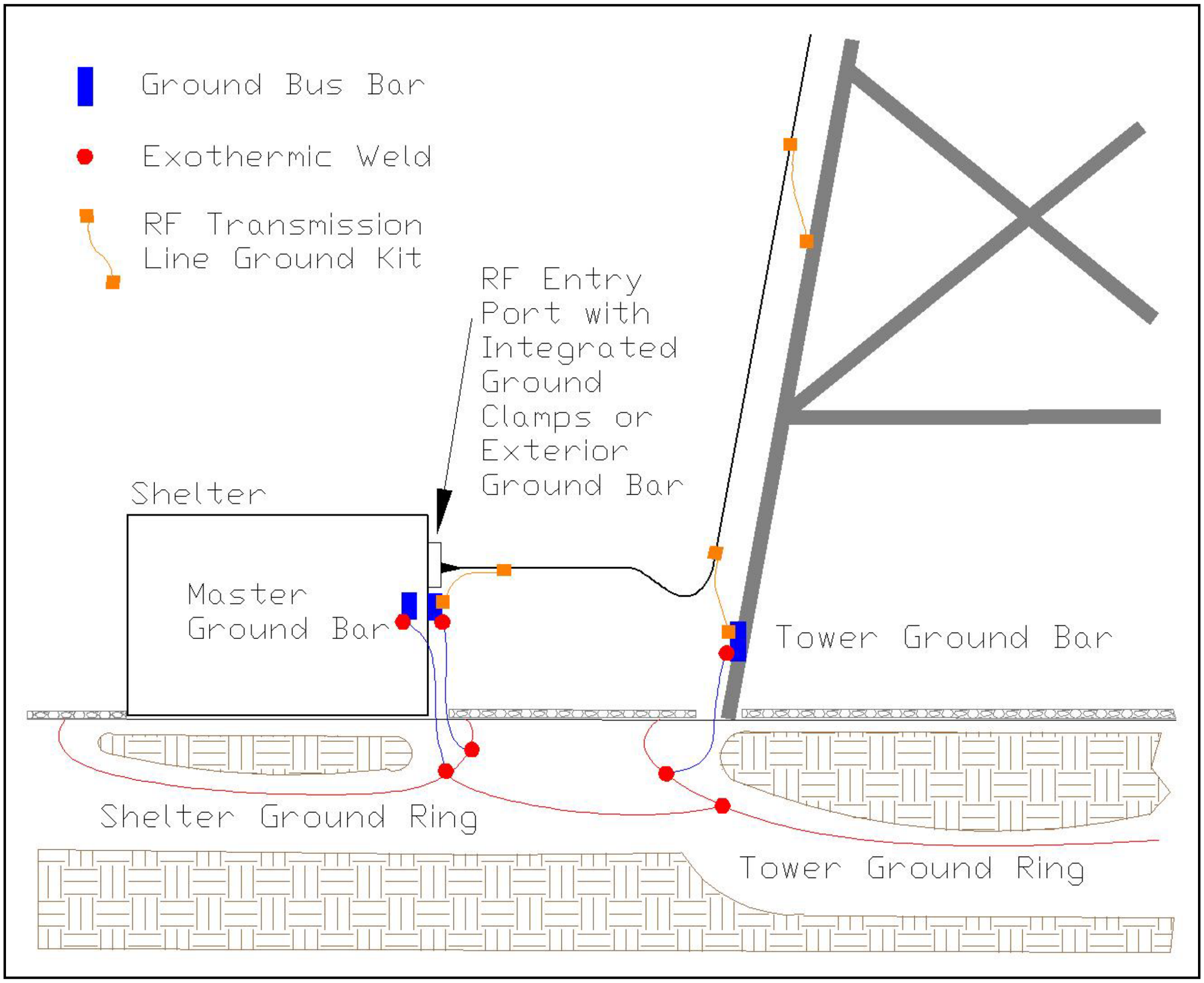



**Figure 4-22: Exterior Ground Bus Bars with Interior MGB Grounding Detail**

### 4.3.1 <u>Tower Ground Bus Bar</u>

A tower ground bus bar should be located on the tower below the point where the RF transmission lines leave the tower. You must bond the tower ground bus bar to the exterior ground ring with at least one #2 AWG, or larger, solid or stranded tinned copper conductor. Two bonding conductors are preferred, and multiple solid copper straps are highly recommended, especially in areas susceptible to a high number of lightning strikes.

You must also bond the tower ground bus bar to the tower. If the bus bar is mounted using insulated standoffs, then you should use a separate conductor to bond the bus bar to the tower. All RF transmission line grounding kits should have a straight path **down** to the tower ground bus bar.

You may install additional tower ground bus bars at the top of the tower below the antennas and at intervals between the top and bottom to provide collecting points for the RF transmission cable ground kit conductors. Bond the additional tower ground bus bars to the tower itself. See Section 4.4 for details on where these additional ground bus bars may be required.

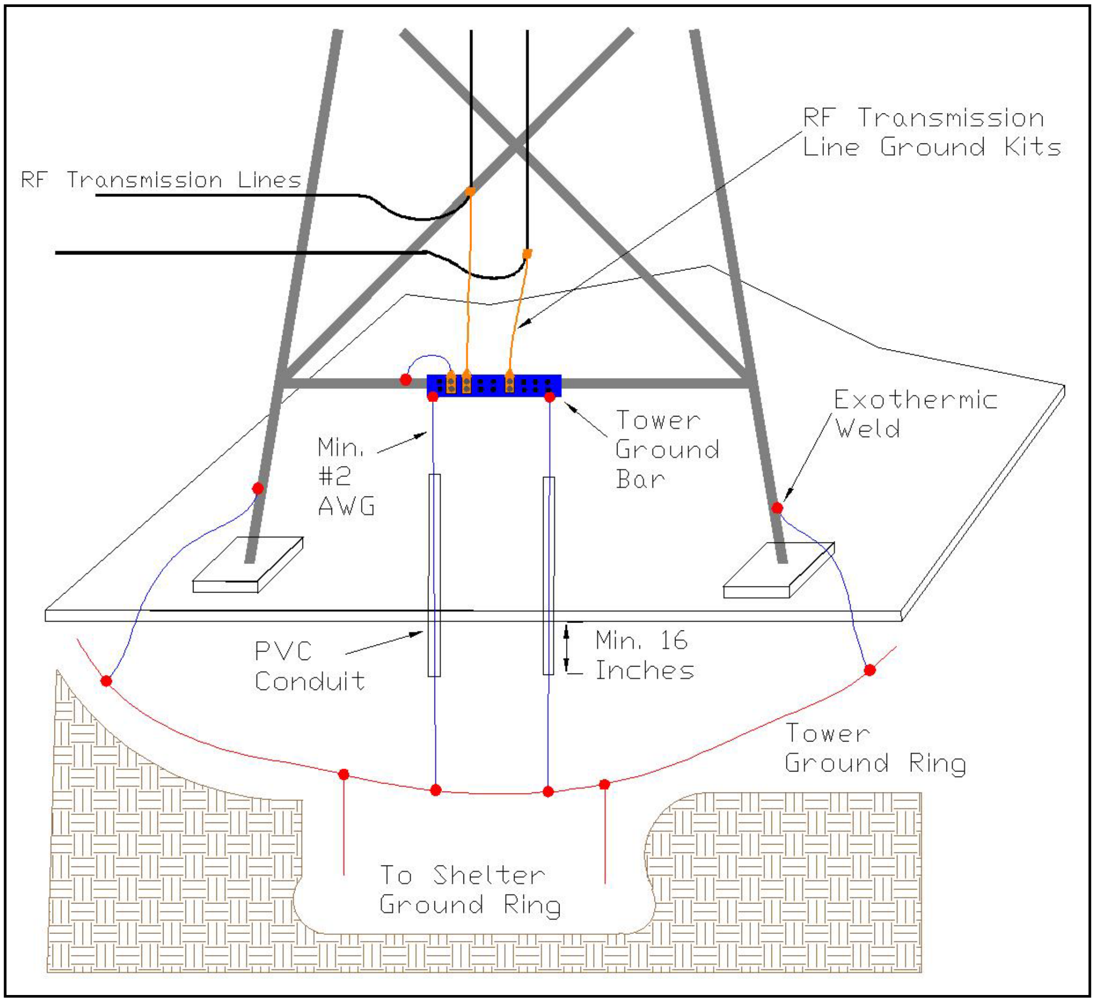



Figure 4-23: Tower Ground Bus Bar Installation Detail

Figure 4-24: Typical Tower Ground Bus Bar

**Figure 4-25: Example of Tower Ground Bus Bar on Monopole Tower**

### 4.3.2 RF Entry Port Grounding Options

All RF transmission lines must have a final ground kit installed within two feet of the shelter RF entry port.

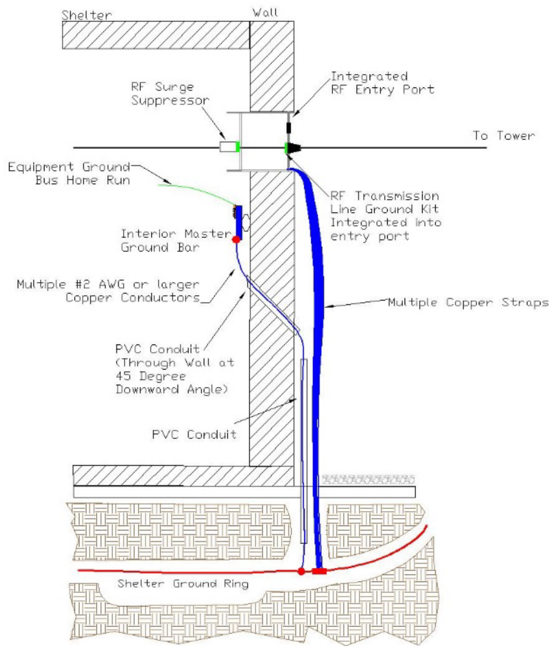
There are multiple RF entry port options available. Some options include entry ports with integrated RF transmission line ground clamps and sometimes grounding or mounting for RF surge suppressors. Other RF entry port options provide only waterproof entry boots that require using a separate shelter Exterior Ground Bar (EGB) for bonding of RF transmission line grounding kits.

While all of these options are effective, some are preferred over others, especially in areas highly prone to lightning. The following two figures depict some of the various options in descending order of preference. The detail drawings in Figure 4-26 (options 1-3) show the preferred RF entry port installation methods for a high profile site or a larger site with many RF transmission cables, especially in areas highly prone to lightning.

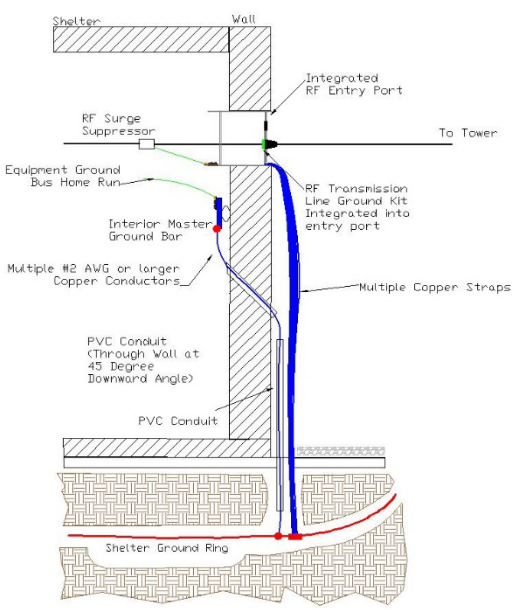
The detail drawings in Figure 4-27 (options 4-6) may be used for smaller low profile sites with few RF transmission cables located in areas with low lightning activity.

NOTE

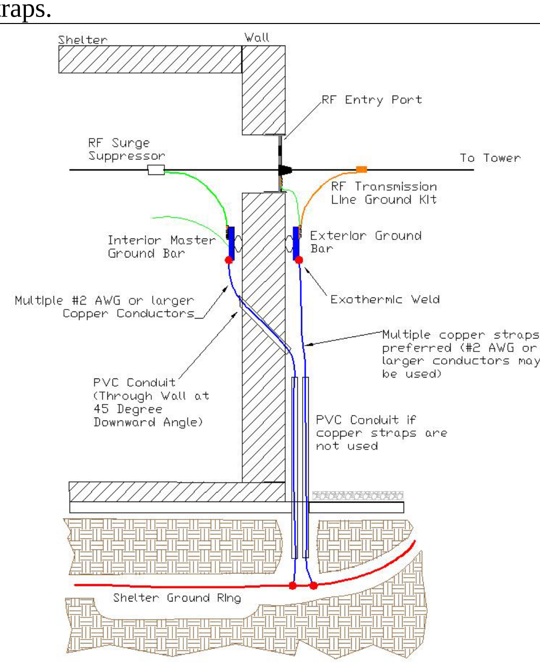
RF surge suppressors should be located inside the shelter or building within two feet of the RF entry port. For equipment rooms located within a larger building, this means the RF SPDs should be located at the cable entrance into the building and not at the equipment room. See Section 6.5 for details.




**Option 1** – RF entry port with integrated ground clamps (no exterior ground bar required) and integrated RF surge suppressor grounding / mounting. RF surge suppressors are mounted directly to RF entry port interior sub panel that provides low inductance ground connection directly to exterior buried ground ring. Separate master ground bar bonded to buried ground ring at same point as RF entry port copper straps.

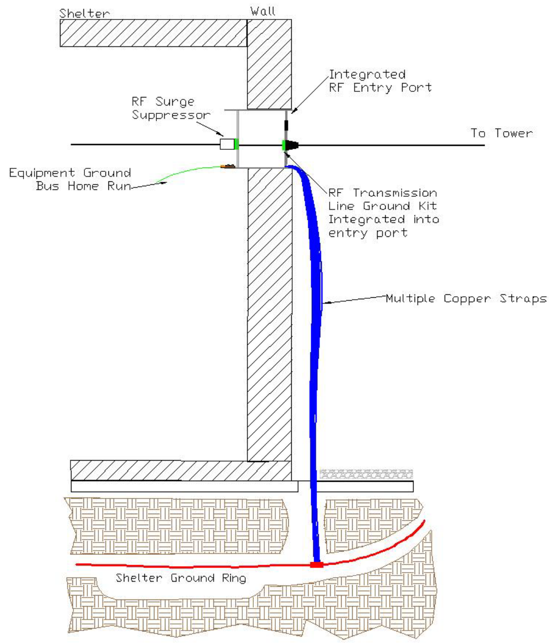



**Option 2** – Same as Option 1, but without integrated RF surge suppressor grounding / mounting. RF surge suppressors are bonded directly to the RF entry port with a two-hole lug.

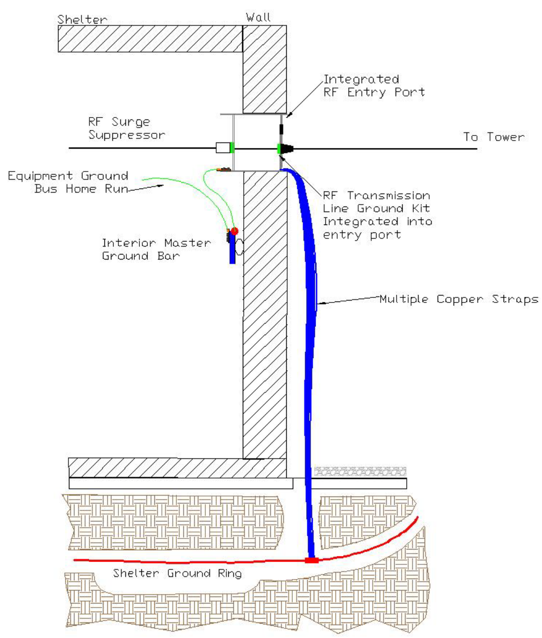



**Option 3** – RF entry port only provides waterproofing. RF transmission cable ground kits installed right before RF entry port and grounded to shelter Exterior Ground Bar (EGB). Separate interior Master Ground Bar (MGB) bonded to buried ground ring at same point as EGB. RF surge suppressors grounded to MGB in PANI surge producers section.

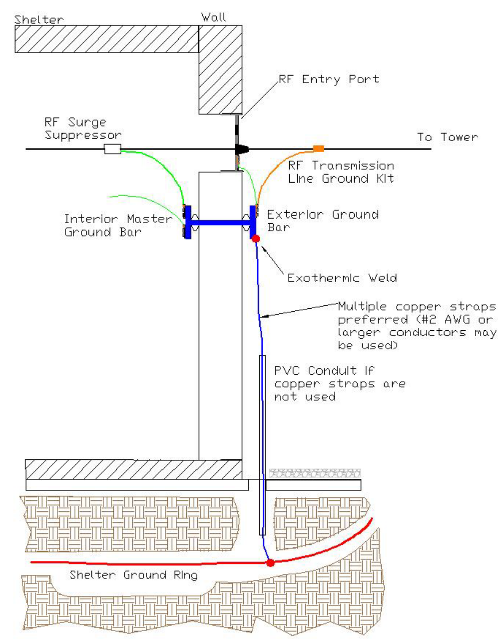
**Figure 4-26: RF Entry Port Installation Detail – Options 1 - 3**




**Option 4** –RF entry port with integrated coaxial ground clamps (no exterior ground bar required) and integrated RF surge suppressor grounding / mounting. No separate master ground bar is installed. All interior shelter ground connections are made back to the RF entry port.




**Option 5** – Same as Option 4, but with a separate interior master ground bar installed to have capacity for more interior ground connections.




**Option 6** – RF entry port only provides weatherproofing. RF transmission cable ground kits installed right before RF entry port and grounded to shelter Exterior Ground Bar (EGB). Separate interior Master Ground Bar (MGB) bonded directly to EGB using through-wall bolts. RF surge suppressors grounded to MGB in PANI surge producers section.

**Figure 4-27: RF Entry Port Installation Detail – Options 4 – 6**

### 4.3.2.1 RF Entry Port with Integrated RF Transmission Cable Ground Clamps

RF entry ports with integrated RF transmission cable ground clamps incorporate the function of the final RF transmission line ground kit and the shelter EGB into their construction. These RF entry ports utilize multiple pre-attached solid copper straps for bonding them to the buried ground system. (See Section 3.2.4.6 for details.) This eliminates the need for a separate EGB and individual cable ground kits at the shelter entry point for RF transmission lines 5/8 inches and larger in diameter.

RF transmission cables less than 5/8 inches in diameter should have a separate ground kit installed. You should ground this ground kit to the exterior of the RF entry port. An additional piece of copper bus bar may be bolted to the outside of the RF entry port to provide connection locations for the separate ground kits.

Some RF entry ports with integrated ground clamps also provide integrated grounding and mounting for the RF surge suppressors located just inside the shelter. These are highly recommended especially in areas highly prone to lightning. (See Section 5.3 for details.)

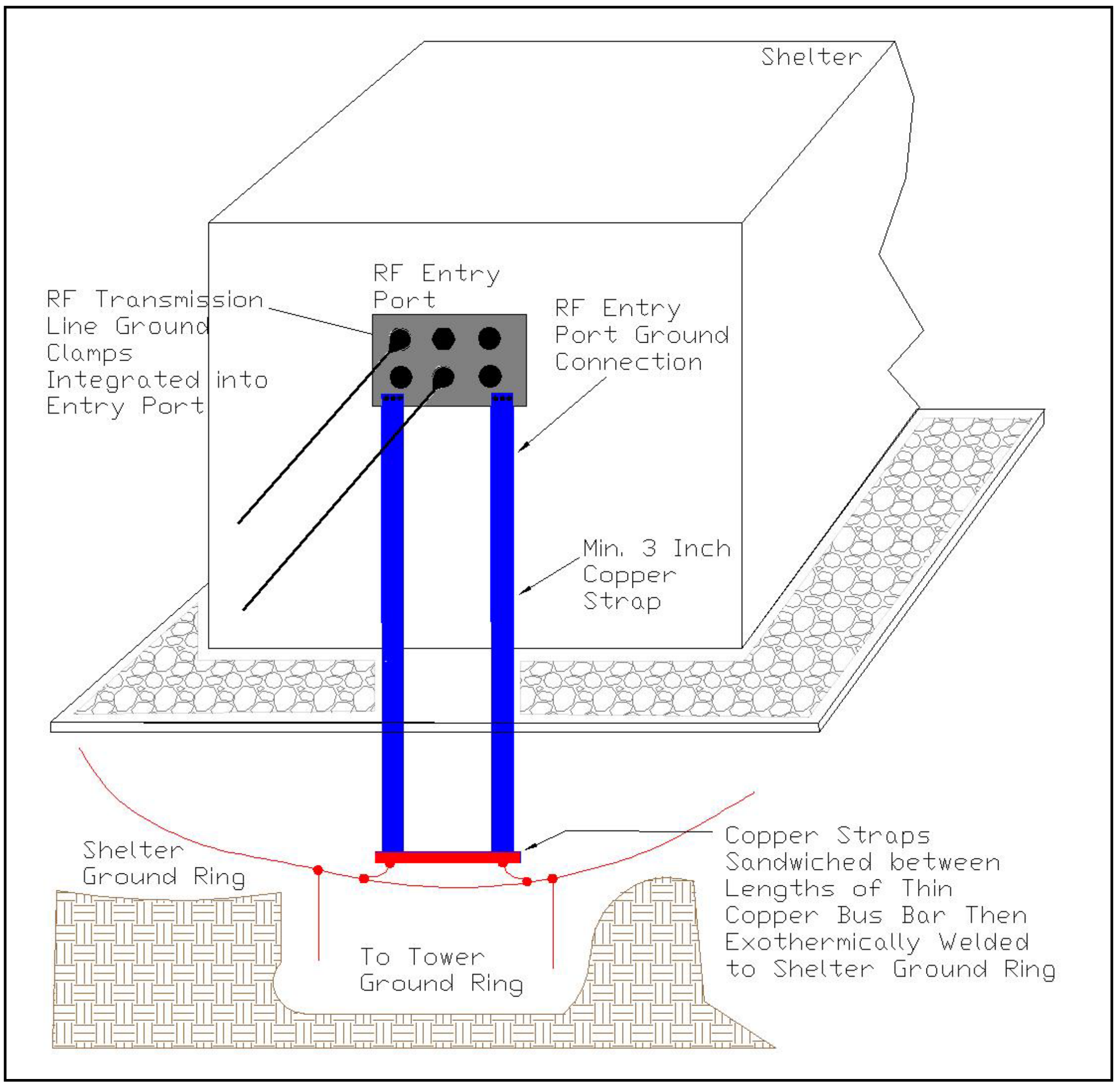



**Figure 4-28: RF Entry Port with Integrated Ground Clamps Detail**

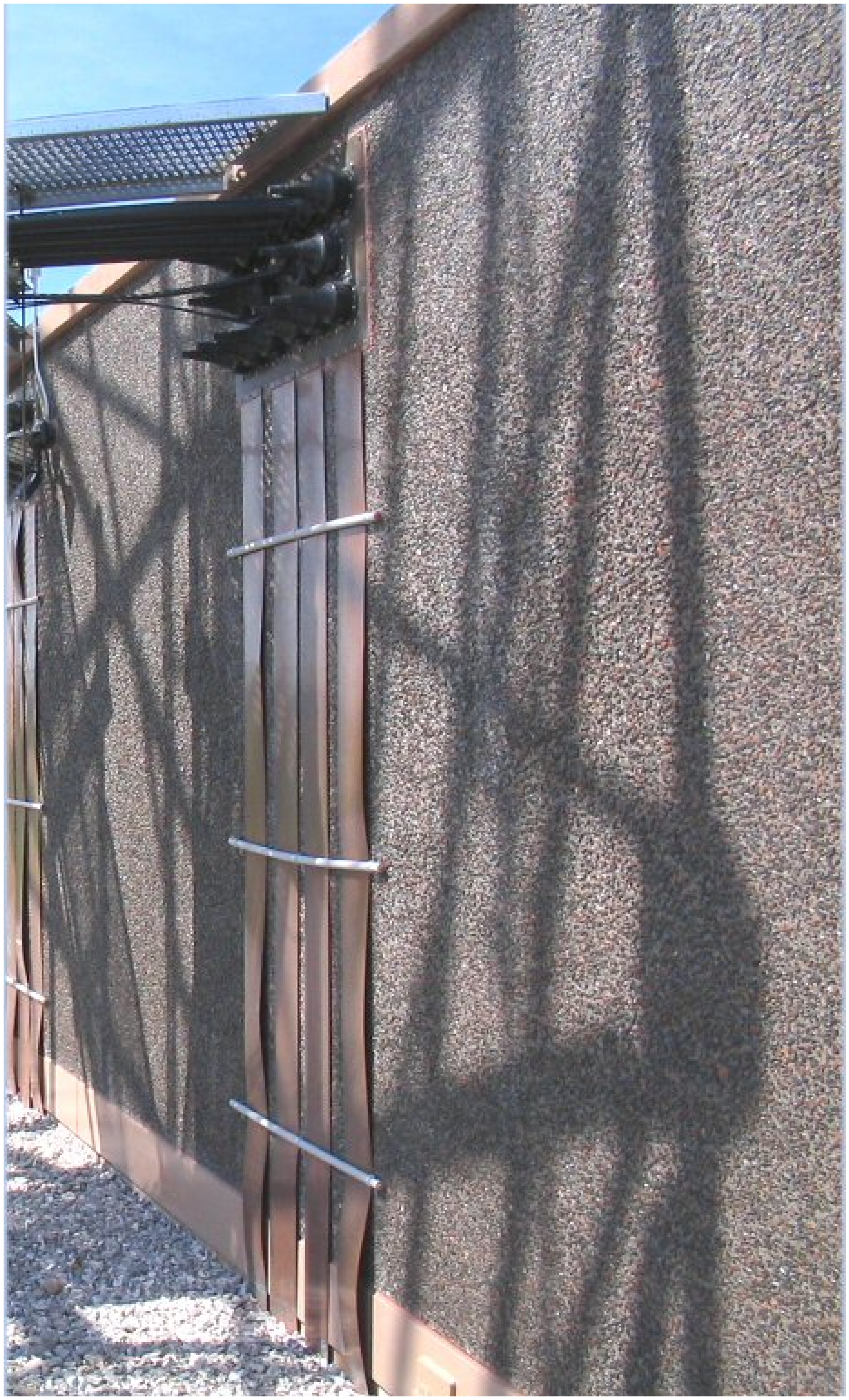


Figure 4-29: RF Entry Port with Integrated Ground Clamps and Ground Straps

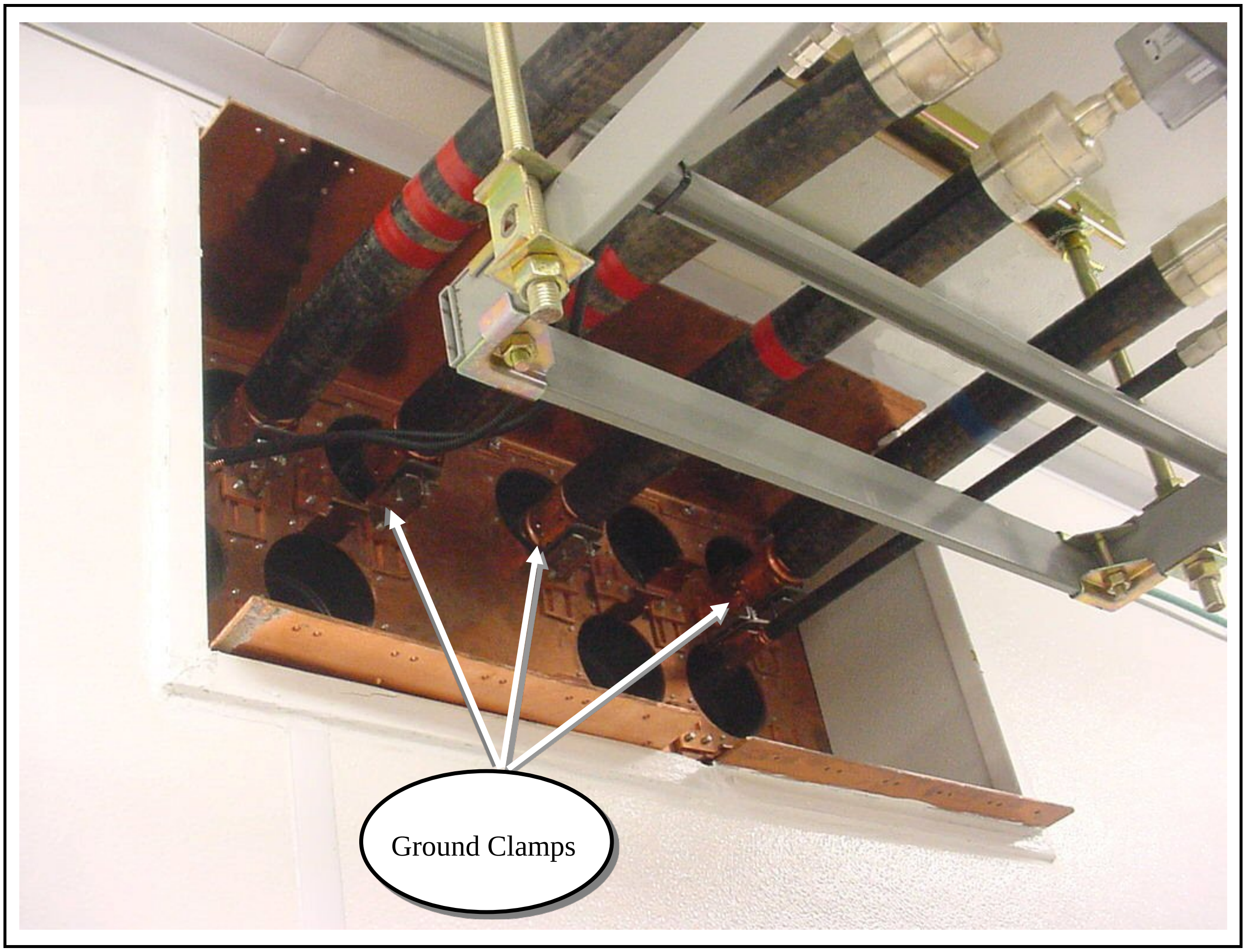



**Figure 4-30: RF Entry Port with Integrated Ground Clamps, Interior View**

#### 4.3.2.2 Equipment Shelter Exterior Ground Bus Bar

If the RF entry port does not have integrated ground clamps, an EGB should be located on the equipment shelter exterior wall below the point where the RF transmission lines enter the equipment shelter at the RF entry port. You must bond this shelter EGB to the shelter exterior ground ring with at least one #2 AWG, or larger, solid or stranded tinned copper conductor. Two conductors are preferred for redundancy and lower inductance.

This conductor from the external ground bar to the buried ground system should be as straight as possible. The conductor may be routed through a PVC conduit that extends at least 16 inches below grade. This will protect the conductor and reduce the step potential on the ground near the conductor.

Multiple solid copper straps may be used for a lower inductance path in lightning prone areas or for at high-density sites.

The shelter exterior ground bus bar should be located so all RF transmission lines grounding kits have a smooth large radius bend **down** to it. Bond the RF entry port's metallic frame to the EGB with a #2 AWG copper conductor using two-hole lugs.

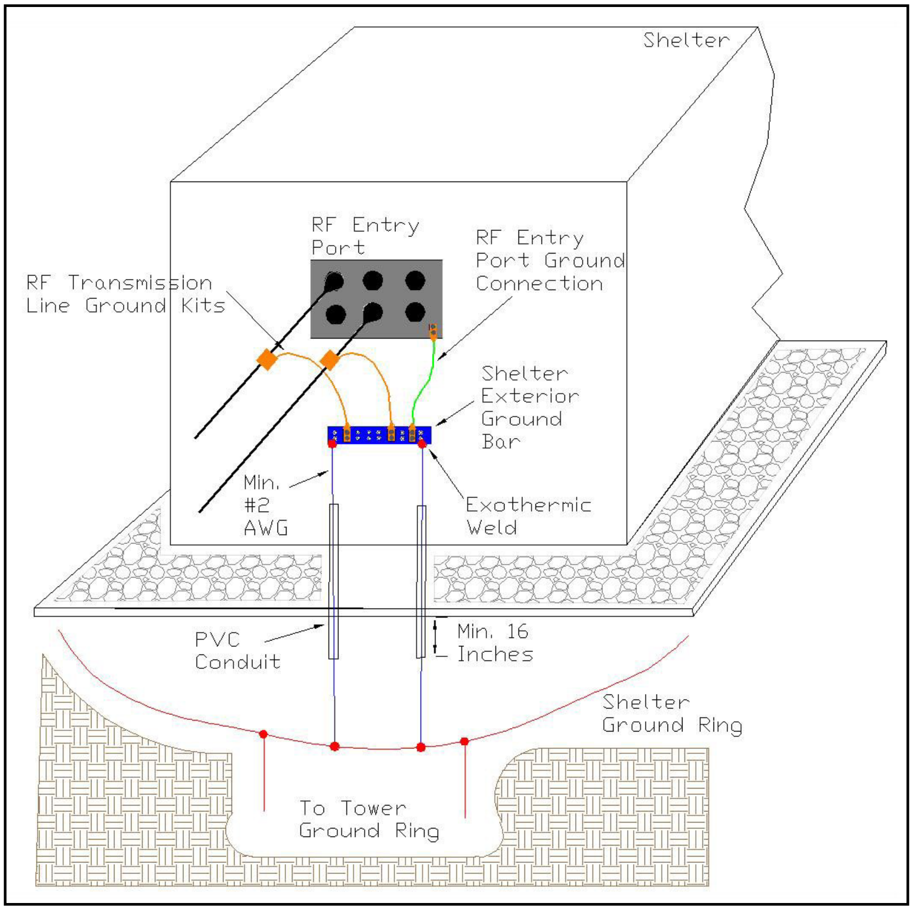



**Figure 4-31: Exterior Equipment Shelter Ground Bus Bars Installation Detail**

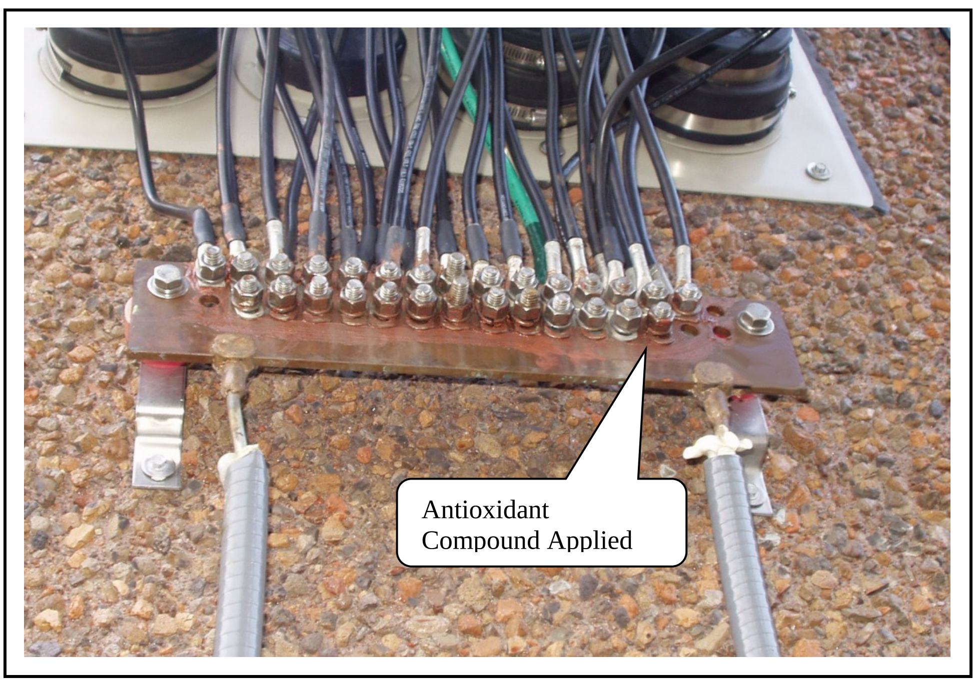



**Figure 4-32: Typical Exterior Ground Bus Bar and RF Entry Port**

**Figure 4-33: Exterior Ground Bus Bar and RF Entry Port Example**

### 4.3.3 Shelter Interior Master Ground Bar Bonding to Exterior Ground Ring

This section provides information for connecting the interior Master Ground Bar (MGB) to the exterior ground ring. This is considered part of the exterior grounding function, since it is a connection to the buried exterior shelter ground ring.

The equipment shelter interior MGB is **the single point ground** for all equipment and metallic objects located inside the shelter. You should not make any other connections to the exterior ground system from inside the shelter.

The MGB should be located on the shelter's interior wall below and within 2 feet of the RF entry port. You should bond the MGB directly to the shelter's buried exterior ground ring with at least one #2 AWG, or larger, solid or stranded tinned copper conductor in close proximity to the point where the shelter exterior ground bar or RF entry port was bonded. You should exothermically weld the conductor to both the MGB and the exterior ground ring.

The conductor should be routed straight down the wall then to the exterior through a PVC feed-through. The feed-through should be installed in the wall at a 45 degree downward angle at least 1 foot above grade. A minimum-bending radius of 8 inches should be observed. Once outside the wall, the conductor may be routed through a PVC conduit that extends at least 16 inches below grade to both protect the conductor and reduce the step potential on the ground near the conductor.

Refer to Figure 4-26 for details.

In areas highly prone to lightning or if more than eight RF surge protectors will be grounded to the MGB, reducing the impedance of the MGB's connection to the exterior ground ring is recommended. There are many ways to do this, but four approaches are discussed below in decreasing order of preference:

- Use one or more #3/0 or #4/0 AWG copper welding cables as the bonding conductor.

  This size welding cable has a similar inductance to a 3 inch wide copper strap, but it still allows the use of a clamp-on ground test meter and is easier to route through the wall.

- Use one or more at least 3 inch wide copper straps for bonding.

  This gives a lower inductance connection, but a clamp-on ground test meter can no longer be easily used to verify ground resistance measurements. Making a weatherproof penetration through the shelter wall may also be an issue.

- Use two #2 AWG, or larger, copper conductors for bonding.

  This gives both a lower inductance connection and redundancy. If two conductors are used, they should be exothermically welded to the MGB next to each other about half way across the ground bar and go through the wall to be bonded to the shelter ground ring. If the two conductors are exothermically welded to opposite ends of the MGB, then they should gently angle toward each other before going through the wall, in a single PVC feed-through, to the outside. This approach still allows for easy testing of the ground system with a clamp-on ground test meter.

- Use a single copper conductor larger than a #2 AWG for bonding.

  This approach still allows using a clamp-on ground test meter.

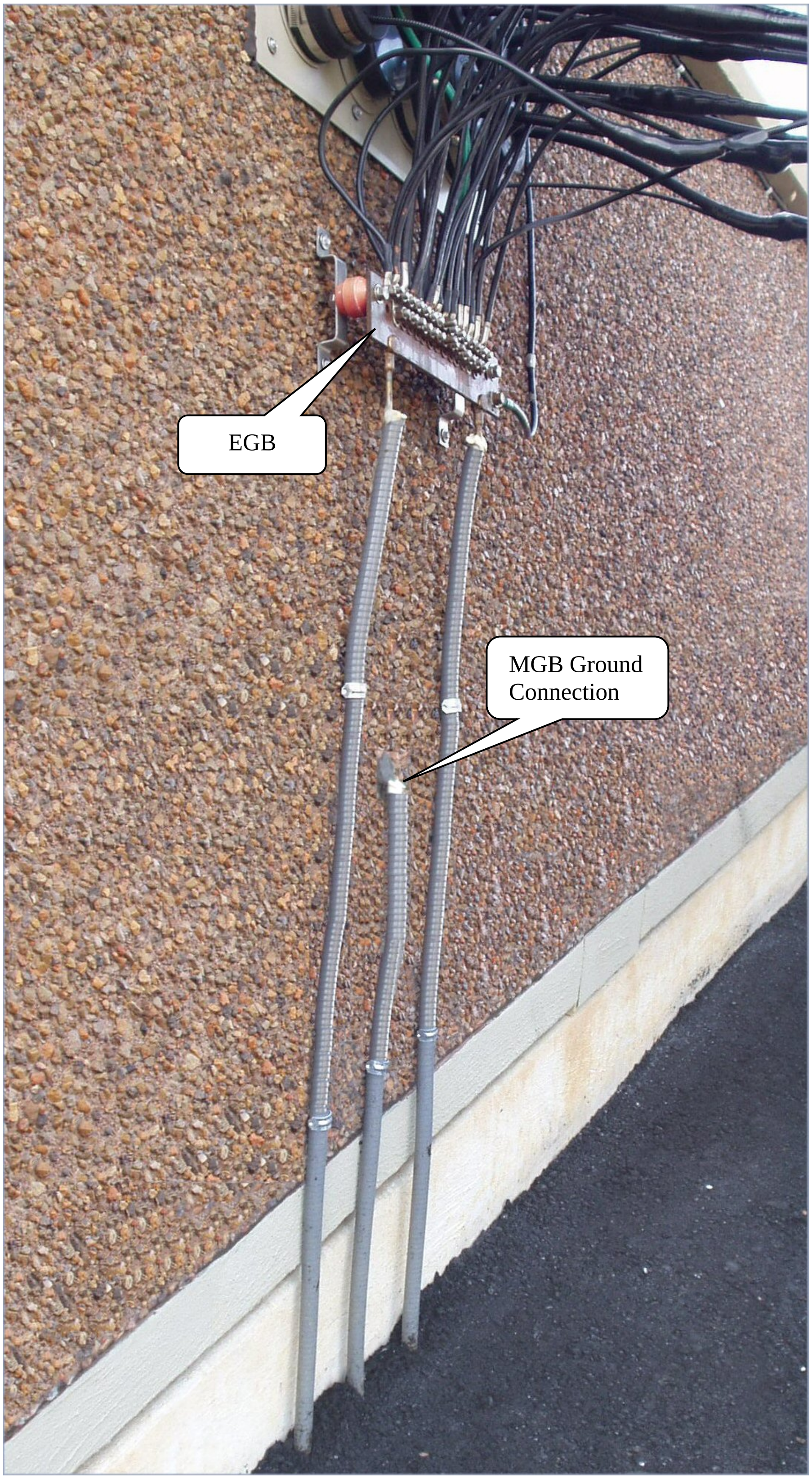



**Figure 4-34: Exterior View of MGB and EGB Connections to Shelter Ground Ring**

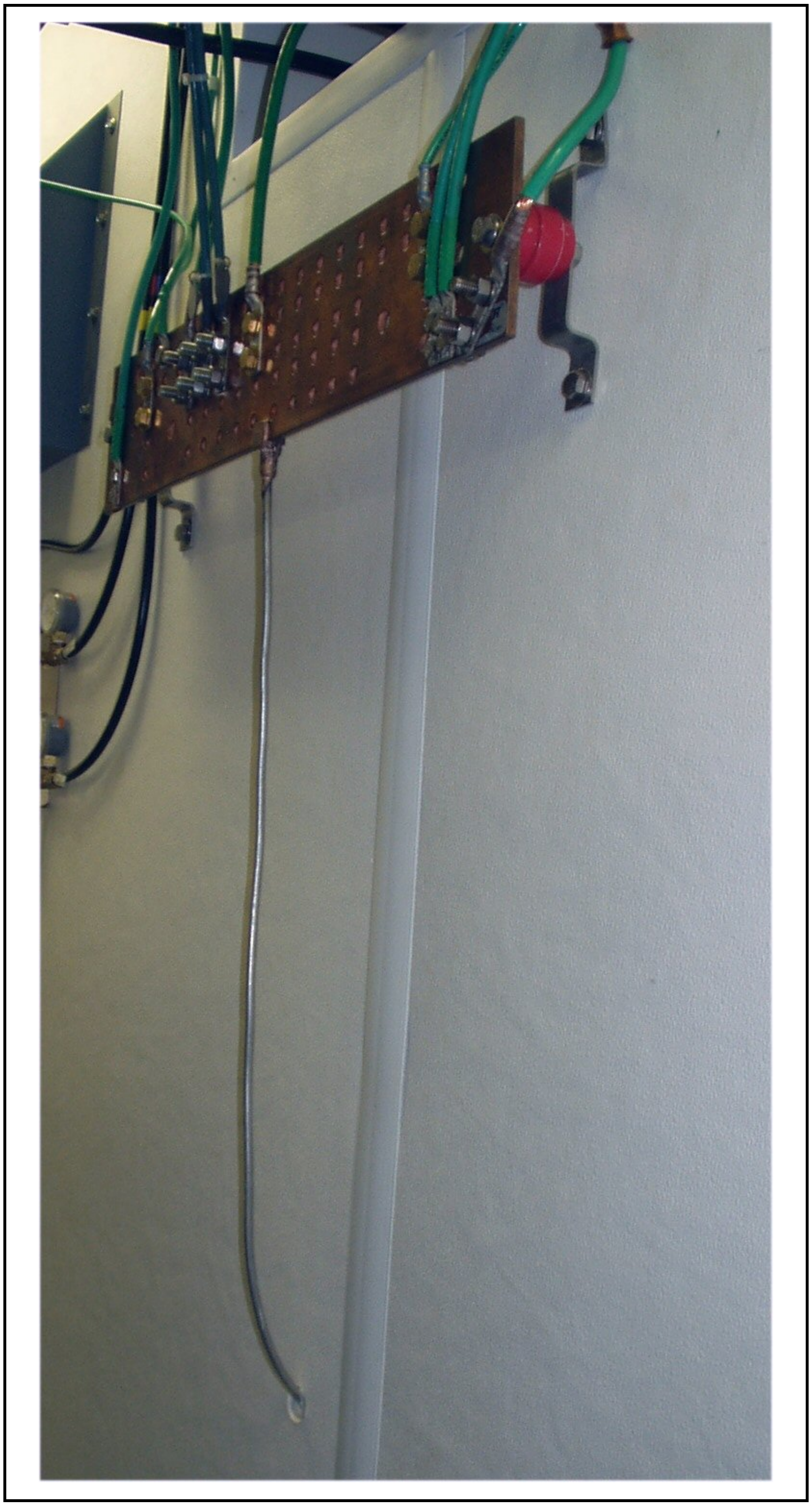


**Figure 4-35: Interior View of Conductor Connecting MGB to Buried Ground Ring**

## 4.4 RF TRANSMISSION LINES

This section applies to the antenna transmission lines outside the communications shelter or building. These requirements do not apply to antenna transmission lines that are contained entirely within the equipment room or communications shelter.

You must ground the outer conductors of coaxial RF transmission cables using appropriate coaxial cable grounding kits. This prevents damaging arcs between the coaxial cables and the tower resulting from the buildup of voltage potentials during a lightning event. It also helps to shunt induced current off the cable ground shield. In all cases, you should install the grounding kit parallel to the RF transmission cable and above the point where it is grounded, so current flow will be toward the ground.

You must install lightning protection grounding kits on each coaxial RF transmission line at three points on the cable (minimum). Install a lightning protection grounding kit:

1. At the top of the vertical cable run (termination) or at the antenna. Ground or bond this point to the tower using the clamp supplied with the grounding kit or to a tower ground bar, if available, using a two-hole lug and conductive antioxidant compound.

2. At the bottom of the vertical run of the cable, at a point not more than 6 feet above the bend onto the ice-bridge or cable support tray toward the equipment shelter. Ground this point to the lowest tower ground bus bar using a two-hole lug and conductive antioxidant compound. This grounding point must be as near to the ground as possible.

3. Immediately outside (within 2 feet) of the cable entrance to the equipment shelter or building. Ground this point to the equipment shelter exterior ground bus bar using a two-hole lug and conductive antioxidant compound. (If the RF entry port has integrated transmission line ground clamps, these clamps satisfy this requirement for RF transmission lines 5/8 inches or larger.) This ground must be located before the RF lightning surge suppressor.

NOTE

You should install additional grounding kits along the vertical run to limit the distance between grounding kits to 75 foot intervals. In lightning prone areas, we recommend decreasing this interval to 50 feet.

Terminate coaxial cable grounding kits using a two-holed lug. Ground all points in accordance with the manufacturer's recommendations and ensure they are fully waterproofed.

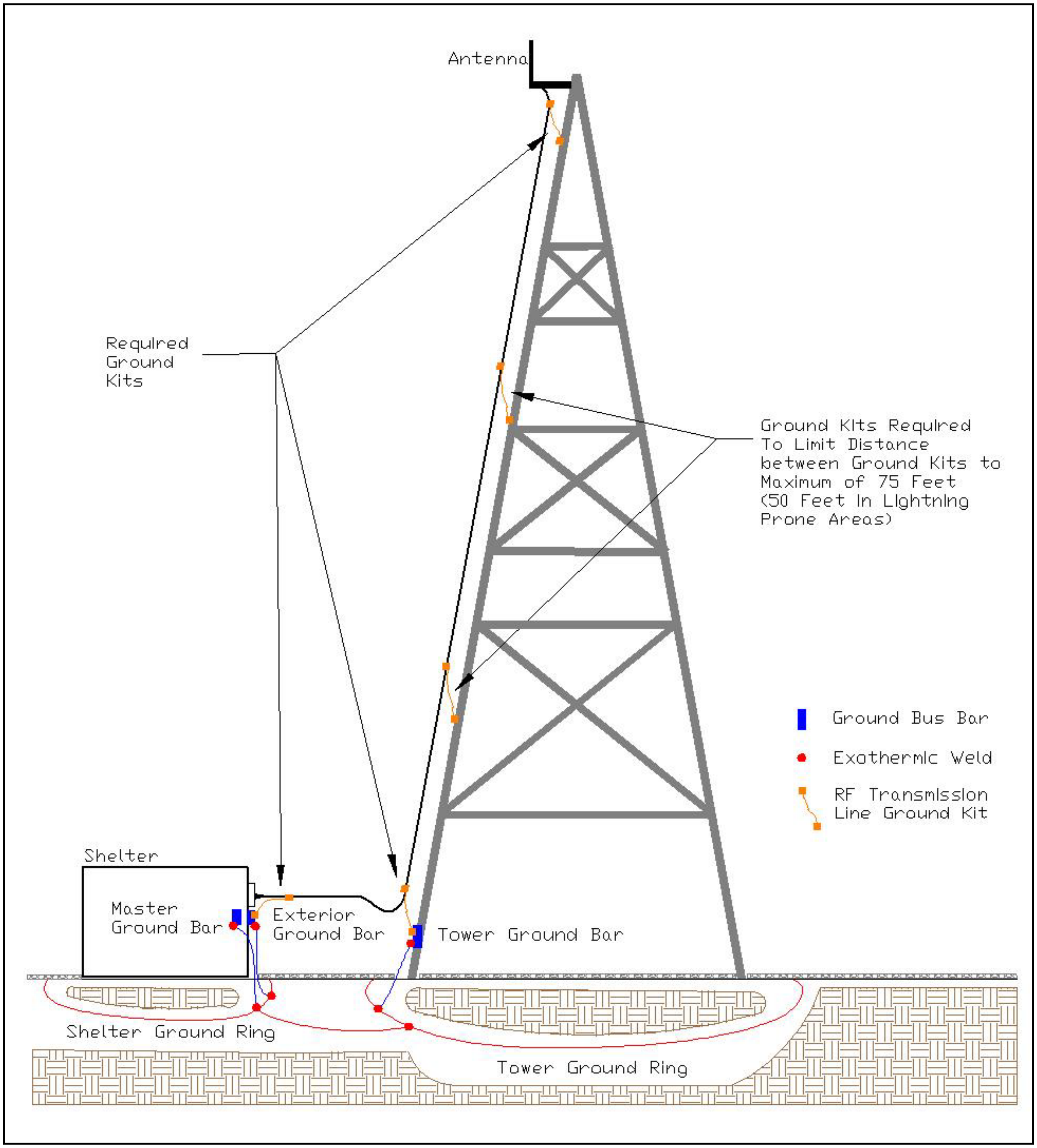



**Figure 4-36: RF Transmission Cable Ground Kit Locations**

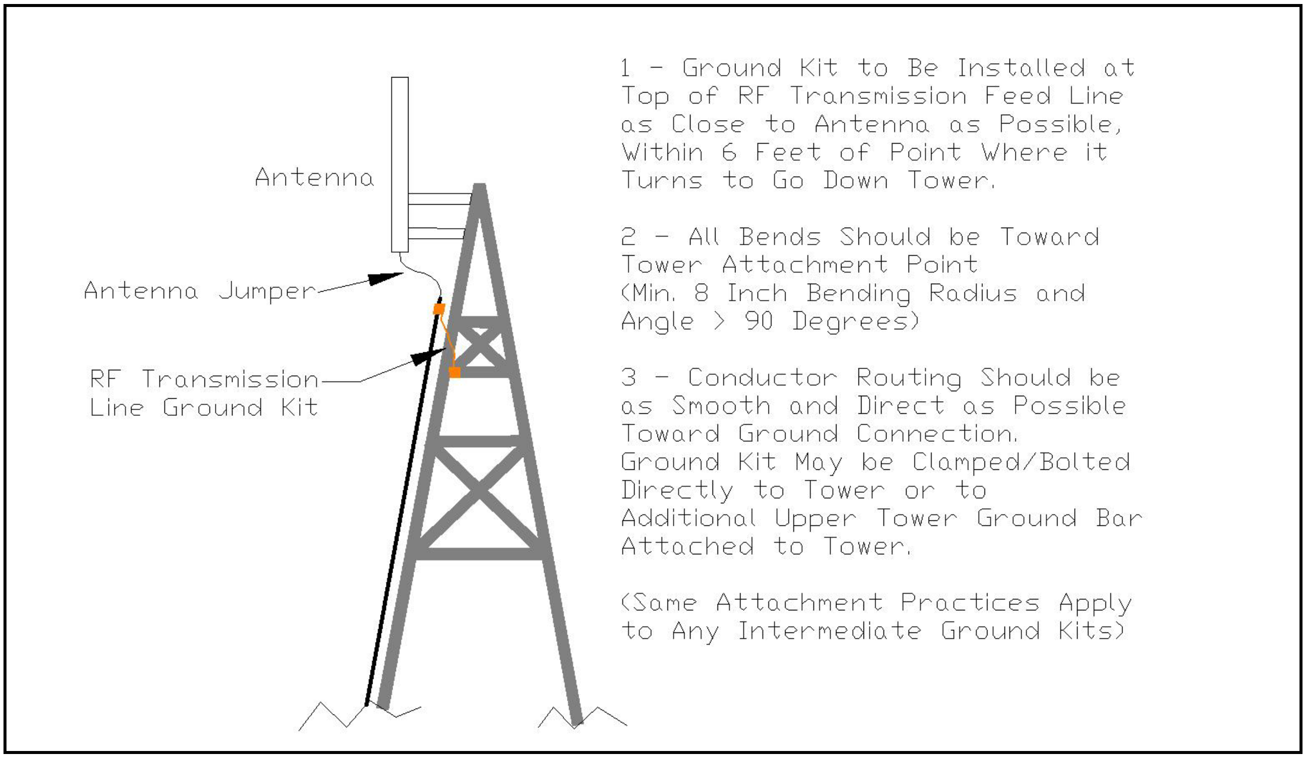



**Figure 4-37: Tower Top RF Transmission Line Ground Kit Detail**

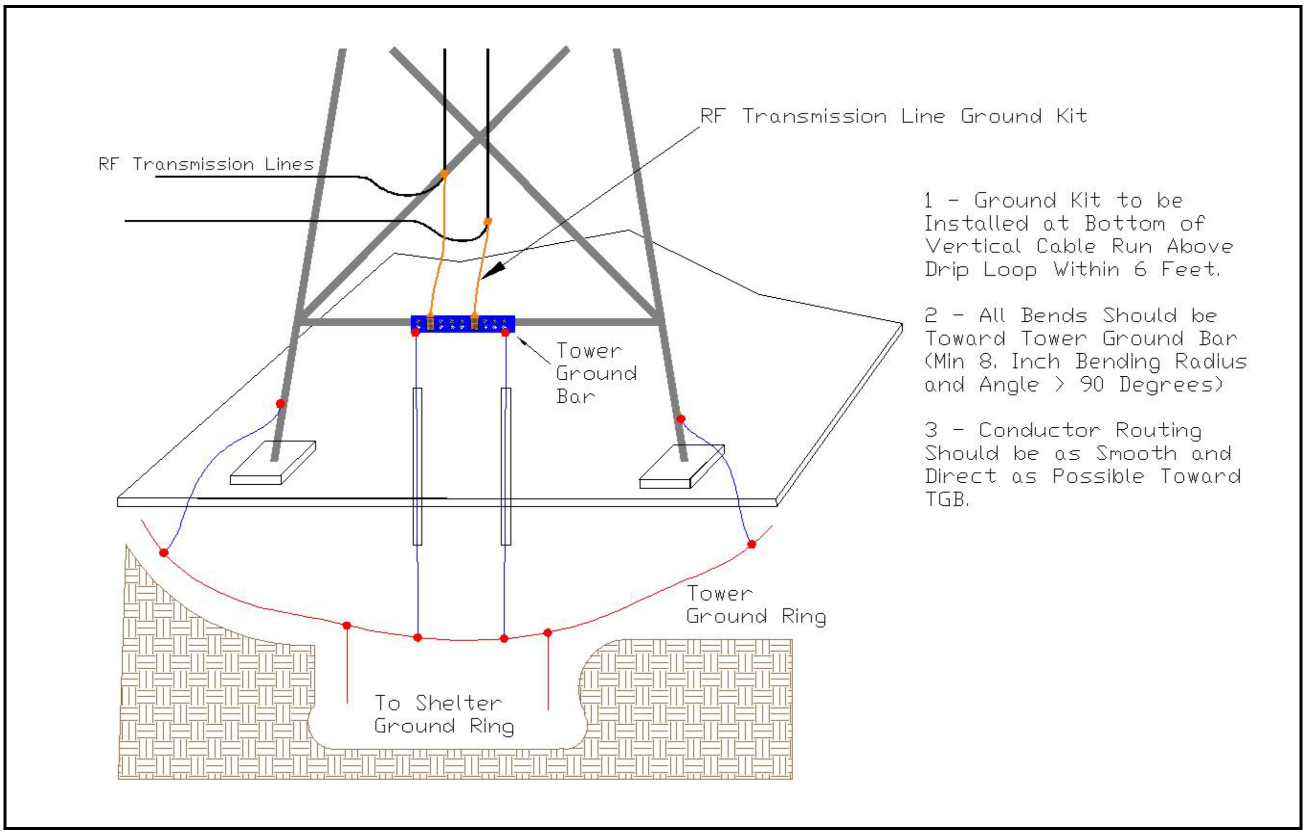



**Figure 4-38: Tower Bottom RF Transmission Line Ground Kit Detail**

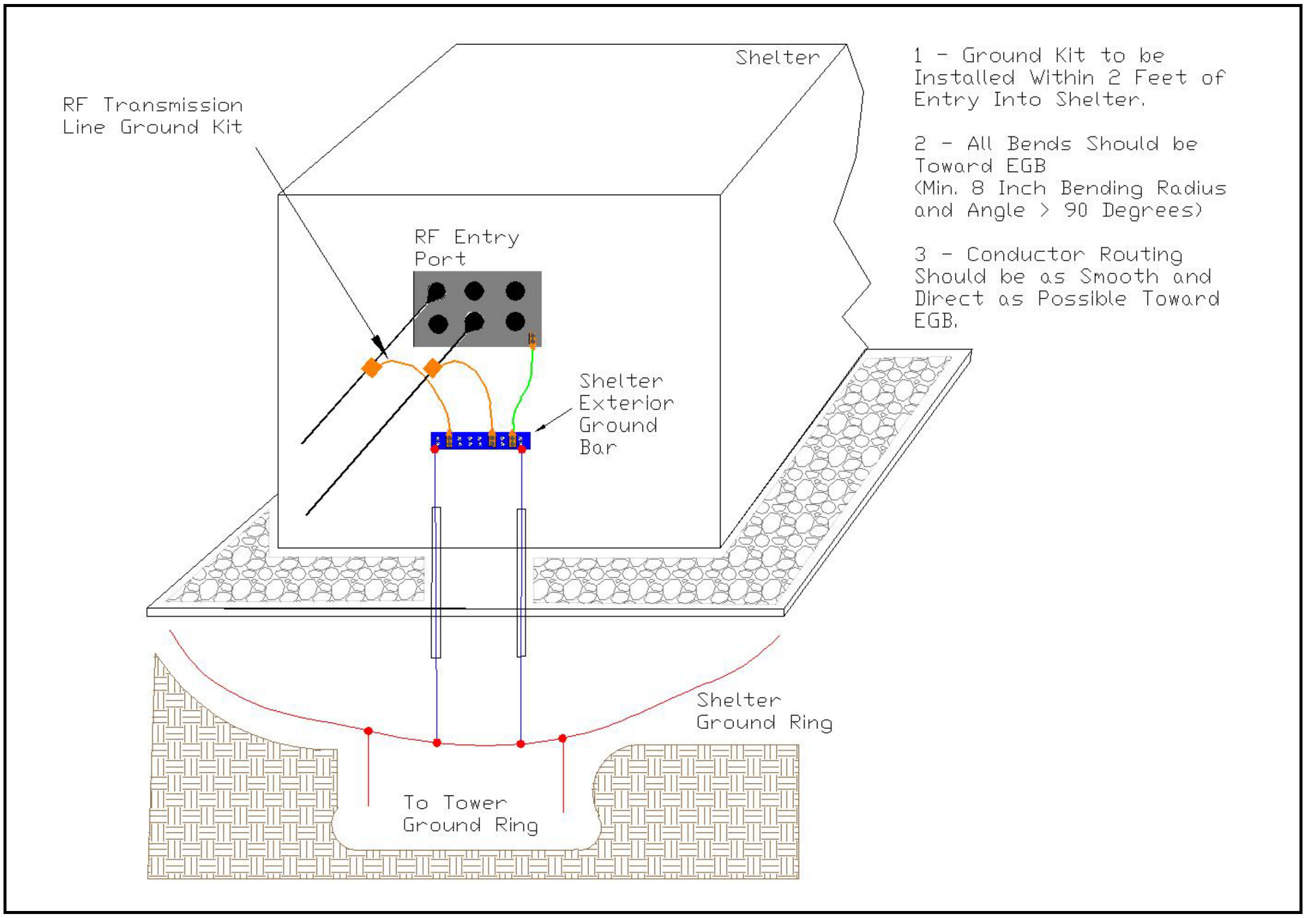



**Figure 4-39: RF Transmission Cable Ground Kit Locations**

**Figure 4-40: RF Transmission Cable Ground Kit Installation (Before Waterproofing)**

Figure 4-41: Installed RF Transmission Line Ground Kit Examples

**Figure 4-42: Installed RF Transmission Line Ground Kit Examples**

### 4.4.1 GPS Antenna Mounting and Coaxial Cable Grounding Considerations

Global Positioning System (GPS) receivers may be more sensitive to induced lightning energy than other RF equipment. GPS antenna coaxial cables, despite their short length, should have at least one RF transmission line ground kit installed at the RF entry port.

In areas highly prone to lightning, GPS antennas should be located on the shelter as far away from the tower as possible. We also recommend using ½ inch RF transmission line.

For maximum protection, you may route the GPS antenna coaxial cable from the GPS antenna to the RF entry port in ferrous metallic conduit. You should also ground the conduit, at the end closest to the RF entry port, to the external ground bar. The ferrous metallic conduit provides additional EMI/RFI shielding for the GPS antenna coaxial cable.

You should always install an RF surge suppressor, designed for GPS antenna lines, inside shelter at the RF entry port.


**Figure 4-43: GPS Antenna Mounting and RF Transmission Cable Routing in Lightning Prone Area**

## 4.5 TOWER-TOP AMPLIFIERS

You must ground the tower-top preamplifier chassis to the tower using a #2 AWG, or larger, solid or stranded tinned copper conductor. Be sure to install the ground conductor according to the manufacturer's recommendations.

## 4.6 ICE BRIDGES/CABLE TRAYS

Metallic ice bridges and cable trays protect and support RF transmission cables between the tower and the equipment shelter. These ice bridges and trays must be bonded to the buried exterior ground system.

You must bond each support post, as shown in Figure 4-44, to the buried exterior ground system using a #2 AWG, or larger, solid or stranded tinned copper conductor. Exothermically weld the conductor to both the post and the buried ground system. You can ground two opposite posts by running a gentle large radius loop underground between the posts and bond it to the ground system in the middle. Making separate connections is also acceptable.

You must also bond each support post to the ice bridge grating or cable tray. If multiple sections of grating or cable tray are used, install a jumper across the joints and sections, to connect the sections together.

If an ice bridge or cable tray does not have support posts, then it should be kept electrically isolated from the tower. In this case, you should bond the bridge or tray to the equipment shelter exterior ground bus bar, as shown in Figure 4-46.

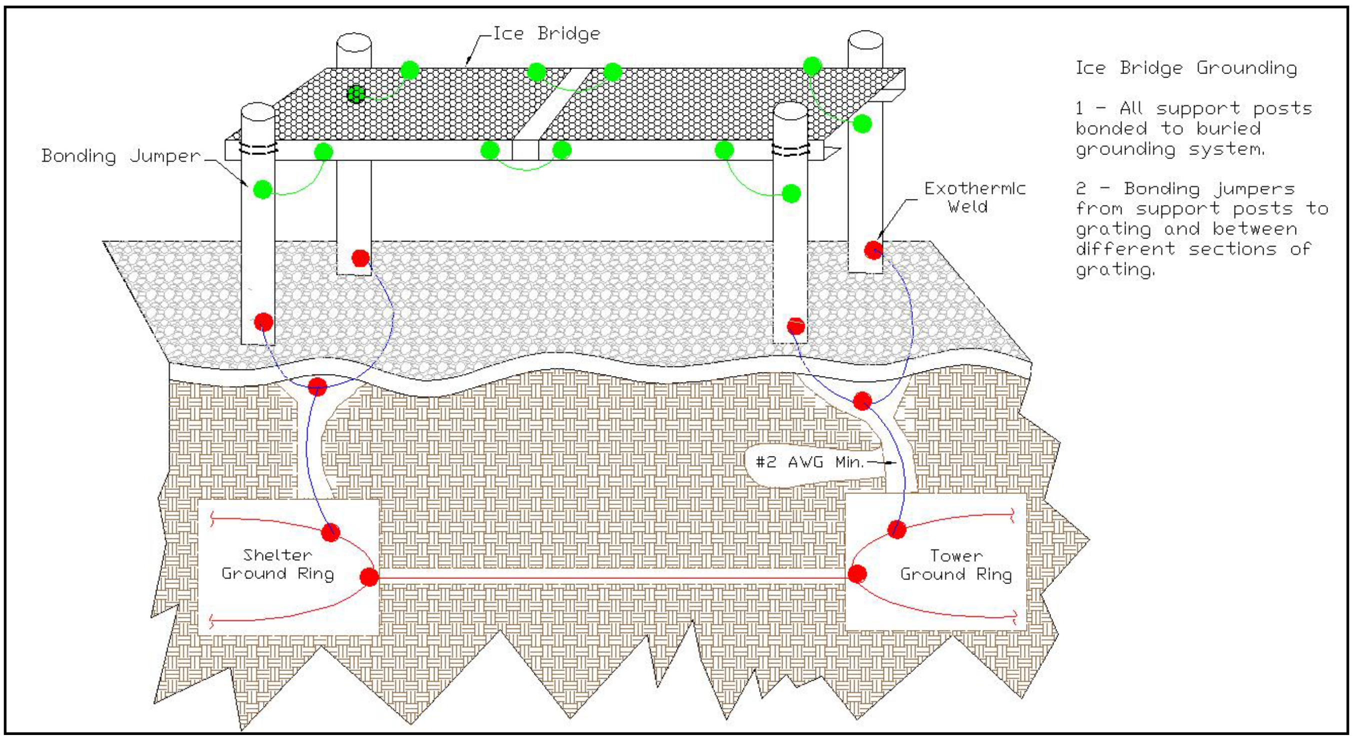



**Figure 4-44: Ice Bridge/Cable Tray Grounding Detail**

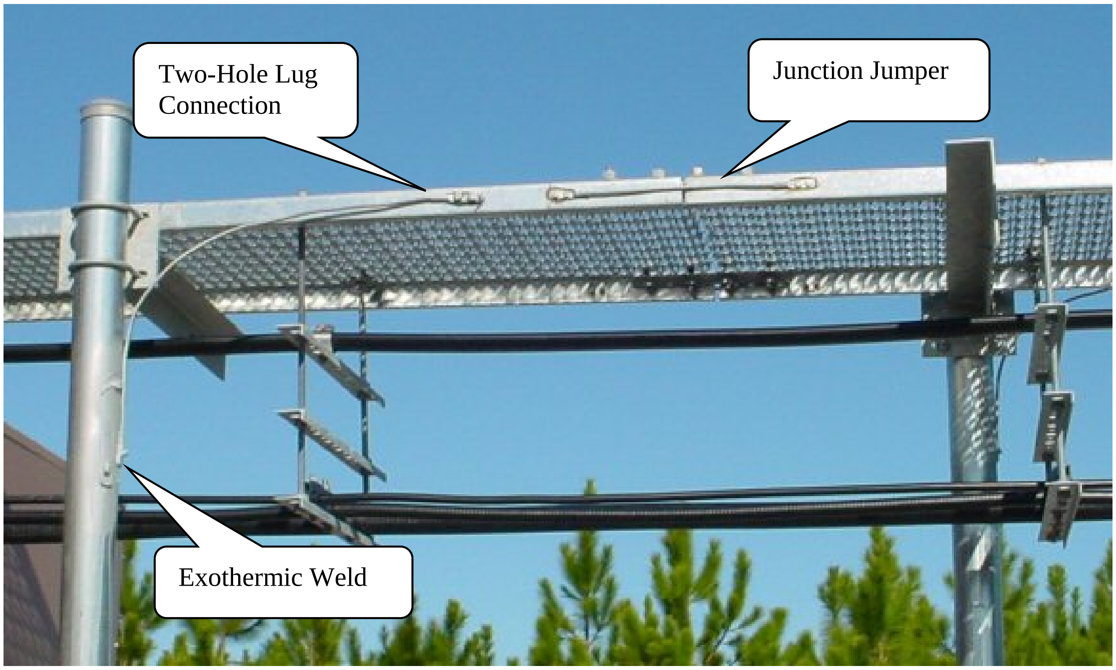



**Figure 4-45: Typical Ice Bridge Support Post to Grating Bonding and Junction Jumper**

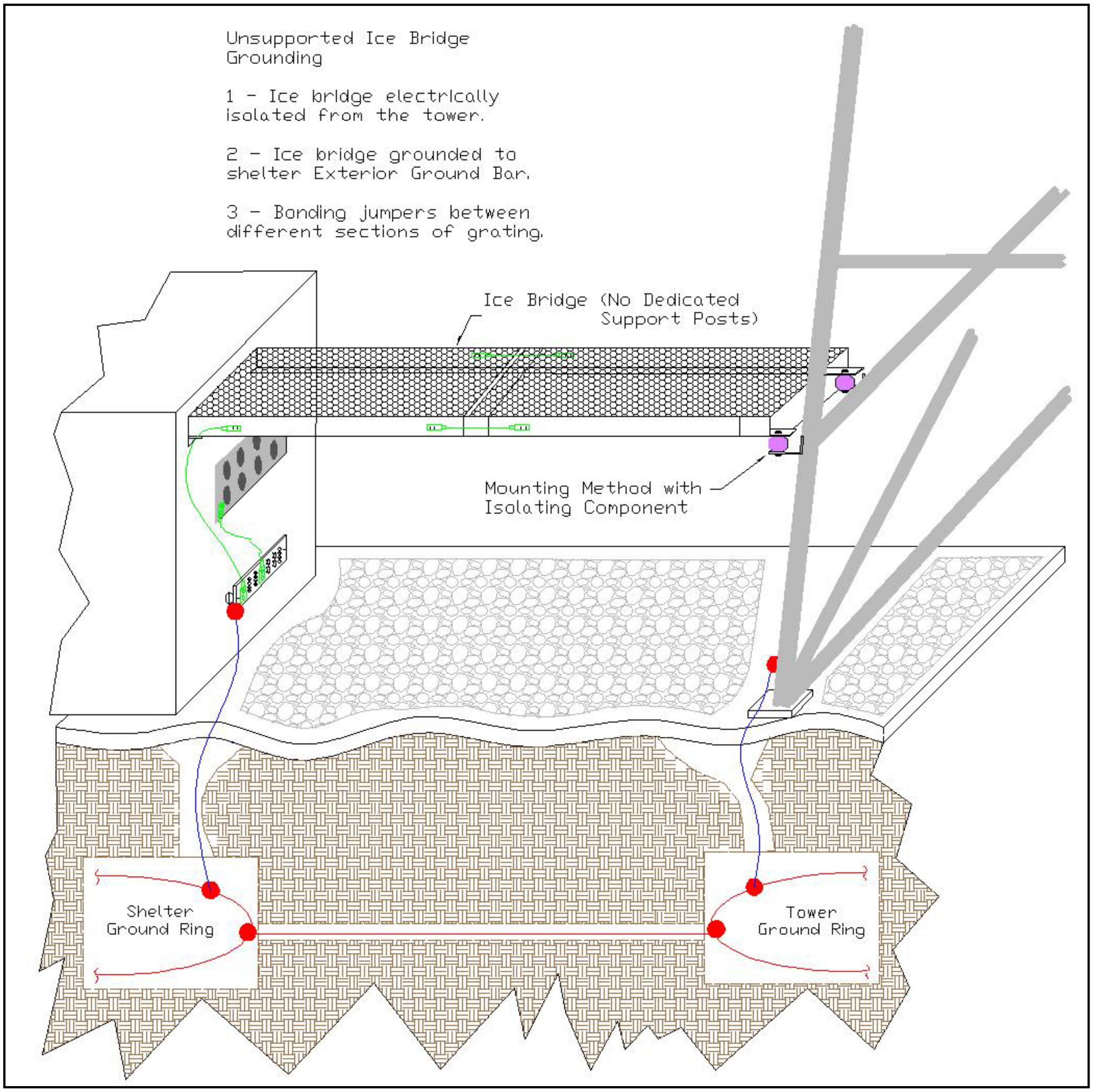



**Figure 4-46: Unsupported Ice Bridge Grounding Detail**

## 4.7 FENCES AND GATES

Metal fences within 10 feet of any ground ring, ground radial, or any grounded object must be bonded to the site grounding system. This minimizes the possibility of side-flashes during a lightning event and protects personnel from shock hazard because of lightning.

At a minimum, you should bond each fence corner post directly to the exterior ground ring system using a dedicated #2 AWG solid or stranded tinned copper ground conductor. Also bond each pair of gate posts together and connect a similar dedicated grounding conductor between the posts and the site grounding system. Also install a jumper between each gate and its post using a highly flexible, #2 AWG stranded copper conductor.

If the distance between fence corner posts is greater than 50 feet, we recommend bonding additional intermediate fence support posts to the exterior ground ring. This may be necessary to ensure the distance between grounded posts is kept below the 50 foot maximum.

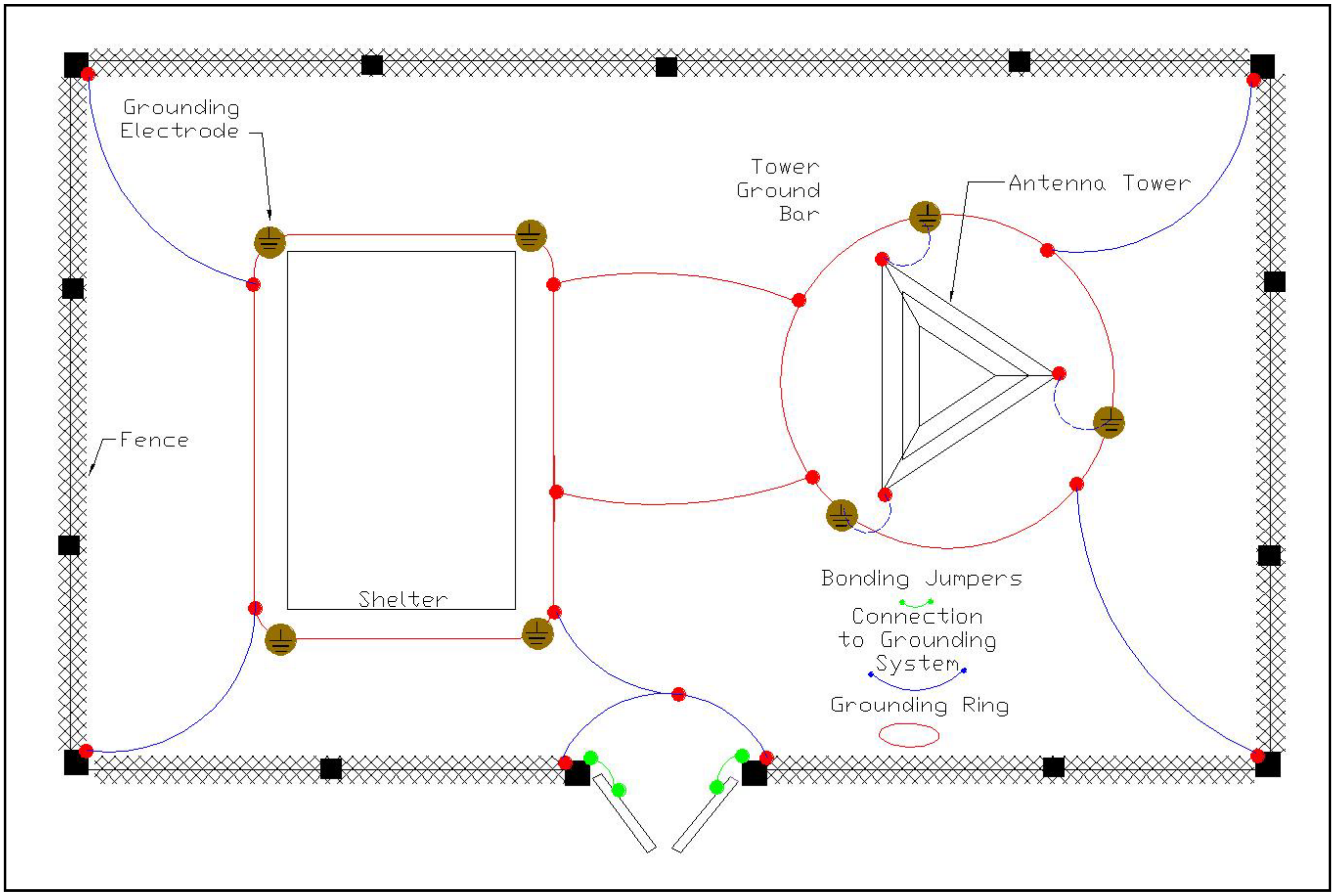



**Figure 4-47: Fence Grounding Overview**

Make all underground connections using exothermic welds. Make above ground connections to commercial-grade fencing using an exothermic weld if possible. Make connections to above ground residential-grade fencing or to existing fencing with a UL-listed grounding pressure clamp located near the bottom of the metal post. Exothermic welding may damage residential-grade or older existing fencing.

Fences around tower guy anchor points should be grounded to the guy anchor ground rod using the methods detailed in this section.

Though not required, non-electrified entry deterrent fence headers and barbed or razor wires may be bonded together and to their supporting corner posts using #2 AWG solid or stranded tinned copper ground conductor. You should bond each run to the grounding conductor using a UL-listed bimetallic clamp, which should be coated in conductive antioxidant compound.

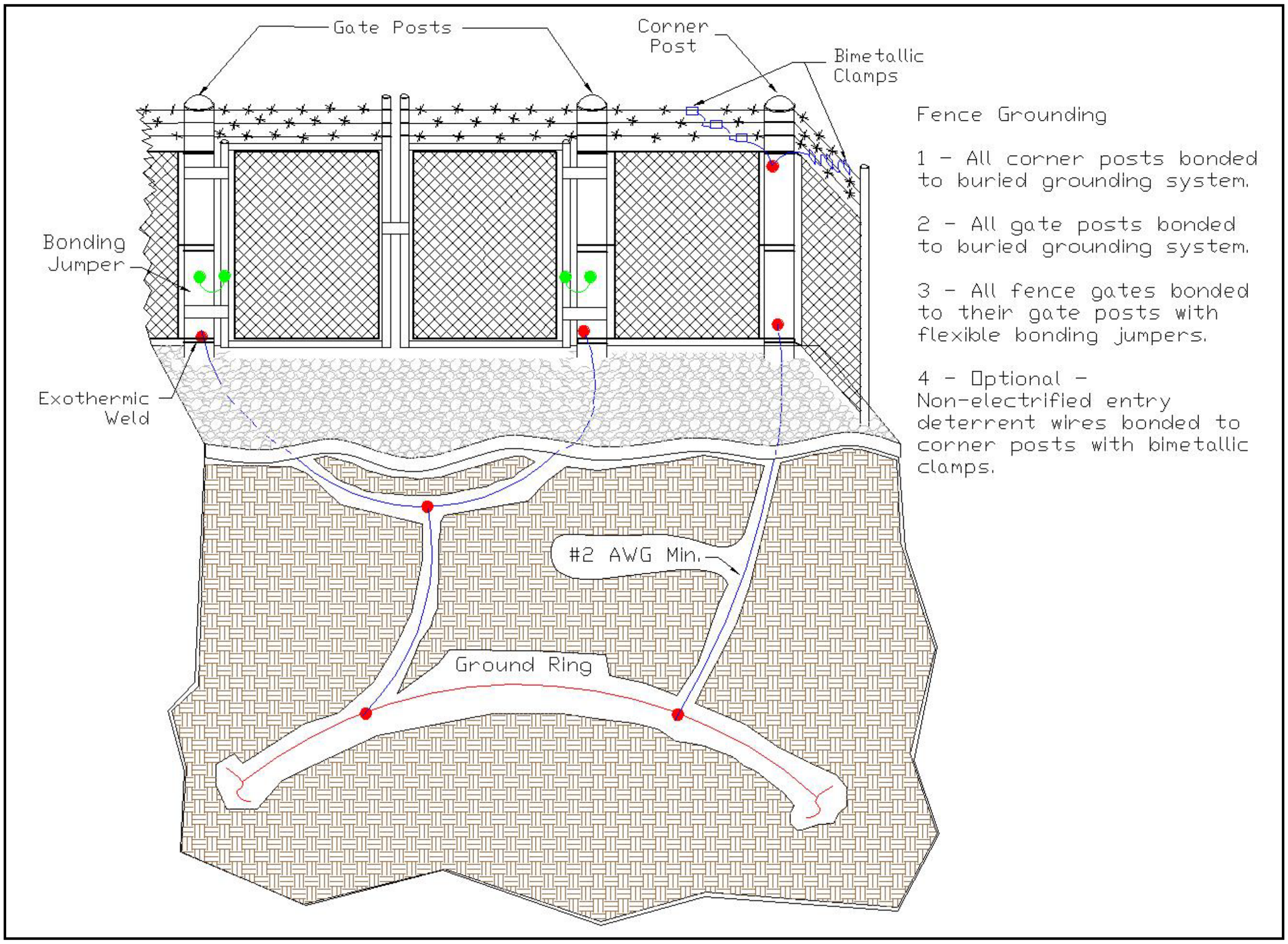



**Figure 4-48: Fence Gate, Corner Post, and Entry Deterrent Wiring Grounding Detail**

**Figure 4-49: Fence Gate Grounding Example**

**Figure 4-50: Fence Corner Post Grounding Example**

## 4.8 EXTERIOR GENERATORS

Generators and their fuel storage tanks (either above or below ground) installed within 6 feet outside the equipment shelter should be bonded to the nearest possible location on the exterior ground ring.

Generators and their fuel storage tanks (either above or below ground) installed more than 6 feet away from the equipment shelter should have an additional ground rod installed near the generator and the ground rod should be bonded to the site exterior ground ring and to the generator itself. You should also bond the generator's fuel storage tank to this additional ground rod.

Be sure to make any connections to the generator chassis according to the manufacturer's recommendations.

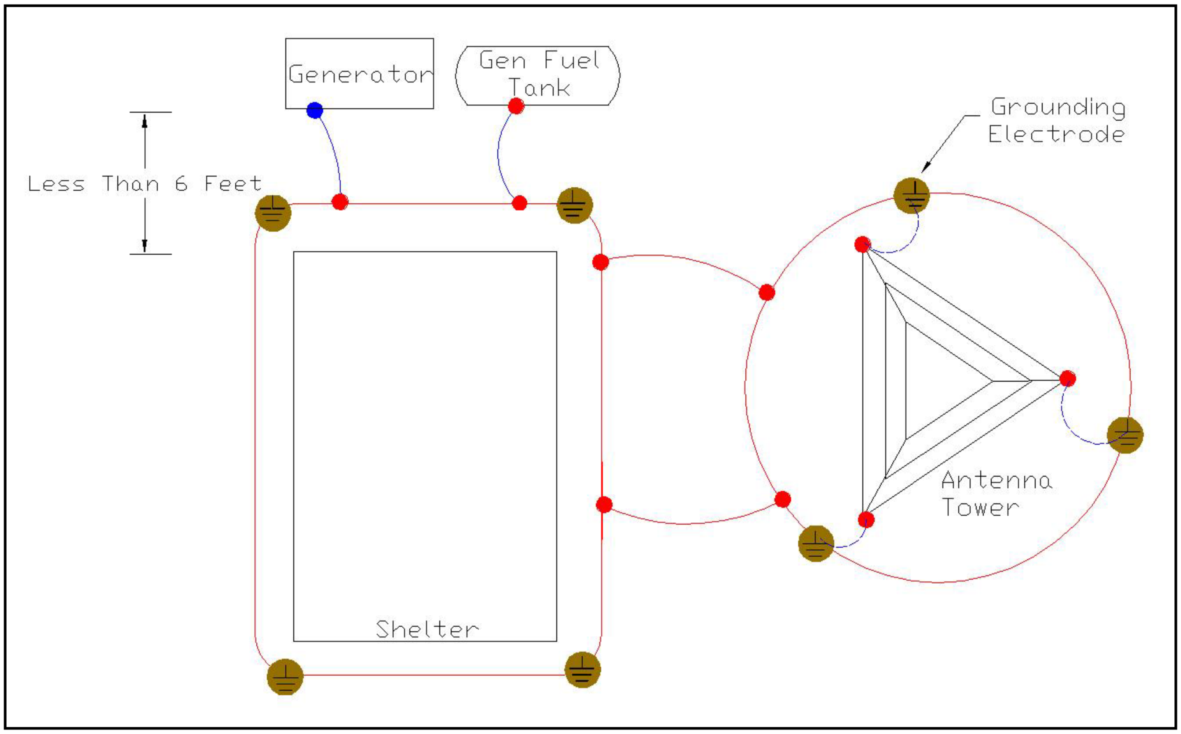



**Figure 4-51: Generator Grounding if Located Less than 6 Feet from Shelter**

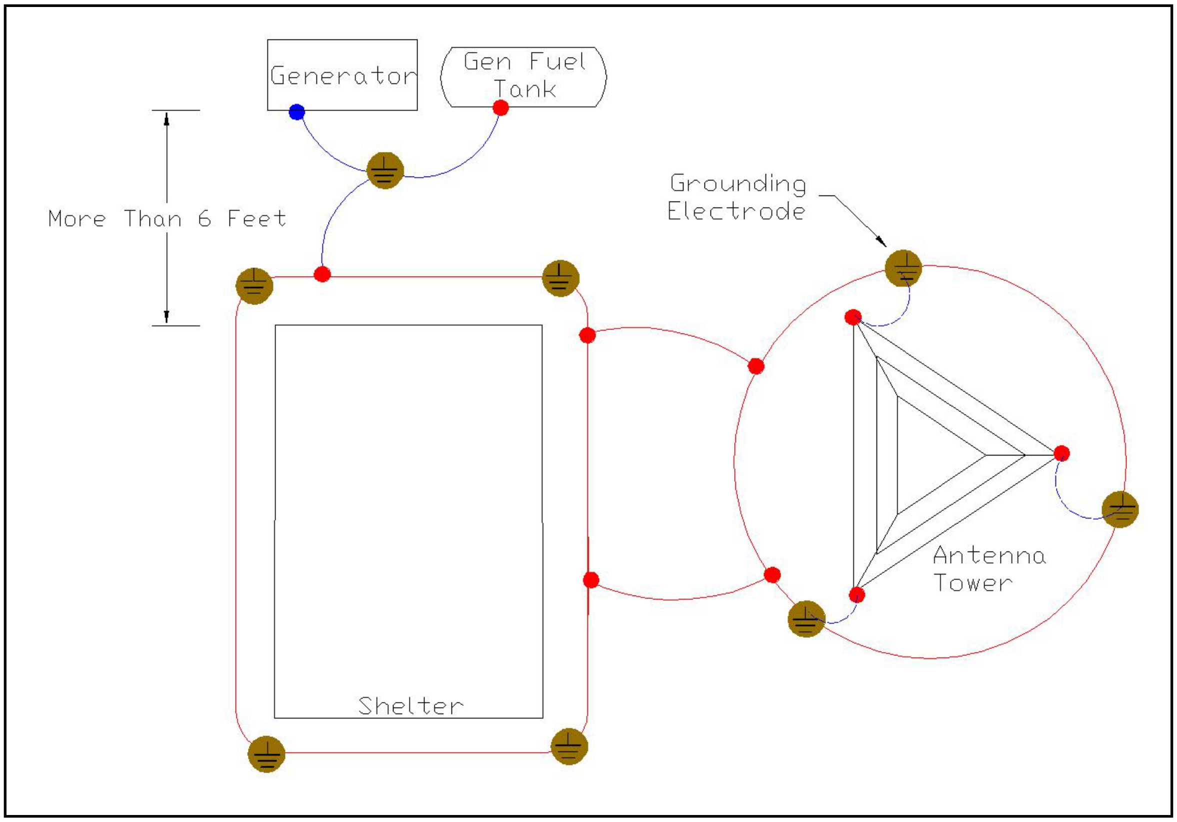



**Figure 4-52: Generator Grounding if Located More than 6 Feet from Shelter**

**Figure 4-53: Typical Generator Grounding**

## 4.9 EQUIPMENT SHELTERS OR BUILDINGS

Any metallic siding, frames, or metallic objects on an equipment shelter should be bonded to the buried shelter ground ring. You should bond these using a #2 AWG copper conductor. If metal siding is installed with weather-stripping, or some other insulating material between sections, then each section should be bonded separately.

Grounding of one shelter anchor tab (closest to the RF entry port and MGB) is especially important since some concrete shelters may use reinforcing metal rebar in the walls, floor, and ceiling that is bonded together providing some faraday cage-like shielding.

You must also bond any metallic object or surface attached to the outside of the shelter to the shelter ground ring. Typically, these items (as shown in Figure 4-54) might include air conditioners, vent covers, conduit, GPS antenna mounts, exterior light fixtures, gutters, metallic stairs and handrails, shelter ice shields, external generator plugs, and metallic entry door hoods or covers.

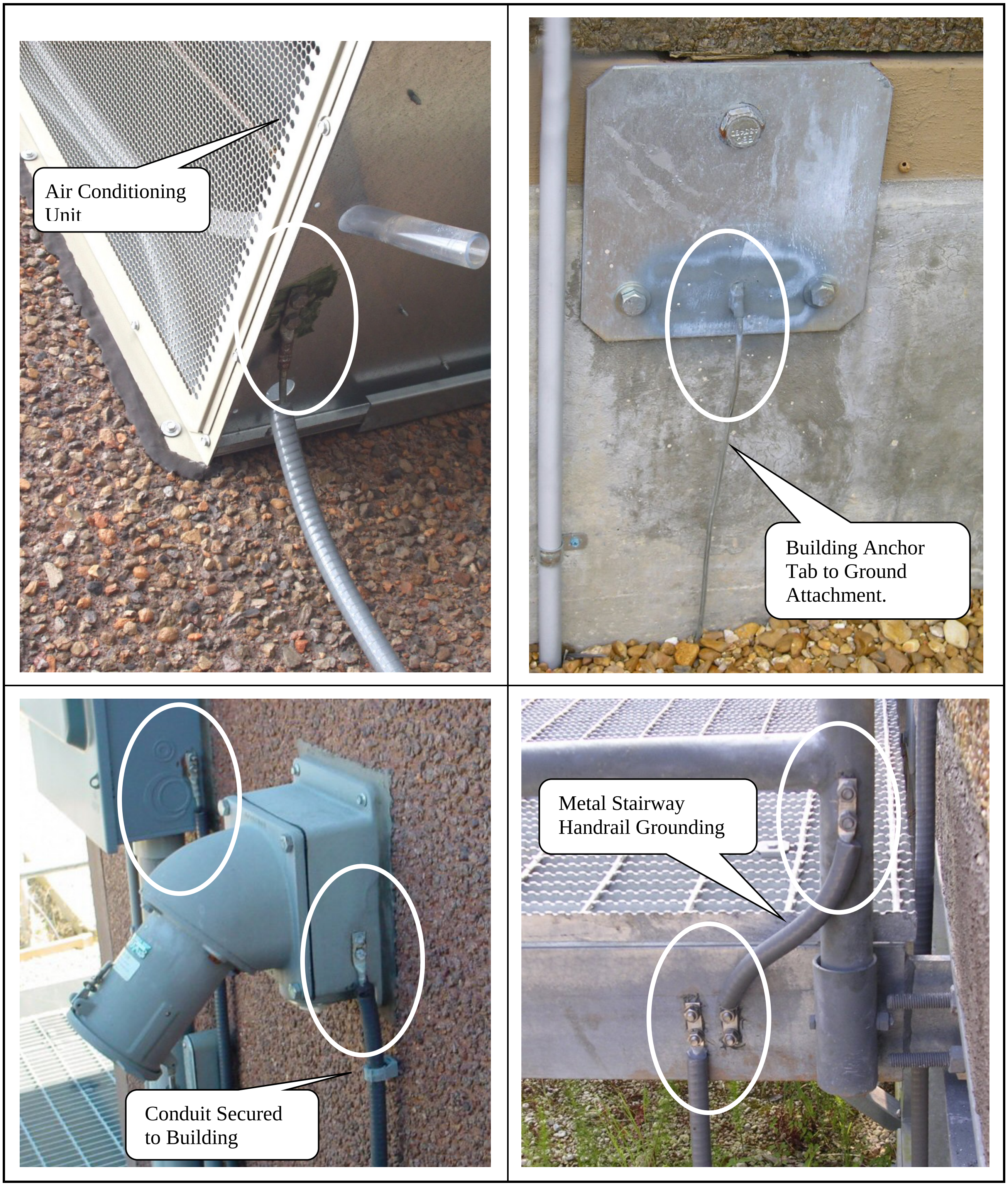



**Figure 4-54: Grounding of Metallic Objects Attached to Building Exterior**

## 4.10 OTHER NEARBY METAL OBJECTS OR GROUND SYSTEMS

All metal objects within 10 feet of any component of the exterior grounding system should be bonded to the buried shelter ground ring using a #2 AWG copper conductor. This includes any other ground systems provided by telephone or electric utility providers (as shown in Figure 4-55). Always observe NEC and any applicable local electric codes when making these connections.

If the site includes retaining walls or other concrete structures that contain rebar, then bond them to the exterior grounding system.

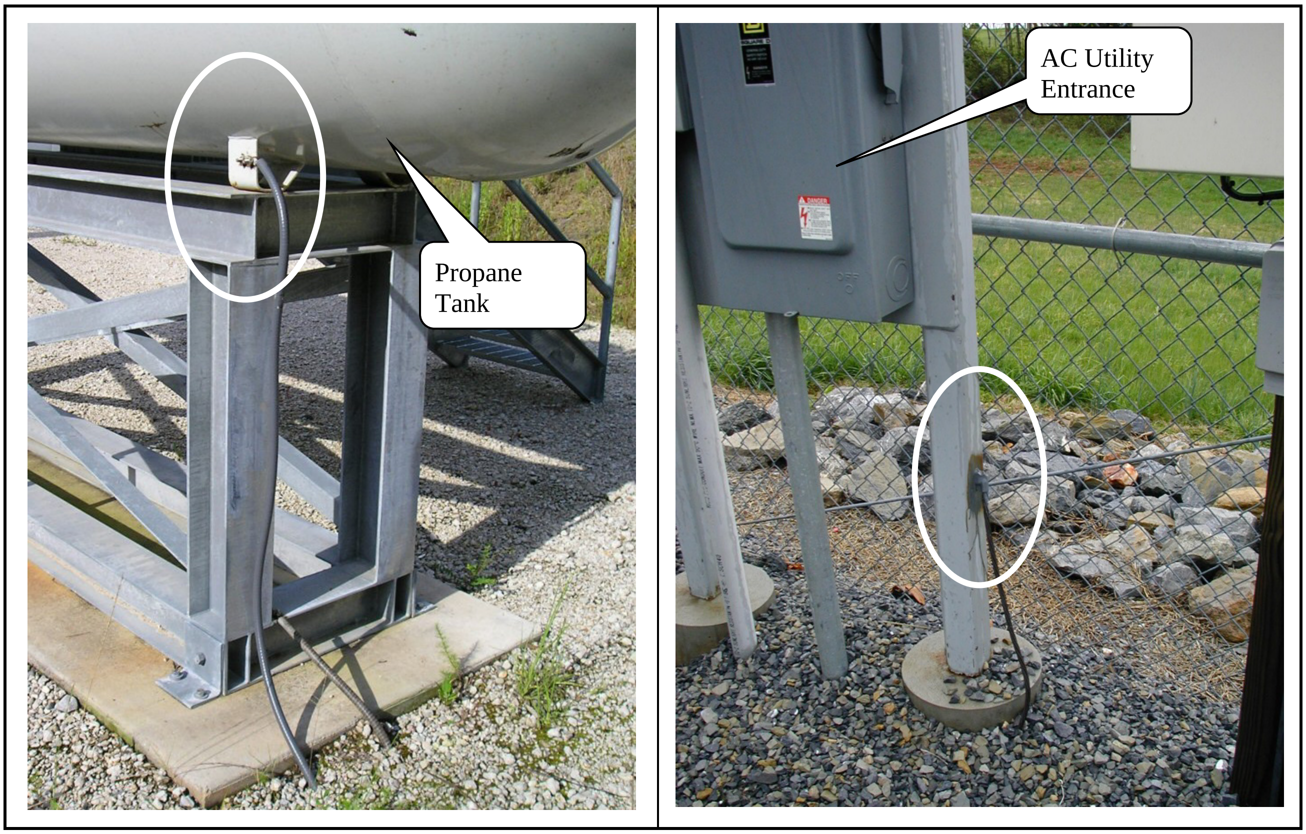



**Figure 4-55: Grounding of Miscellaneous Exterior Metallic Objects Located Around Site**

# 5. INTERIOR SITE GROUNDING

All Harris site installations should use a single point ground system. The rationale for this type of grounding system is: if all equipment and metallic objects inside a shelter are connected to the exterior buried ground system at a single point, then the voltage potential of all of the equipment will rise and fall together should a lightning strike occur. This reduces the possibility of current flowing through the equipment. The single point ground system also reduces the possibility of arcing between metallic surfaces during a lightning event.

The interior MGB is the only point where any interior equipment grounds or metallic objects should connect with the site's exterior ground system. All equipment grounds, non-RF surge suppression grounds, AC equipment ground (green wire), DC power plant grounds, ancillary support equipment grounds, and all interior extraneous metallic object grounds are routed to the MGB. The MGB is the earth ground reference for all interior shelter components.

NOTE

If an RF entry port with integrated ground kits and RF surge suppression grounding is used, then bond all RF surge suppressors to the RF entry port. This does not violate the single point ground since both the Integrated RF entry port and the MGB are bonded to the exterior buried ground system at the same location. If an RF entry port without integrated ground kits is used, the RF surge suppressor ground connections are also brought back to the MGB. (See Section 4.3.2 for details.)

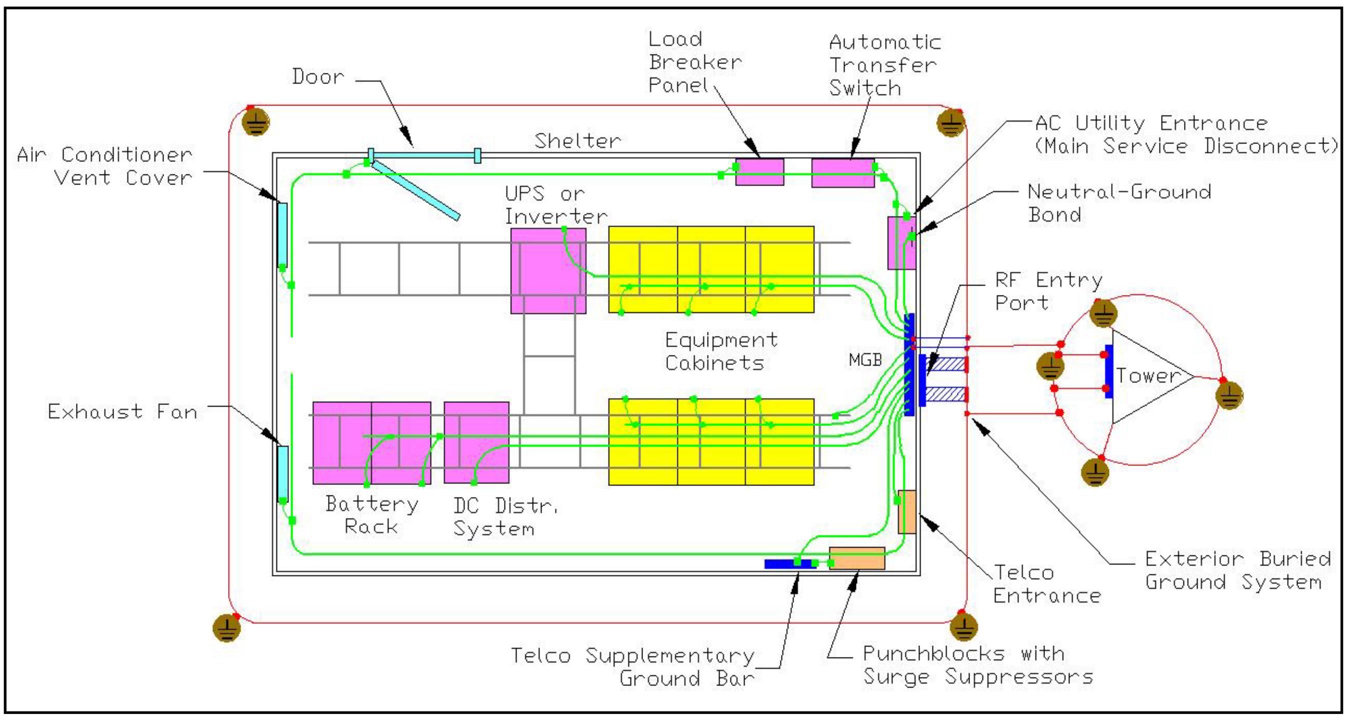



**Figure 5-1: Interior Grounding Overview**

## 5.1 GENERAL REQUIREMENTS

It is important to establish and maintain the single point ground concept. All equipment racks, cabinets, power frames, and power distribution units must be isolated from the building steel, ducts, pipes, etc., to ensure no ground loops are created in which extraneous currents could flow. You must connect interior grounds only to the single ground reference point at the MGB. This ensures all radio site components are at the same ground integrity, as related to true earth ground.

All ground connections must be tight, and all connections to the MGB must be as straight as possible with a minimum number of bends.

You should maintain a minimum separation of 2 inches between all grounding conductors and any communication cables. This is required by NEC to avoid inductance of noise into the shields of communications cables.

All individual ground connections, as shown in Figure 5-2, must be connected directly back to the MGB, to a ground bus conductor (“home run”) going back to the MGB, to a ground drop conductor (“drop”) connecting to a ground bus conductor, or to a supplemental ground bar that is connected back to the MGB. Do not daisy chain equipment grounds. Installing bonding jumpers to ensure electrical continuity of cable ladders and trays, metallic conduit, and battery racks is not considered daisy chaining.

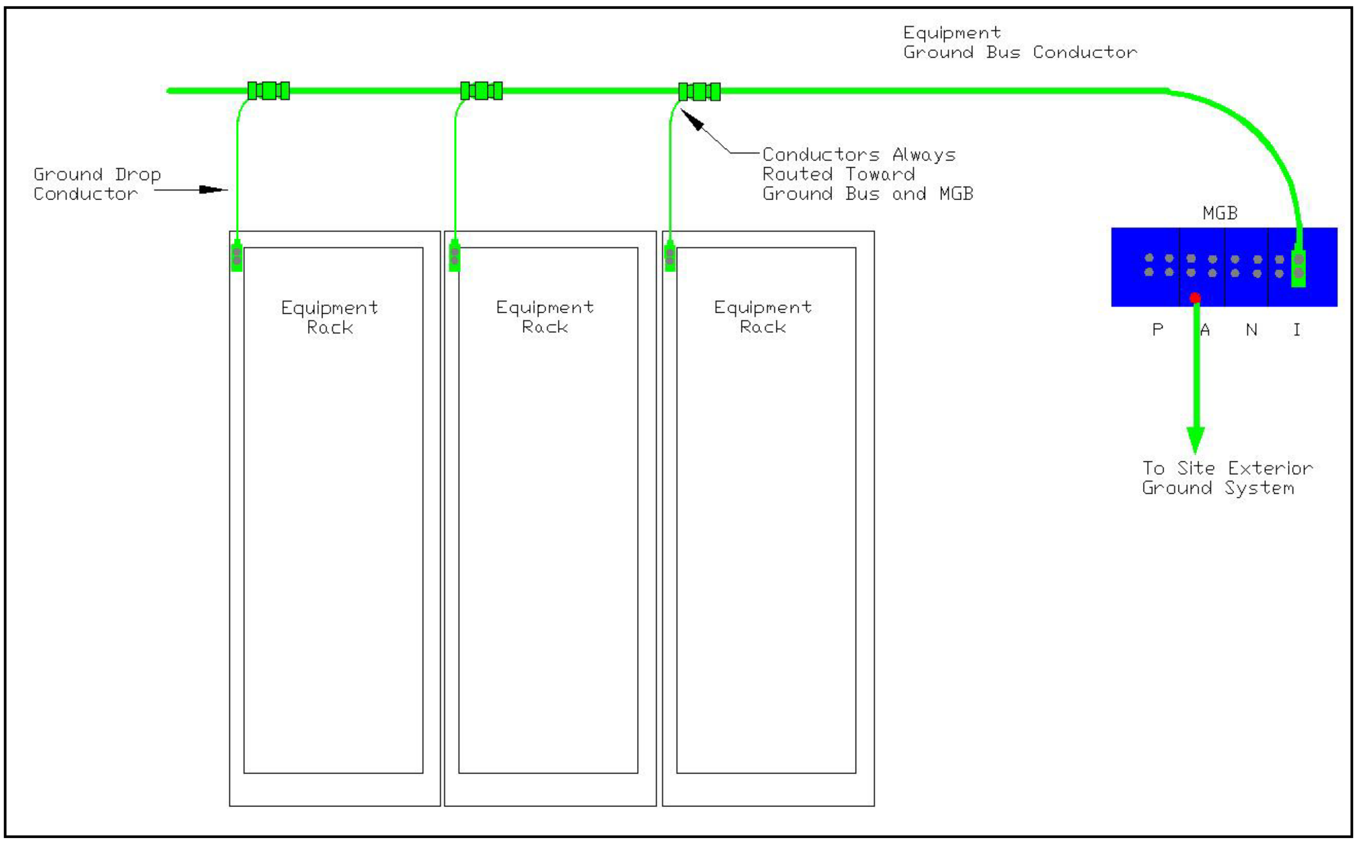



**Figure 5-2: Acceptable Method of Grounding Equipment**

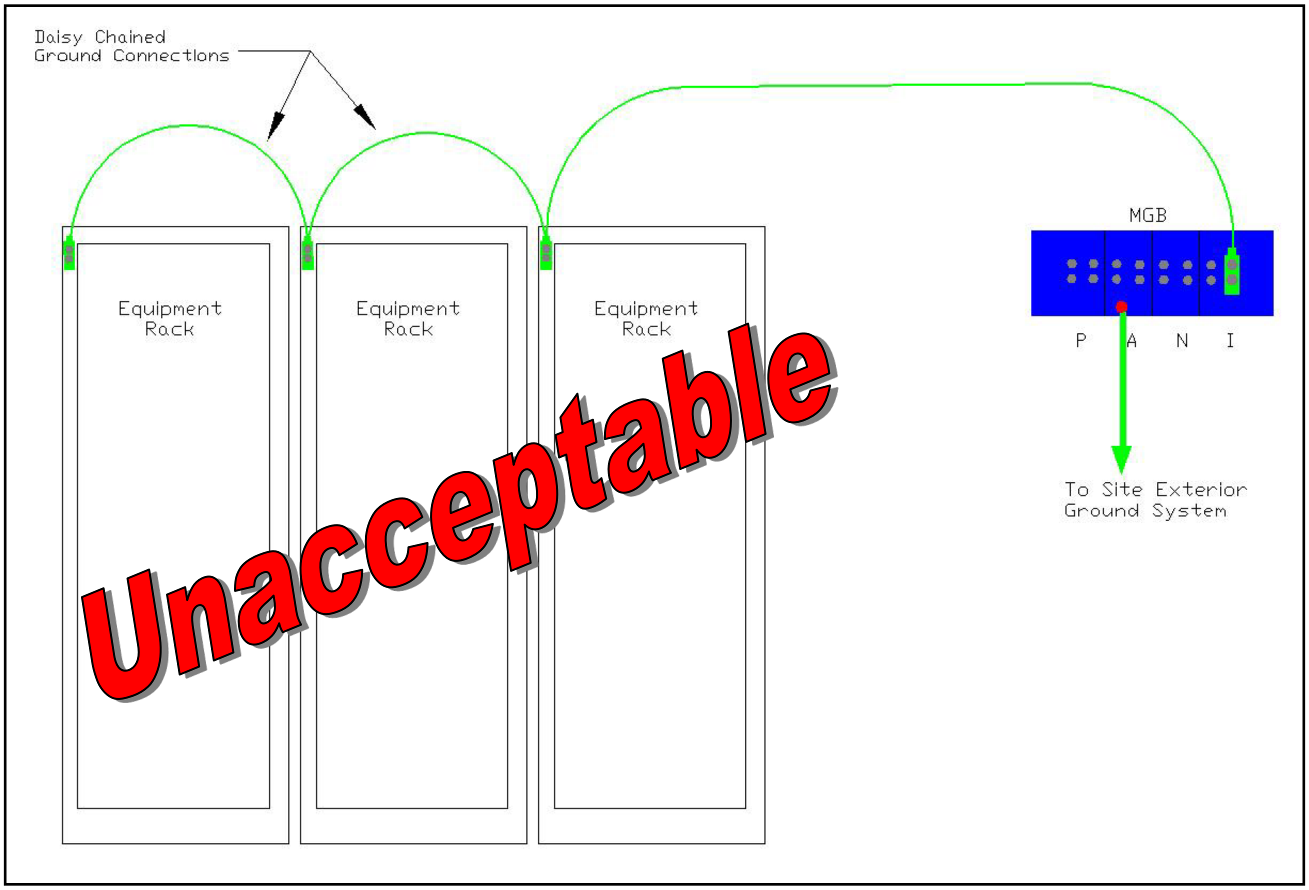



**Figure 5-3: Daisy Chaining - Unacceptable Method of Grounding Equipment**

Avoid placing grounding and cabinet bonding conductors in a ferrous metallic conduit. If it is necessary to place grounding conductors in ferrous metallic conduit, then you must bond the conductors to each end of the conduit with a #6 AWG, or larger, conductor. Similarly, if a grounding conductor must be run through a small hole (less than three times the diameter of the conductor) in a ferrous metal surface, the conductor should be bonded to the metal surface where it passes through.

When securing or dressing grounding conductors, use plastic clamps, tie wraps, or stand-offs. Do not use metallic clamps to secure grounding conductors.

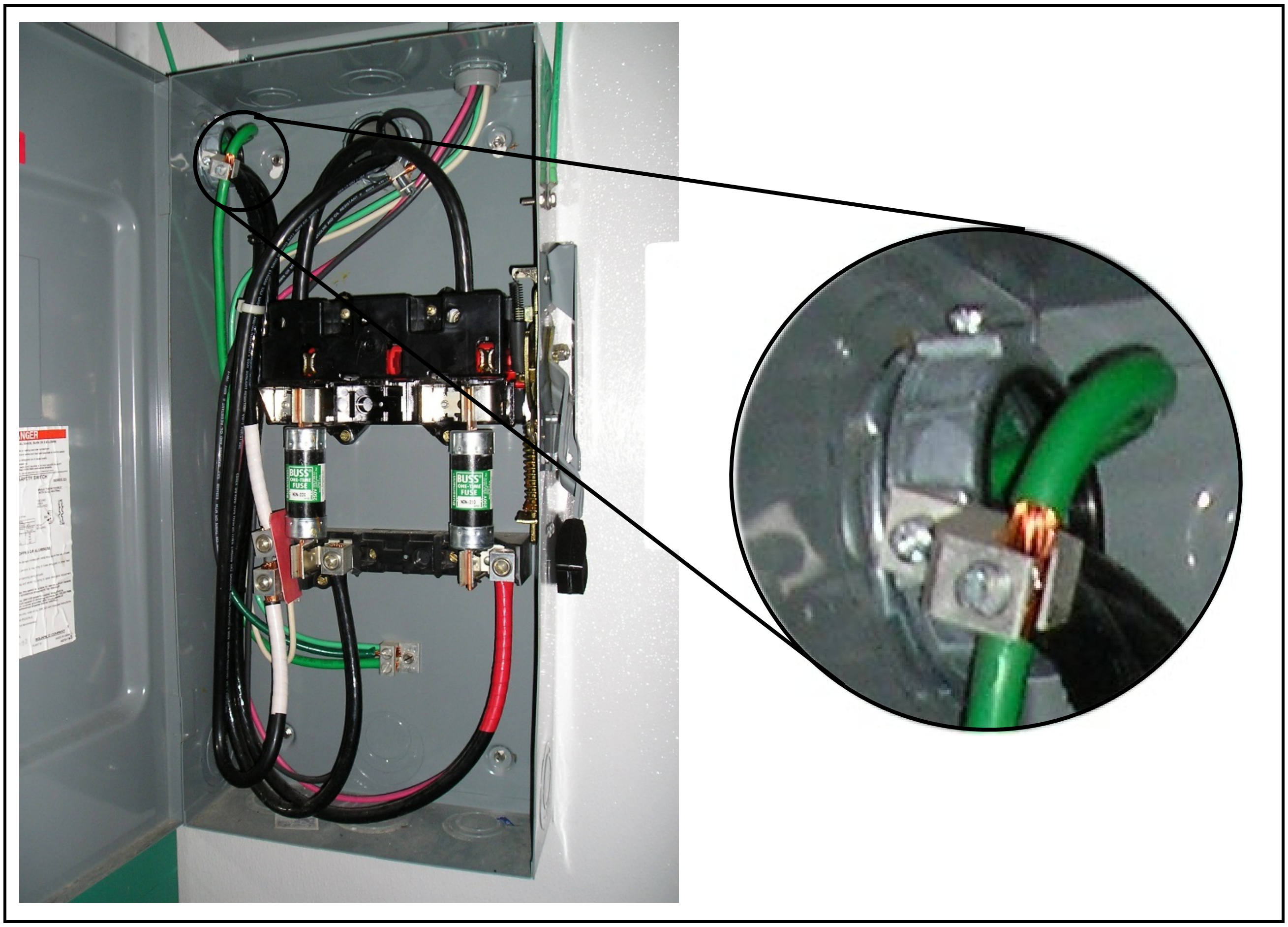


Figure 5-4: Example of Proper Bonding when Ground Conductor Must Be Placed in Metallic Conduit

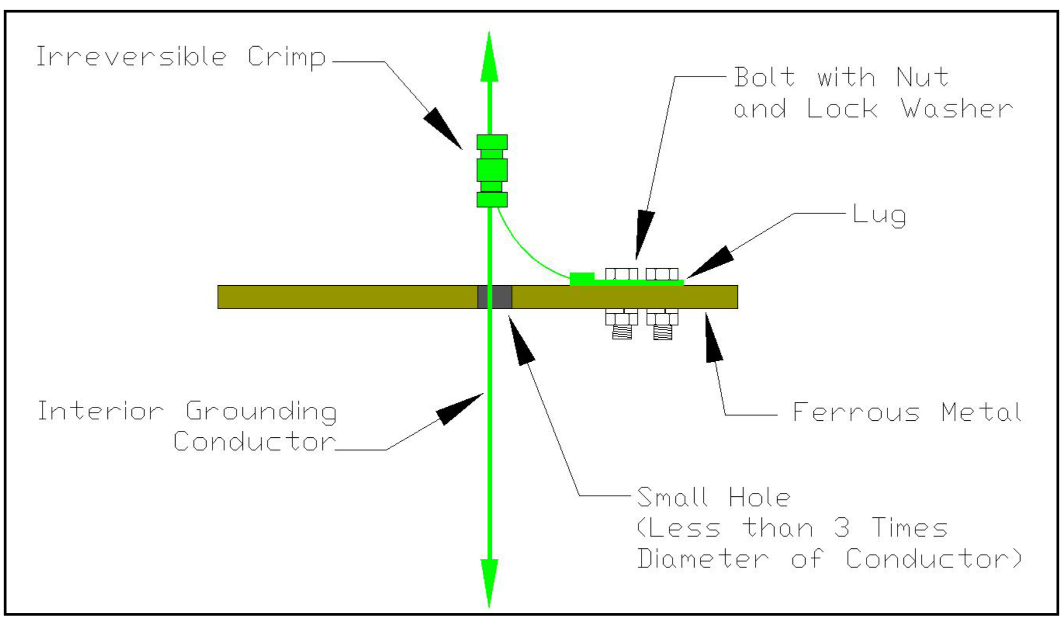



Figure 5-5: Detail of Proper Bonding when Ground Conductor Must Pass Through Small Hole in Metal Surface

### 5.1.1 Interior Grounding Conductors

Interior ground conductors can generally be grouped into three categories:

- Ground bus conductors ("home runs")

  These provide a connecting point for multiple grounding conductors and are brought back to the MGB. Ground bus conductors should be #2 AWG, or larger, insulated stranded copper conductor. We recommend using stranded wire, but a solid copper conductor or strap may also be used.

- Ground drop conductors ("drops")

  These connect a single cabinet, rack, or other object to a ground bus conductor, a supplemental ground bar, or directly to the MGB. Ground drop conductors should be #6 AWG, or larger, insulated stranded copper conductor. Inside a cabinet or rack, you may connect multiple individual grounding conductors to the ground drop conductor.

- Individual grounding conductors

  These connect the ground points for different pieces of equipment, inside a cabinet or rack, to an internal cabinet ground bus bar or conductor, to a ground drop conductor from a ground bus conductor, or to a supplemental ground bar. Individual grounding conductors should be #14 AWG, or larger, insulated stranded copper conductor.

All interior ground conductors should either have a **green jacket** or **green with a yellow stripe jacket**. This quickly identifies them as ground conductors. If you must use a conductor with a black jacket, then it must have green tape wrapped around it at points designated by *NFPA 70* or local codes.

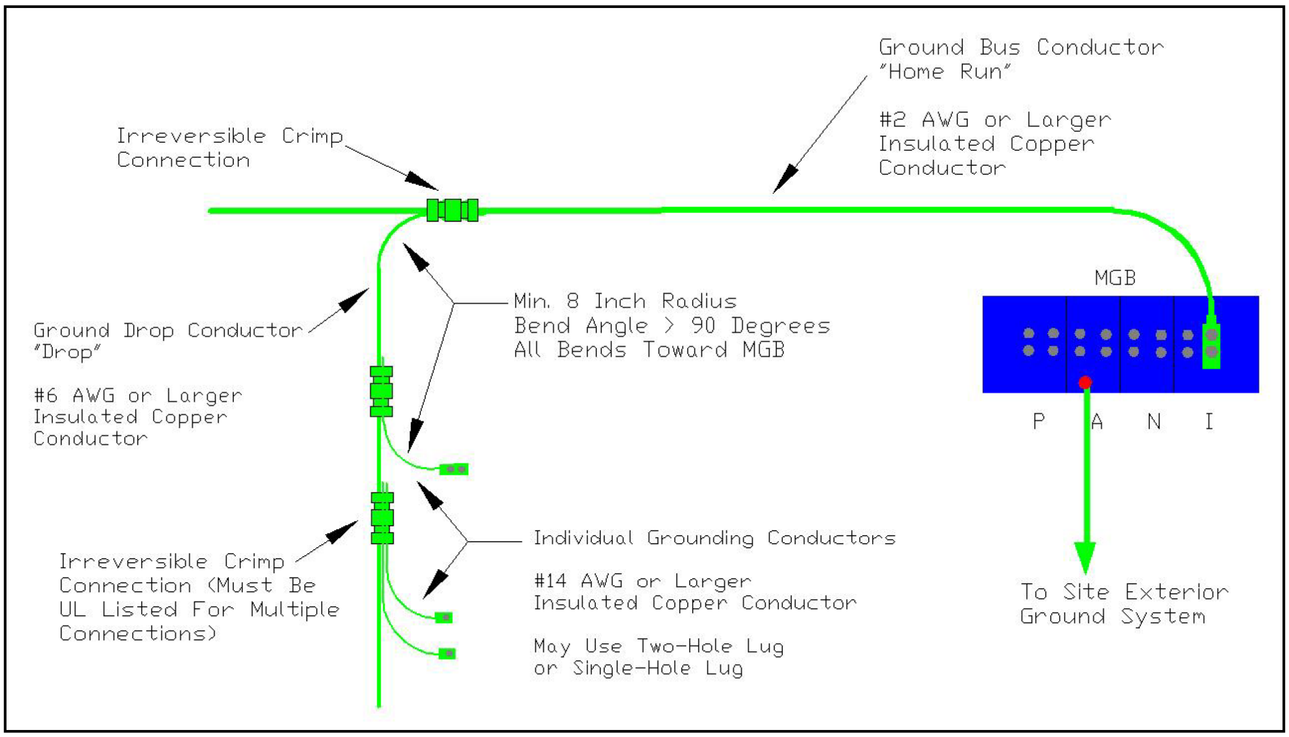



**Figure 5-6: Interior Grounding Conductors Detail**

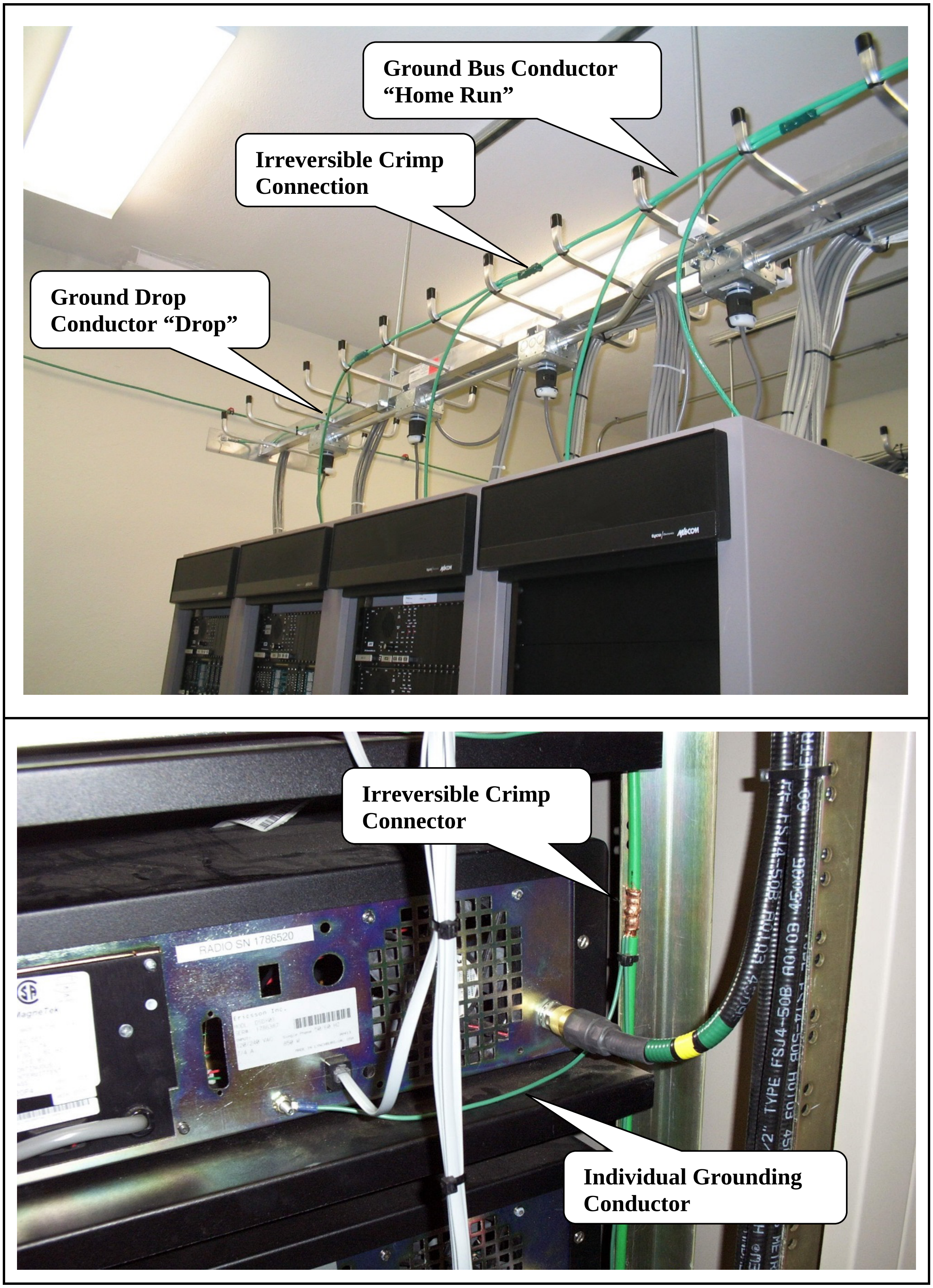



**Figure 5-7: Examples of Interior Grounding Conductors**

Grounding conductor runs should be as short and straight as possible to minimize their impedance. All bends, curves, and connections should be toward the MGB. A bending radius should be 8 inches (minimum) or more, and the angles of the bends should not be less than 90 degrees. Connecting conductors should always transition in the direction of current flow or toward the MGB.

### 5.1.2 Interior Grounding Connections

You should make interior grounding connections with UL-listed pressure connectors, compression terminals, lugs, or clamps. Be sure the device chosen is the proper the size for number of conductors being connected.


**Figure 5-8: Examples of Irreversible High-Compression C-Tap Connectors**

(Courtesy of Burndy and Thomas & Betts)

**Figure 5-9: Examples of Irreversible High-Compression Lugs and Splices**

(Courtesy of Thomas & Betts)

UL-listed compression-type connections are preferred for applications ***inside*** communications rooms or shelters. They should include the crimped die index and the manufacturer's company logo. Compression-type connections include connectors for taps, lugs, splices, and structural steel terminations. You should encase tap and splice connections with a non-conductive covering to prevent accidental contact with other metallic objects. This non-conductive covering may be UL-listed electrical tape or plastic snap covers intended for this purpose. If electrical tape is used, you may want to use a non-conductive padding to avoid sharp edges piercing the tape.

NOTE

If using split bolts to make interior connections, they must be checked for tightness frequently.

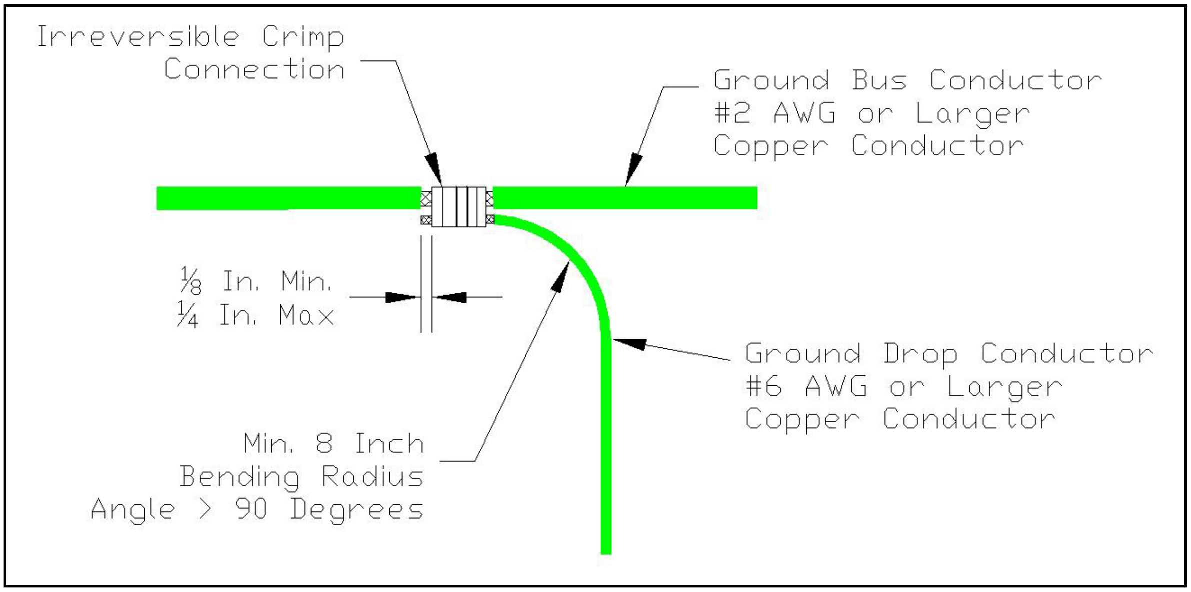



**Figure 5-10: Irreversible Crimp (C-Tap) Connection Detail**

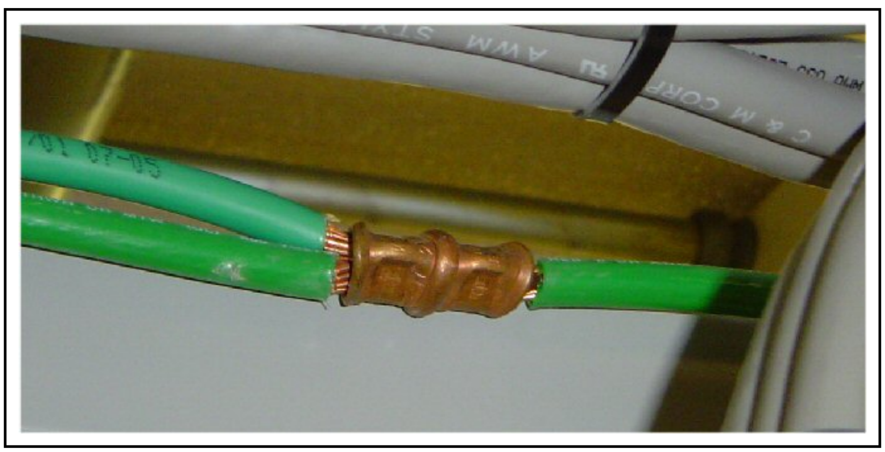


**Figure 5-11: Example of Irreversible Crimp Connection (C-Tap) Before Being Insulated**

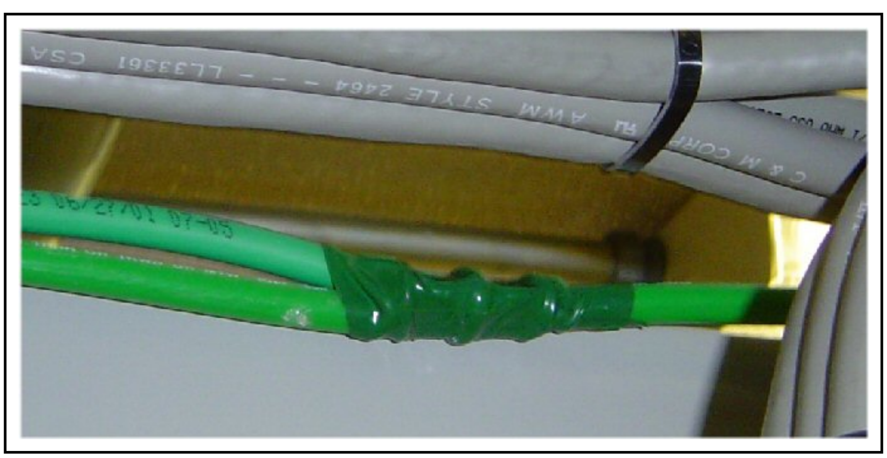


**Figure 5-12: Example of Irreversible Crimp Connection (C-Tap) After Being Insulated**

#### 5.1.2.1 Master Ground Bar Connections

We recommend long barrel two-hole compression lugs for connections to the MGB. You should always place the lugs in direct contact with the surface to which they are attached. You should use bolts in both holes with the lock washers placed on the nut side. If threaded holes are available, you should place a lock washer or star washer under the head of the screw or bolt. Do not piggyback lugs especially on a ground bar. Each connection should use a dedicated bolt or screw. If more connecting points are needed than are available on the existing ground bar, then a second ground bar should be added and bonded directly back to the MGB.

We recommend labeling of each ground bus conductor attached to the MGB.

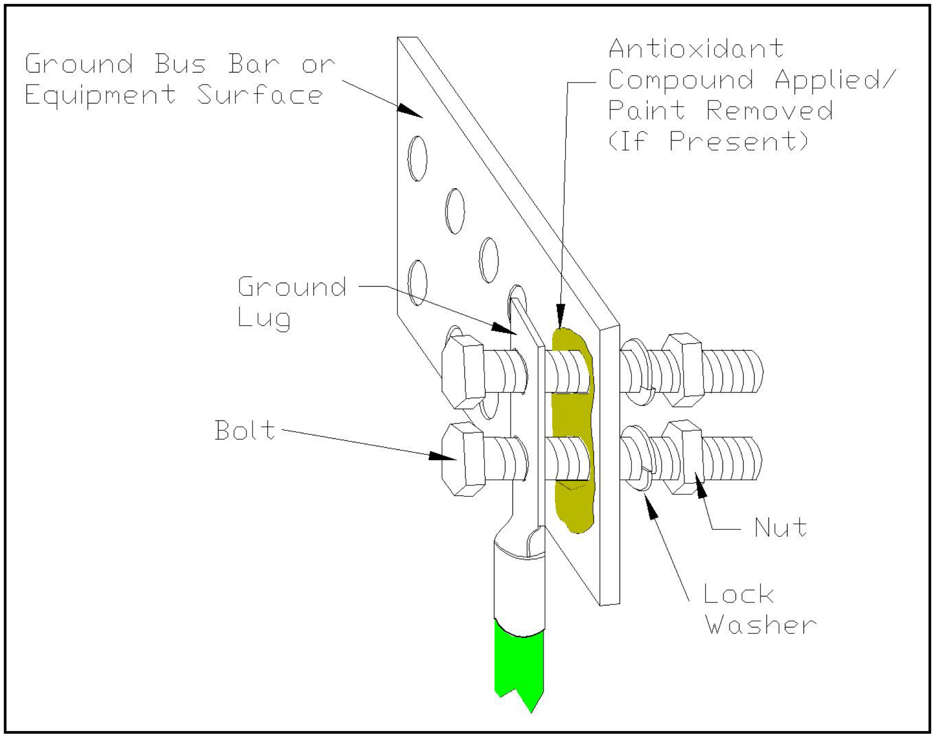



**Figure 5-13: Two-Hole Lug Connection Detail**

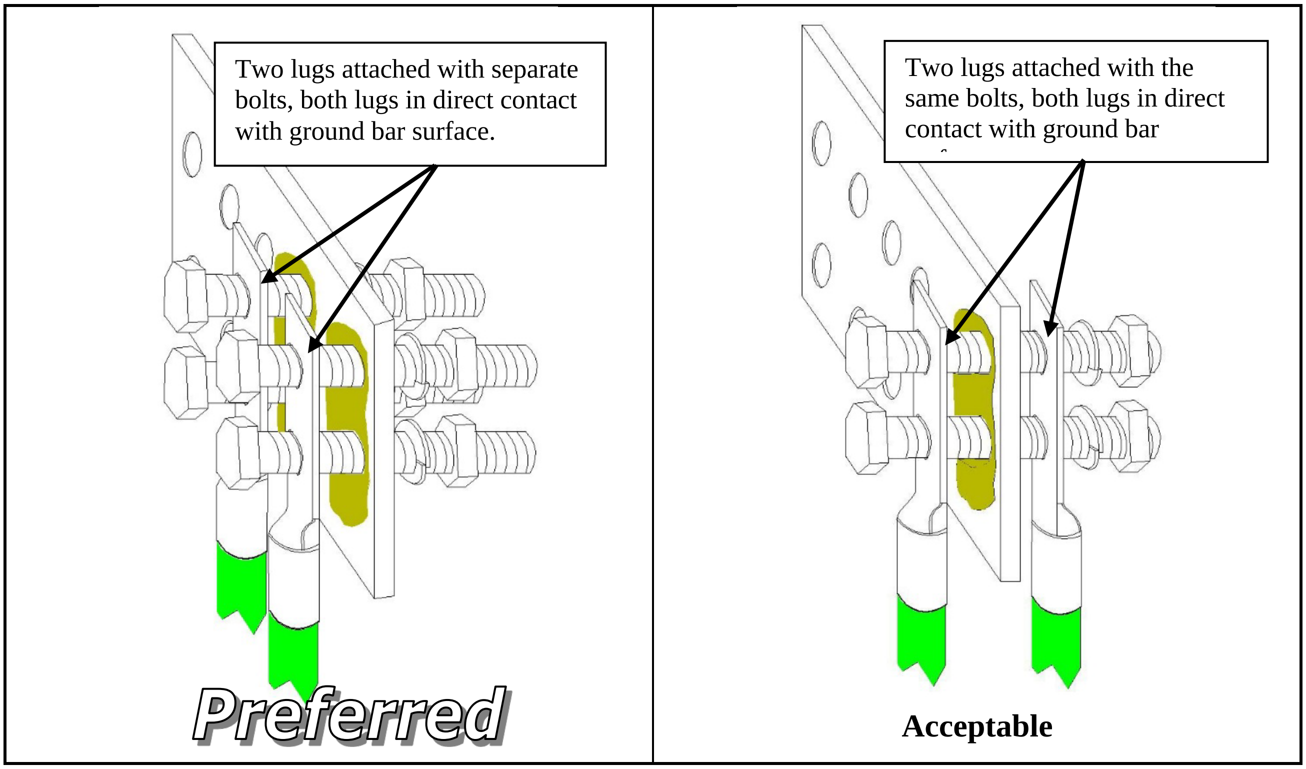



**Figure 5-14: Acceptable Two-Hole Lug Connection Examples**

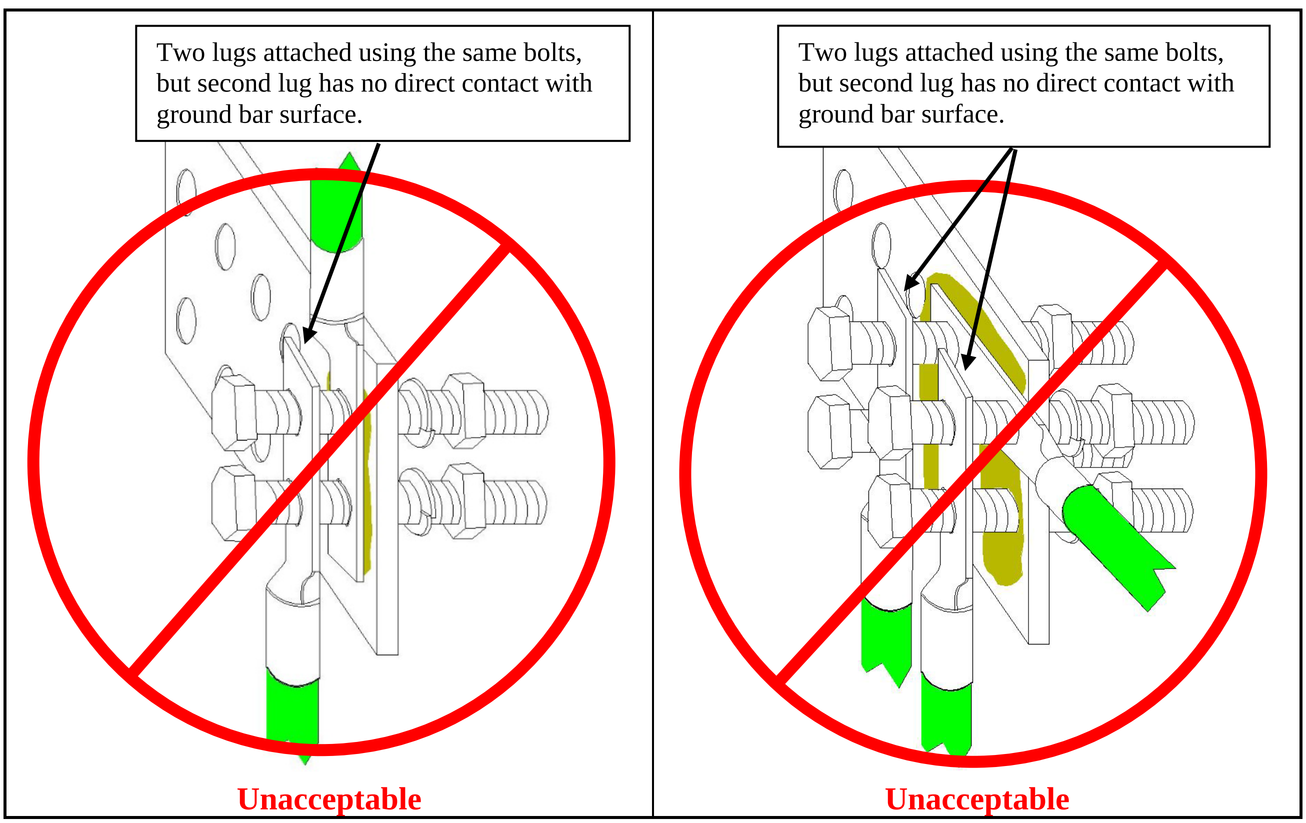



**Figure 5-15: Unacceptable Two-Hole Lug Connection Examples**

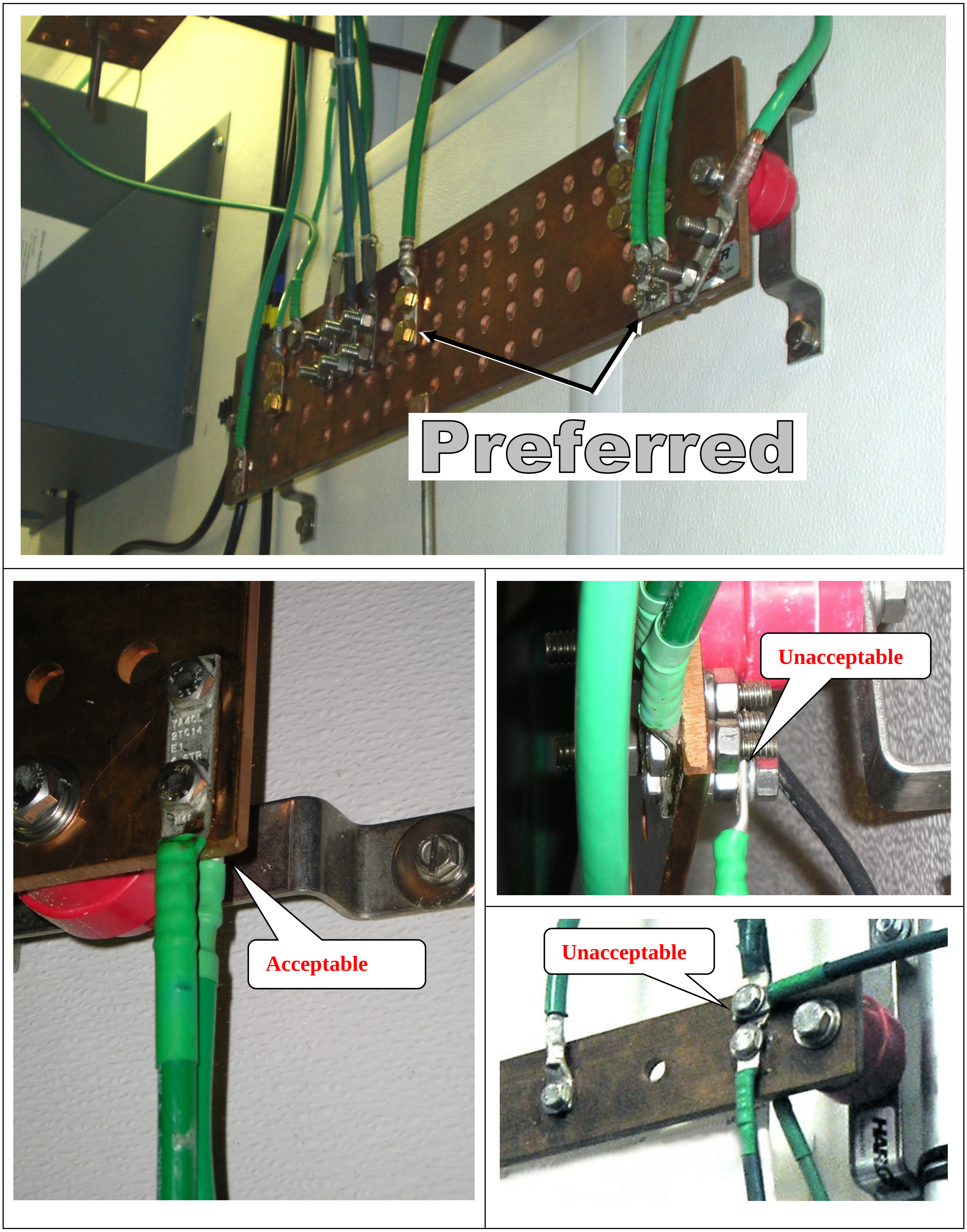



**Figure 5-16: Examples of MGB Connections**

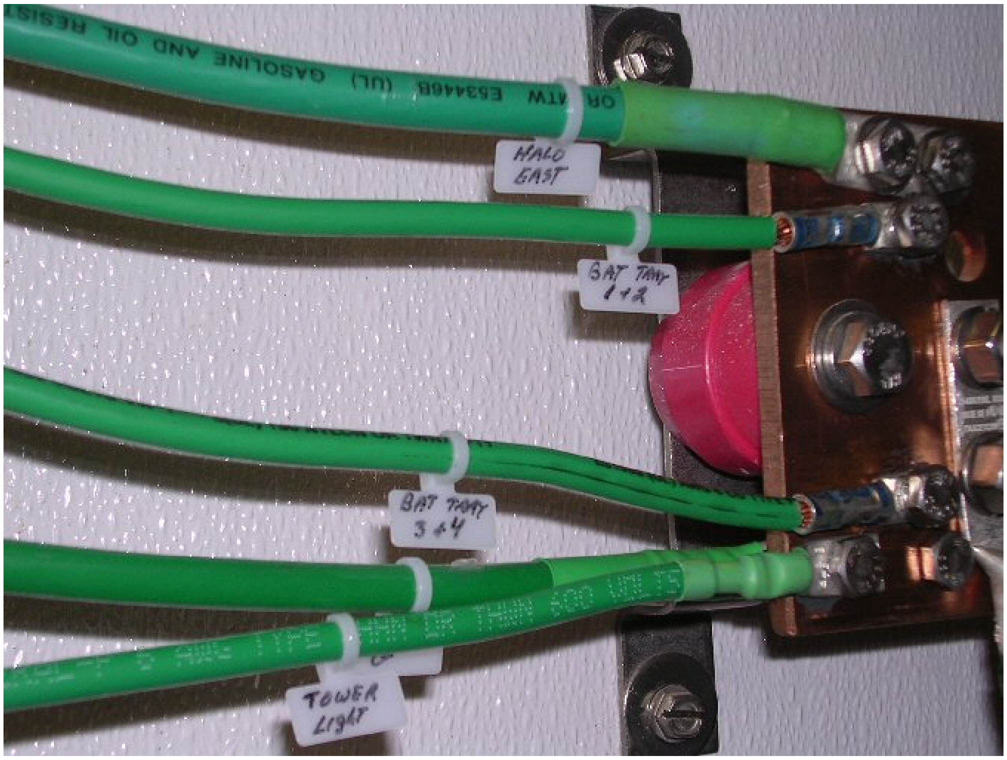



**Figure 5-17: Example of MGB Grounding Conductor Labeling**

### 5.1.2.2 Other Interior Ground Lug Connections

Two-hole lugs are also preferred for other interior connections, but single-hole lugs are acceptable. Always place lugs in direct contact with the surface to which they are attached. Use bolts in both holes with the lock washers placed on the nut side. If threaded holes are available, you should place a lock washer or star washer under the head of the screw or bolt. Do not piggyback lugs. Each connection should use a dedicated bolt or screw.

When making a connection to a surface with paint or other nonconductive coating, remove the paint or coating before installing the lugs. Lugs should be in direct contact with the surface. Do not place star washers between the lug and the surface.

NOTE

Be sure to check all interior ground lug connections for tightness immediately after installation and annually thereafter as part of the site's preventative maintenance routine.

**Ground Attachment for:**

- Racks
- Cable ladders/Trays
- Equipment inside cabinets or racks
- Miscellaneous metallic objects

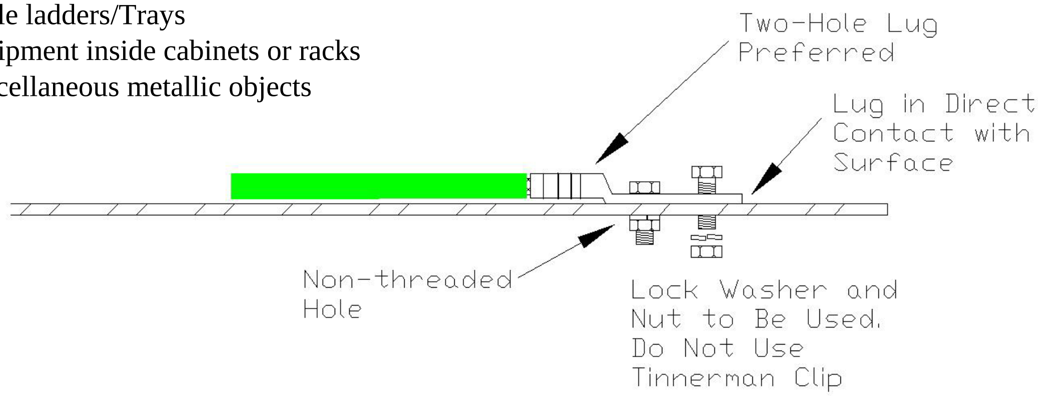



**Figure 5-18: Non-Threaded Hole Ground Attachment Methodology**

**Ground Attachment for:**

- Racks
- Cable ladders/Trays
- Equipment inside cabinets or racks
- Miscellaneous metallic objects

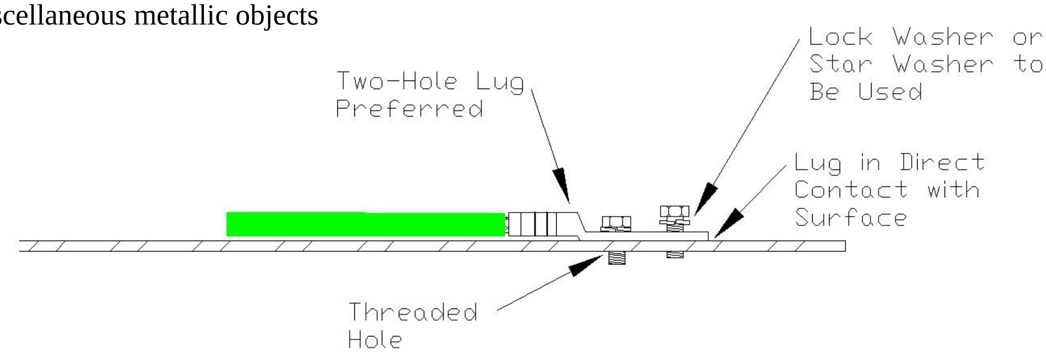



**Figure 5-19: Threaded Hole Ground Attachment Methodology**

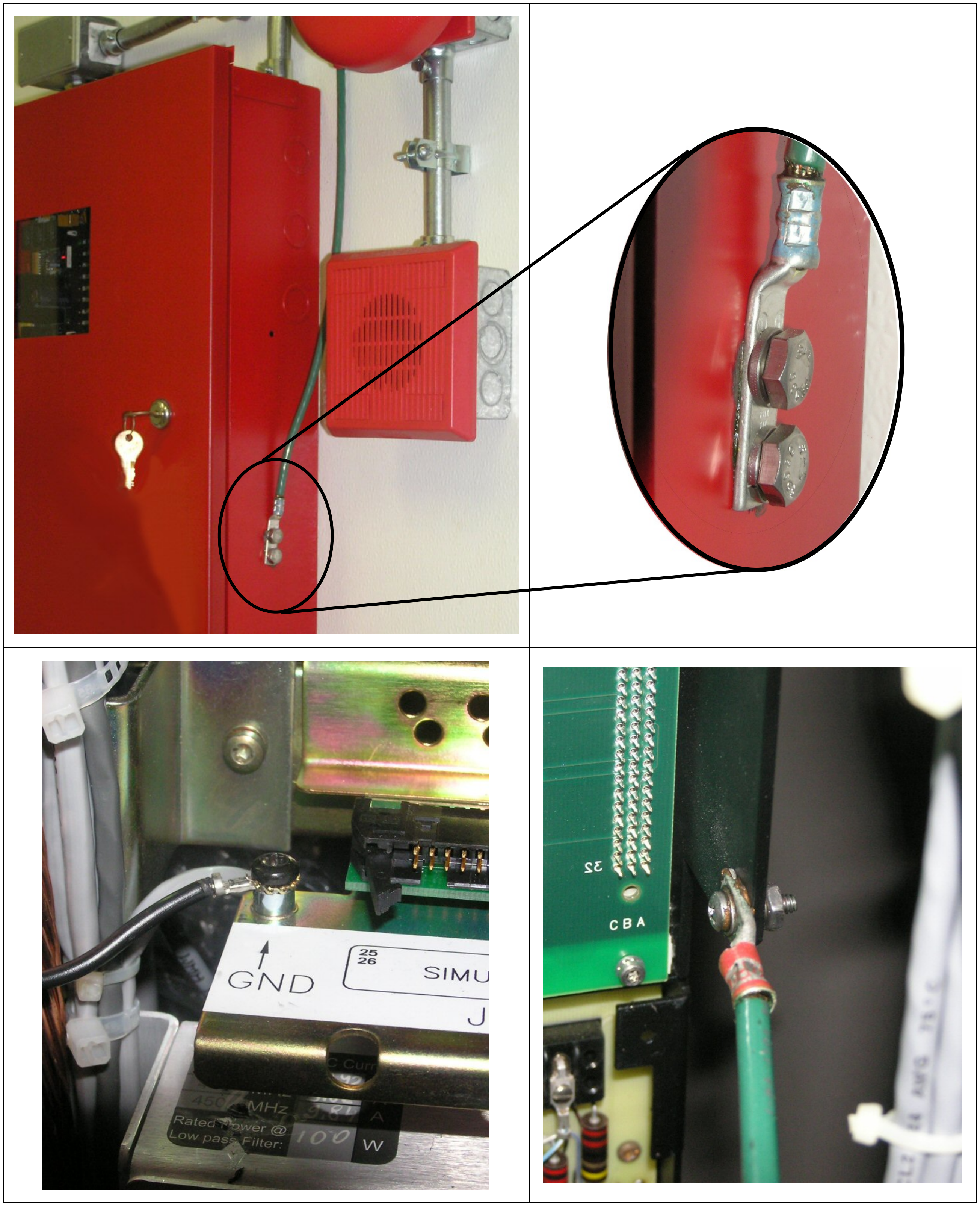



**Figure 5-20: Examples of Interior Ground Connection Attachments**

Connections to pipes, conduit, and other round metallic objects should use an UL-listed brass or bronze bolted clamp.

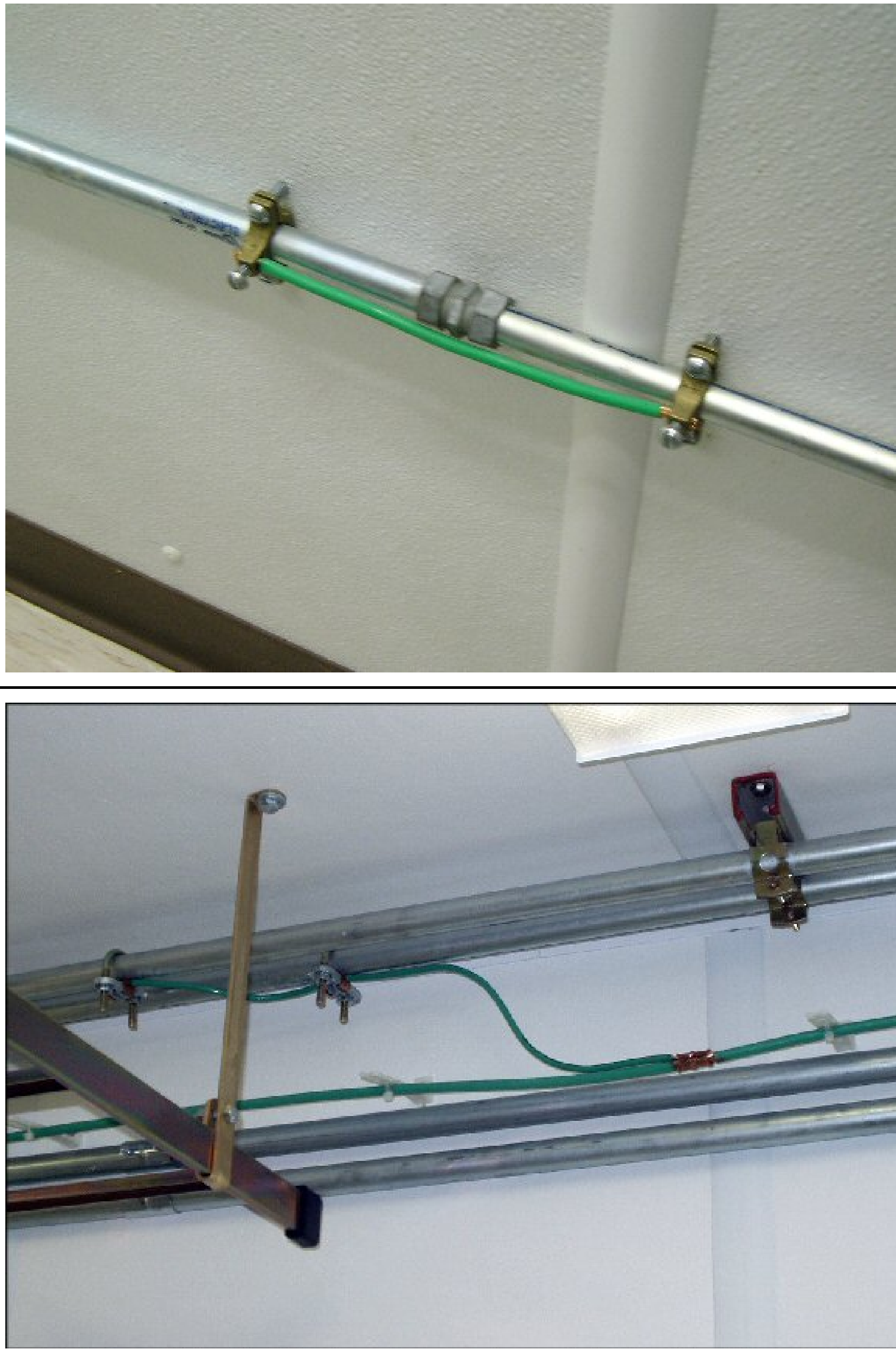


**Figure 5-21: Examples of Clamps Used for Conduit Ground Jumpering**

Connections between two dissimilar metals (see Section 3.2.4.3) should be avoided. If you cannot avoid making dissimilar metal connections, use a bimetal connector approved for the two specific metals. We recommend using a conductive antioxidant compound on all connections, especially for connections between dissimilar metals.

Do not use insulation piercing or aluminum connectors. Do not use self-tapping screws, sheet metal screws, or Tinnerman clips to make connections. Do not use soldered connections.

### 5.1.3 Optimal Location of Utility Entrances

The entry points for the AC power and telecommunications should be located as close to the MGB and RF entry port as possible. This allows optimal single point bonding of the MGB grounding electrode conductor and the AC electrical service and telephone network interface grounding electrode conductors to the exterior grounding electrode system. This minimizes potential current flow through any equipment that may be tied to more than one of these different interfaces.

See Sections 5.6 AC Utility Entrance Grounding and 5.7 Telecommunications Service Entrance for details.

NOTE

Depending on the AC utility entrance configuration, the AC ground connection to the MGB may serve as the grounding electrode conductor as defined by NEC. If so, this eliminates the multipoint ground created by the AC ground rod connection.

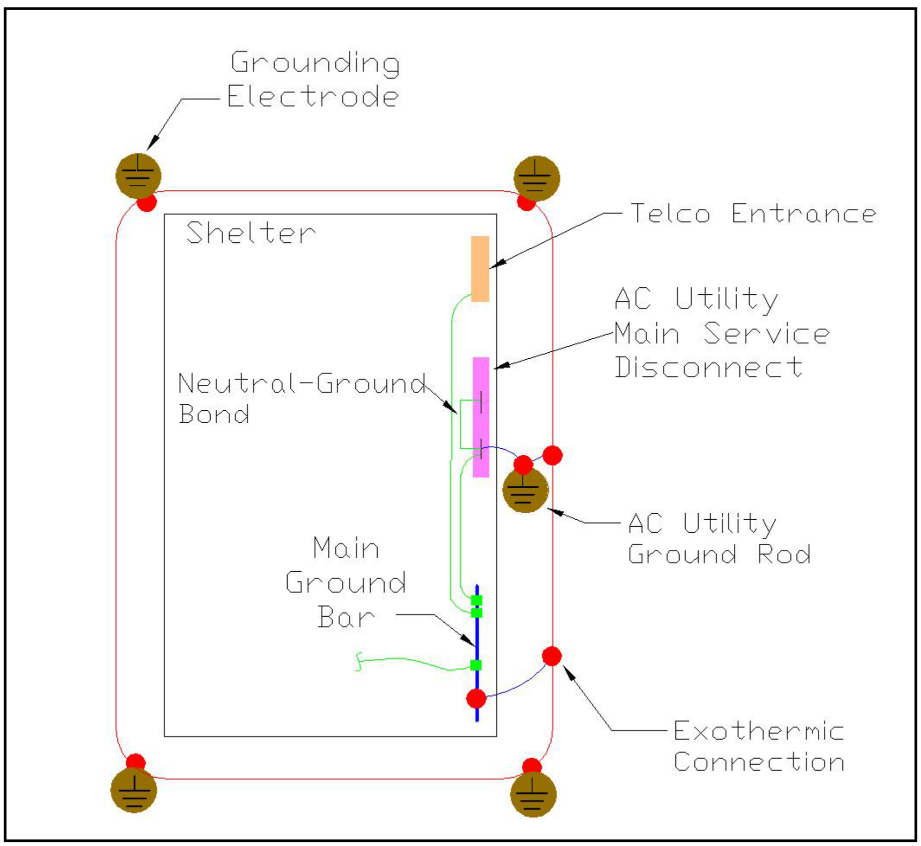



**Figure 5-22: Optimal Location of AC Utility Entrance and Telco Entrances Close to MGB**

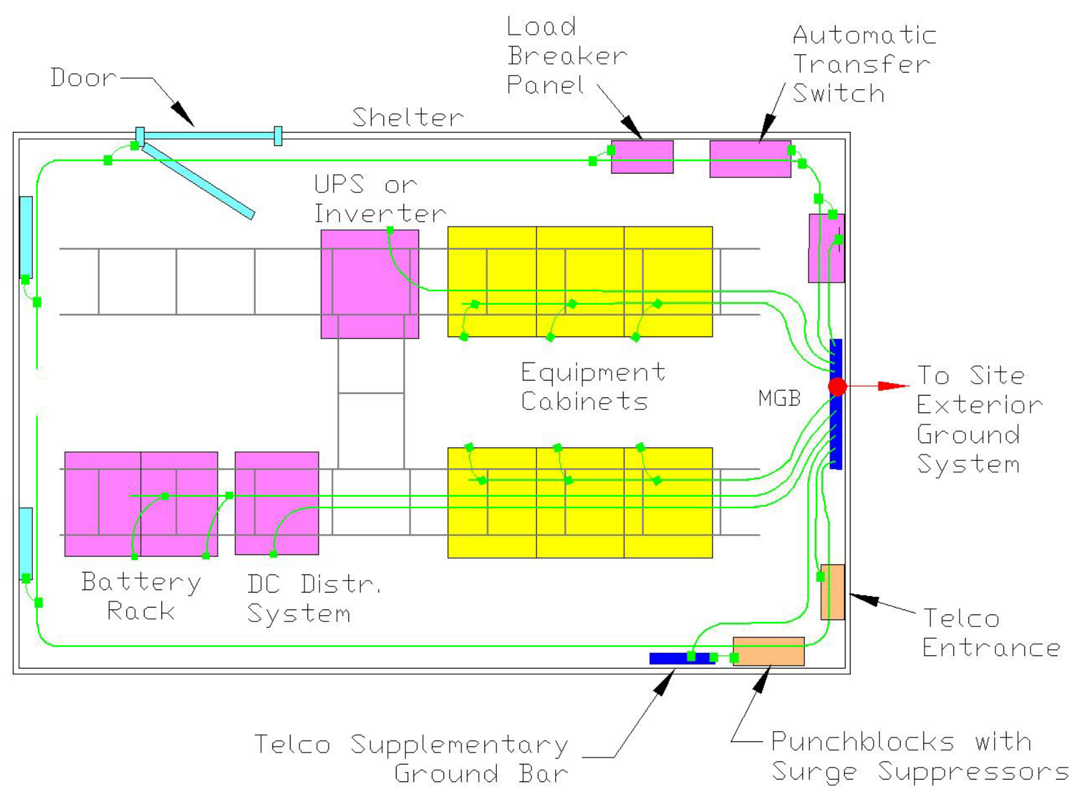
### 5.1.4 Segregation of Different Ground Types

Within a shelter, there are generally three different types of grounds:

- isolated grounds
- non-isolated grounds,
- surge producer grounds

Isolated grounds are from the site equipment. Non-isolated grounds are from the non-current grounds, DC power plant returns, and miscellaneous metallic objects in a shelter. Surge producer grounds are from the AC utility or generator ground and surge arrestors on RF coaxial cables, AC input, tower lighting, telephone lines, alarm lines, etc.

By design, surge arrestors can shunt large amounts of surge current to their grounds when they activate. To avoid localized ground potential rises within the shelter, you should segregate these different types of grounds from one another. You should use a separate ground bus conductor or supplemental ground bus bar for each type of ground when possible. At the MGB where they all connect to the single point earth ground, a special connection order helps to maintain this segregation. (See Section 5.2.1.1 for details.)




**Note:** Equipment cabinet grounds on separate "home runs" to MGB from DC equipment and Telco surge protection SGB "home runs." All miscellaneous metallic objects around perimeter of room bonded to Horseshoe Halo Ground bus.

**Figure 5-23: Example of Segregation of Different Ground Types**

## 5.2 INTERIOR GROUND BUS BARS

Interior ground bus bars provide convenient collecting points to connect multiple ground conductors. The most important interior ground bus bar is the Master Ground Bar (MGB). The MGB is the single point on the inside of the shelter and connects to the exterior grounding electrode system. All interior ground connections should come to the MGB, either directly or through ground bus conductors or through supplemental ground bus bars that are connected back to the MGB.

The interior ground bus bars should be adequately sized with factory pre-drilled holes to accommodate all available grounding conductors. These bonding conductors should be connected with dedicated two-hole lugs and bolts as shown in Section 5.1.2.1. Multiple connections to the same bolt or ground bar hole should be avoided.

Interior ground bus bars should be UL-listed bare copper or electro-tin plated copper at least ¼ inch thick and 2 inches wide. The number of holes (length and width of bar) depends on the number of grounding conductors being connected to the bar. The holes should be the proper size and spaced to accept the two-holed lugs and bolts.

### 5.2.1 <u>Master Ground Bus Bar</u>

The equipment shelter interior **MGB** is **the single point ground** for all equipment and metallic objects located inside the shelter. No other connections to the exterior ground system should be made from inside the shelter.

The MGB should be located on the interior wall of the shelter below the RF entry port. You should securely mount the MGB to the wall using insulated standoffs. The MGB should also be bonded directly to the shelter's buried exterior ground ring as detailed in Section 4.3.2.

The MGB should be adequately sized with factory pre-drilled holes to accommodate all available grounding conductors. It should be UL-listed bare copper or electro-tin plated copper at least ¼ inch thick and 2 inches wide. The number of holes (length and width of bar) depends on the number of grounding conductors being connected. The holes should be the proper size and spaced to accept the lugs and bolts to be used. Two-holed lugs are preferred for connections to the MGB.

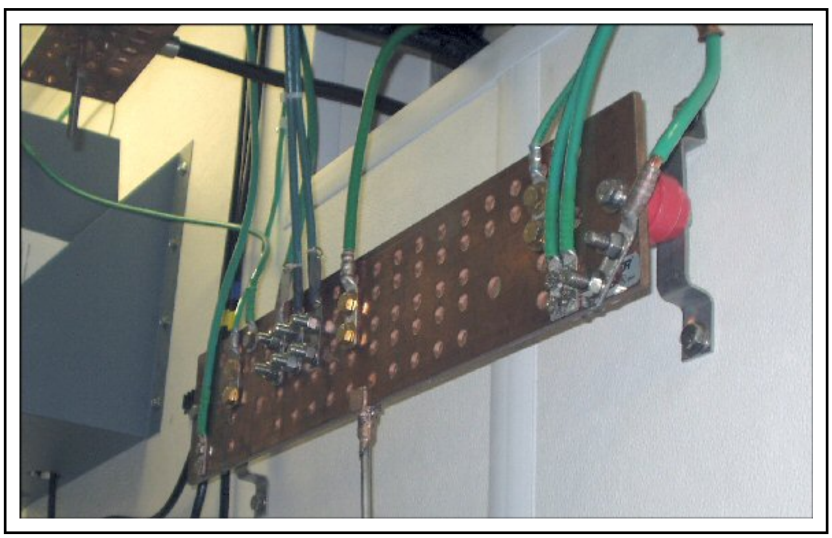


**Figure 5-24: Example of the Master Ground Bar**

#### 5.2.1.1 Ground Connection Order to Master Ground Bar

We recommend using the PANI method when making connections to the MGB. This method allocates specific areas of the MGB for bonding the following:

- surge energy producers (P)
- surge energy absorbers (A)
- non-isolated grounds (N)
- isolated grounds (I)

The idea behind this ordering is that all of the surge energy producers are separated from the other interior grounds by the low impedance direct path to earth ground. The isolated equipment grounds are placed at the far end of the MGB to provide the most isolation.

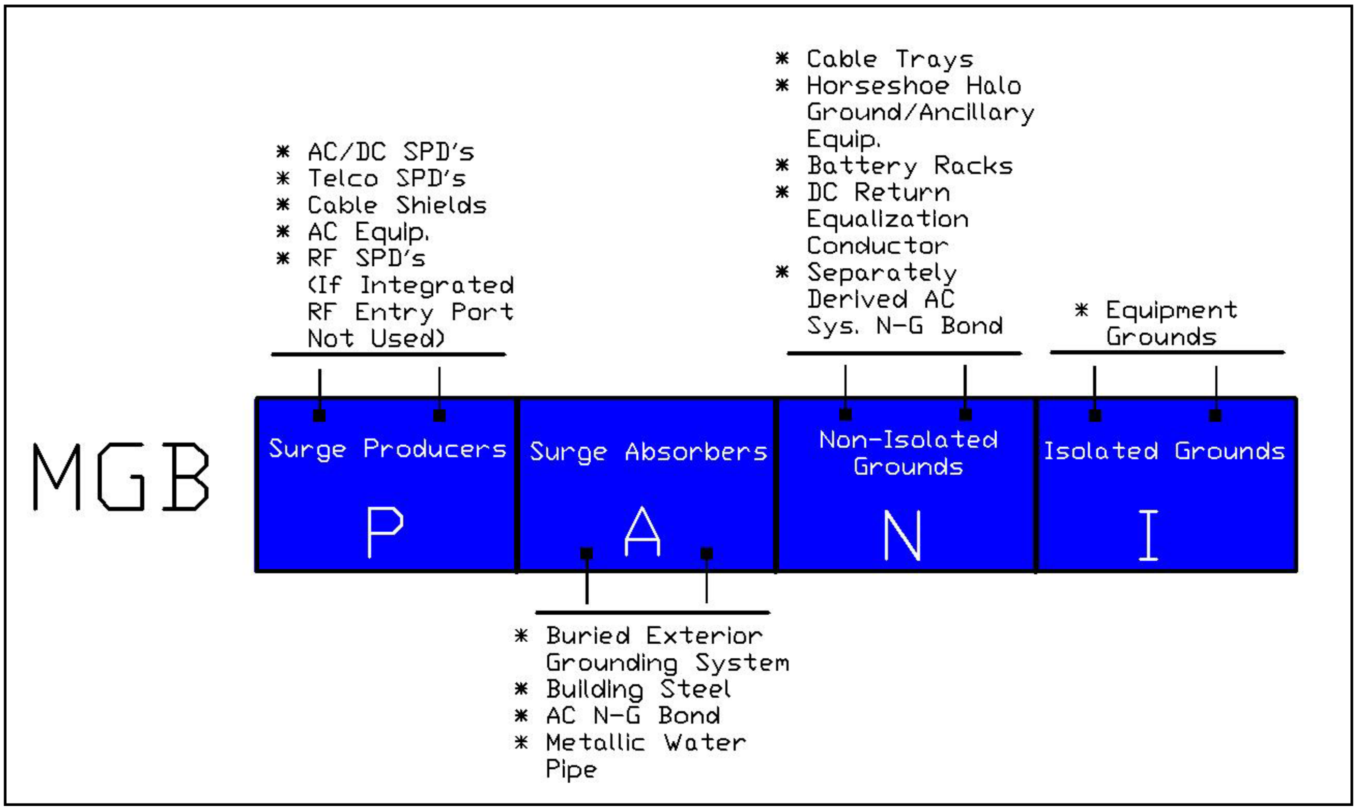



**Figure 5-25: Recommended PANI Ground Attachment Order on MGB**

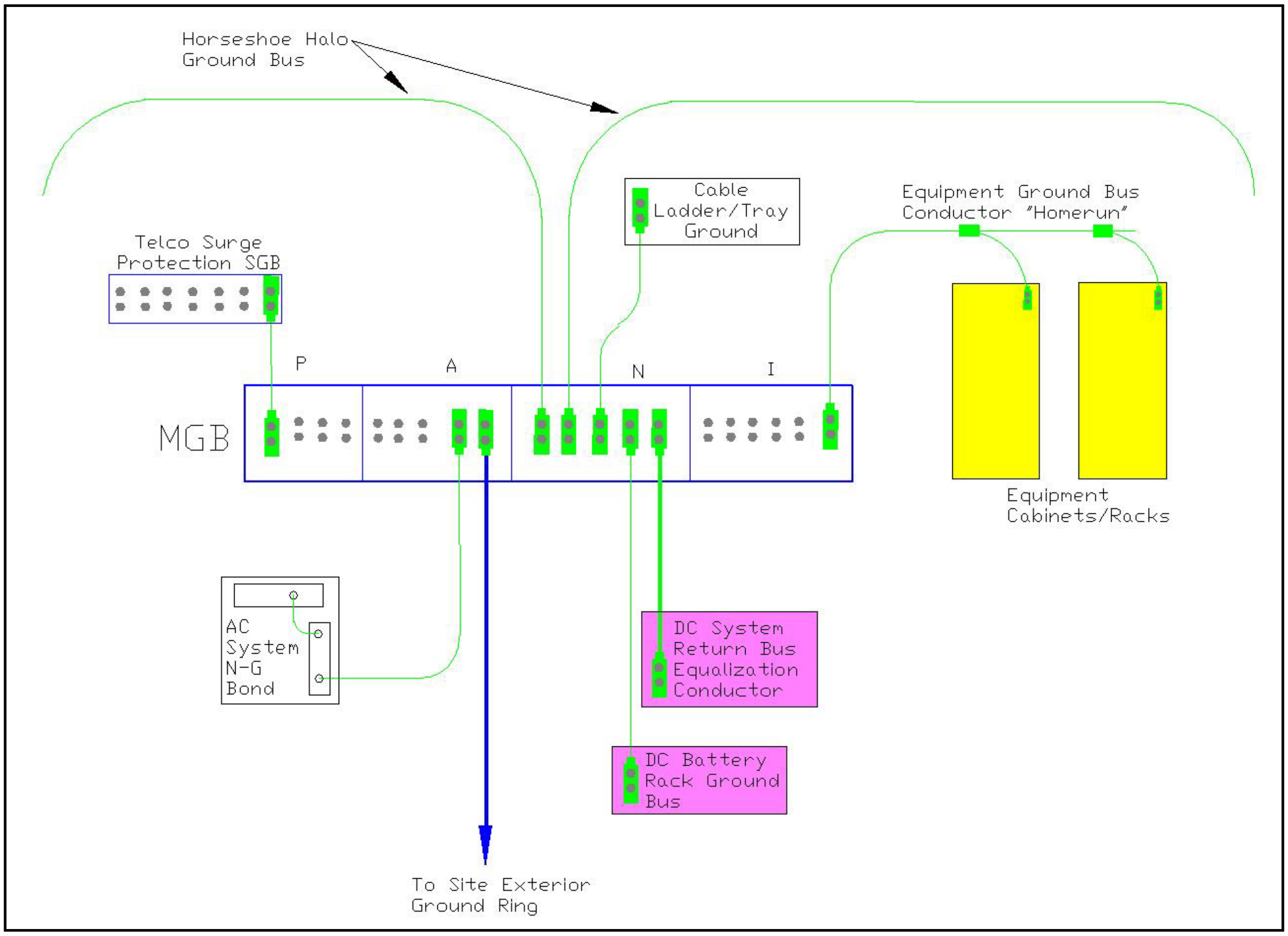



**Figure 5-26: Typical Connections Made to MGB at RF Site**

### 5.2.2 Supplemental Ground Bus Bars

The equipment shelter interior MGB is the single point ground for all equipment and metallic objects located inside the shelter. No other connections to the exterior ground system should be made from inside the shelter. However, you may install one or more Supplemental Ground Bars (SGB) in the equipment room or nearby rooms to gather multiple ground connections in that location. The SGB is bonded directly back to the MGB using a dedicated #2 AWG, or larger, copper conductor. If the SGB is located more than 75 feet from the MGB, then a #2/0 AWG, or larger, copper conductor should be used.

Some SGBs are co-located in the equipment room with the MGB. These SGBs gather large numbers of RF surge arrestor grounds or telecommunications line surge arrestor grounds. Other SGBs are located in rooms away from the MGB. This includes SGBs in a generator room, DC power plant room, equipment subsystem room, or co-located dispatch console room.

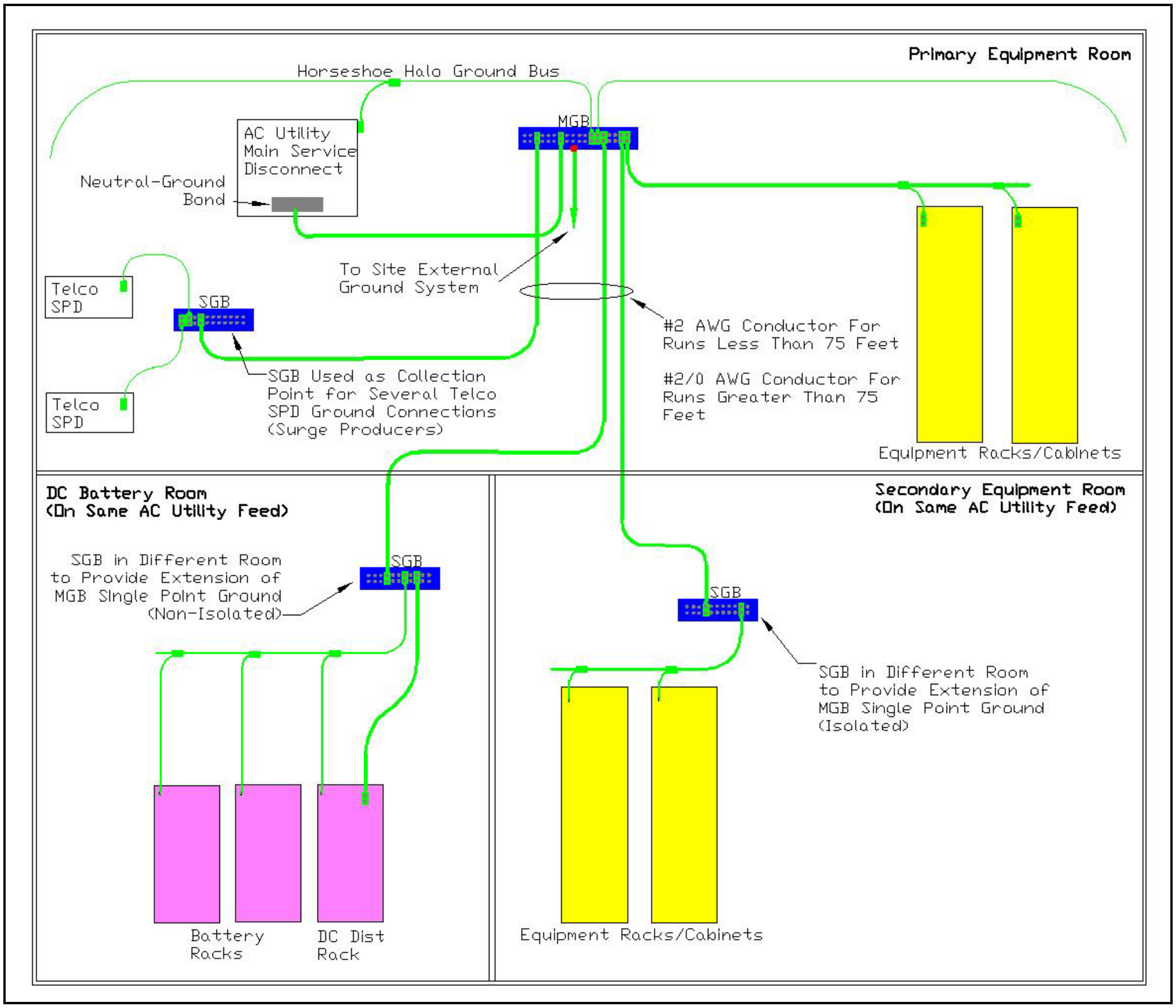



**Figure 5-27: Examples of Acceptable Supplemental Ground Bar Applications**

When possible, do not mix surge arrestor grounds and other isolated or non-isolated grounds on an SGB.

Applications not suitable to using a SGB are separate buildings, or even areas in the same building, that receive AC utility power from an alternate source that does not connect to the MGB.

Securely mount the SGB to the wall using insulated standoffs. The SGB should be adequately sized with factory pre-drilled holes to accommodate the needed grounding conductors. It should be UL-listed bare copper or electro-tin plated copper at least ¼ inch thick and 2 inches wide. The number of holes (length and width of bar) depends on the number of grounding conductors being connected. The holes should be the proper sized and spaced to accept the lugs and bolts being used. Two-hole lugs are preferred for connections to the SGB.

Bond the SGB to the MGB using a dedicated #2 AWG, or larger, stranded copper conductor.

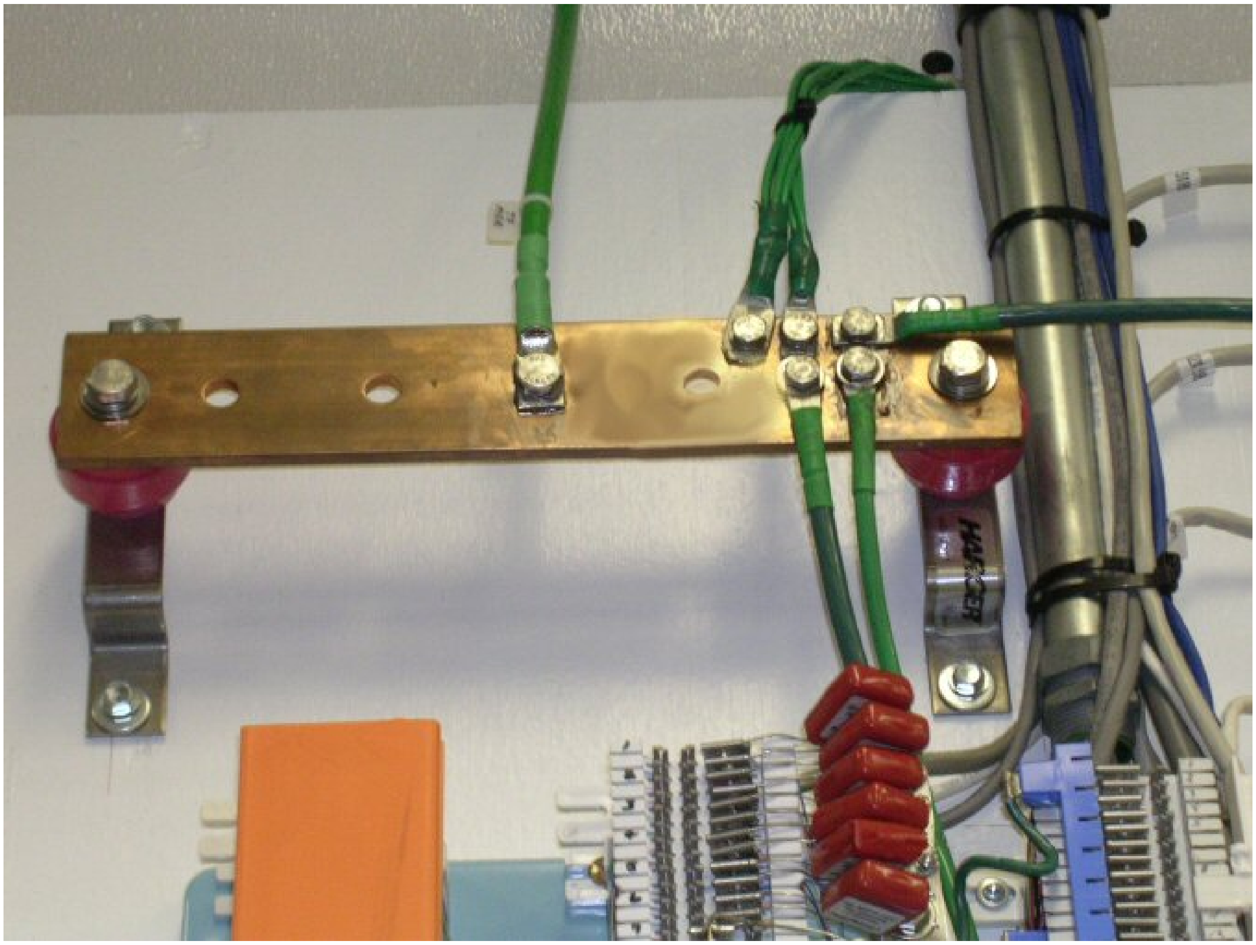


**Figure 5-28: Typical Supplemental Ground Bar Application**

## 5.3 RF ENTRY PORT/BULKHEAD PANEL (RF SURGE PROTECTOR GROUNDING)

A weatherproof metal RF entry port or bulkhead panel must be installed on the shelter or building wall where the RF transmission lines enter. The number and diameter of the transmission lines passing through it determine the panel size. Use appropriate cable boots to weatherproof the connections.

There are multiple RF entry port options available. Some options include entry ports with integrated RF transmission line ground clamps and sometimes grounding/mounting for RF surge suppressors. Other RF entry port options provide only waterproof entry boots that require the use of a separate shelter EGB for bonding of RF transmission line grounding kits. (See Section 4.3.2 for more details.)

### 5.3.1 RF Entry Port with Integrated RF Surge Suppressor Grounding

RF entry ports designed with integrated RF ground clamps and integrated RF surge suppressor grounding usually have pre-attached solid copper straps that connect directly to the exterior buried ground system directly below the RF entry port. (See Section 4.3.2.1 for more details.)

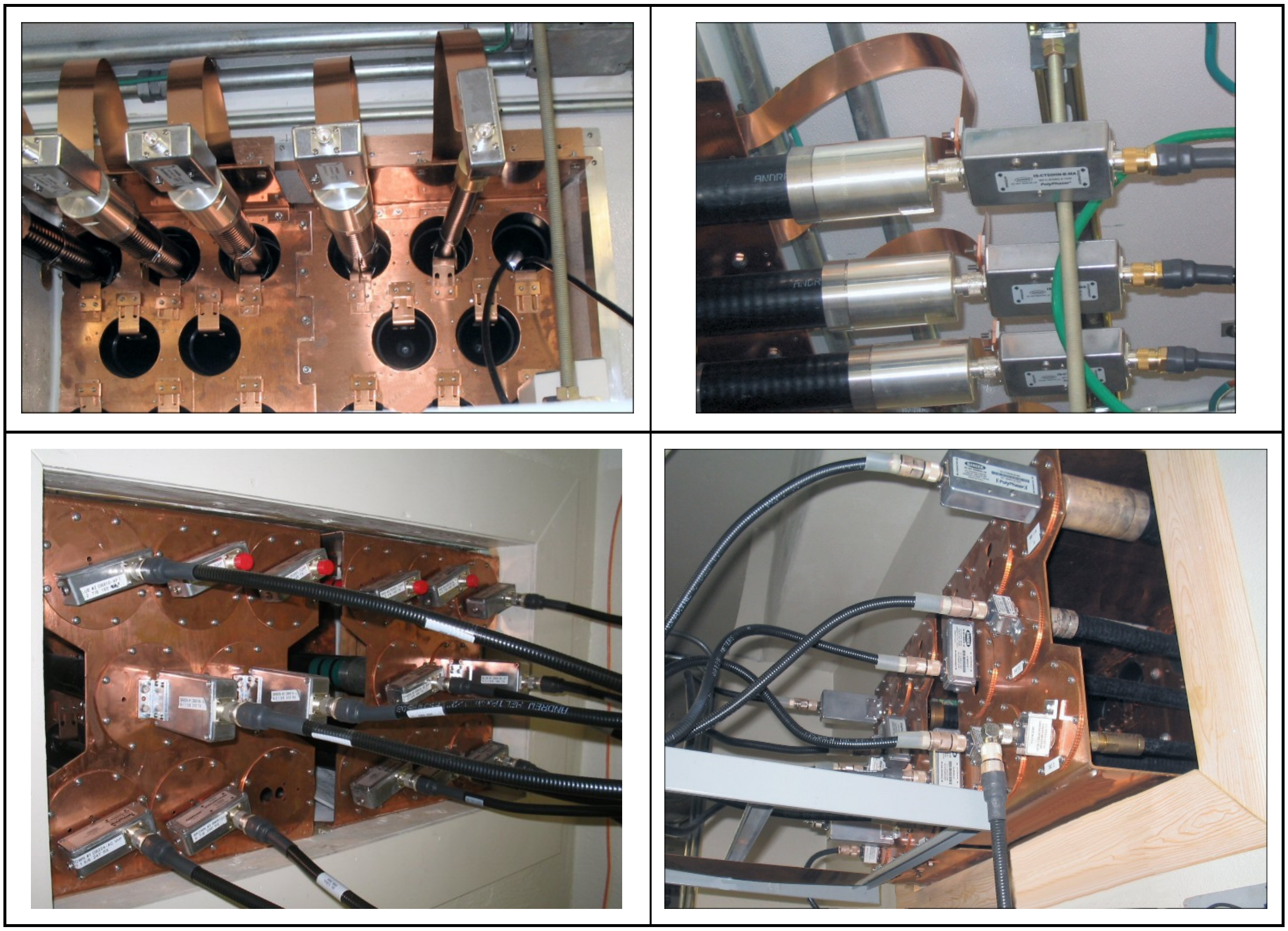


**Figure 5-29: Example of RF Surge Suppressors Grounded Directly to Two Different Styles of RF Entry Panel**

The RF surge suppressor mounting methods may differ, but the RF entry port's interior sub panel is designed to be the grounding point for the RF surge suppressors. You should install the RF entry port and surge suppressors according to the manufacturer's recommendation. This will ensure proper bonding of the various components to the exterior section and its copper straps.

When this type of RF entry port is used, bond all RF surge suppressors to the RF entry port's interior sub panel and not to the MGB.

### 5.3.2 RF Entry Port without Integrated RF Surge Suppressor Grounding

RF surge suppressors at RF entry ports that only provide waterproof entry boots need to be grounded to the MGB.

Any surge suppressor not attached directly to the RF entry port should be grounded to a ground bar (preferably the MGB) by short lengths of an insulated #6 AWG (or larger) conductor or flexible copper straps. Multiple RF surge suppressors may necessitate using an RF surge suppressor supplemental ground bar (RF SGB) to provide enough grounding points. You may use the RF SGB to provide both a mounting platform and grounding point.

You must connect the RF SGB to the MGB using a #2 AWG, or larger, insulated cable using two-hole lugs. This RF SGB must be located within 2 feet of the RF entry port and within 2 feet of the MGB. If multiple RF SGBs are required to accommodate a large number of RF surge suppressor ground connections, each RF SGB should have a separate connection to the MGB.

If connecting more than eight RF surge suppressors to any RF SGB, then #2/0 AWG copper conductor is recommended to bond the RF SGB back to the MGB.

It is very important that the RF entry port or bulkhead panel is properly grounded and that it is only grounded one time to the EGB. If the RF entry port consists of interior and exterior sub panels, the interior sub-panel must be securely bonded to the exterior bulkhead panel.

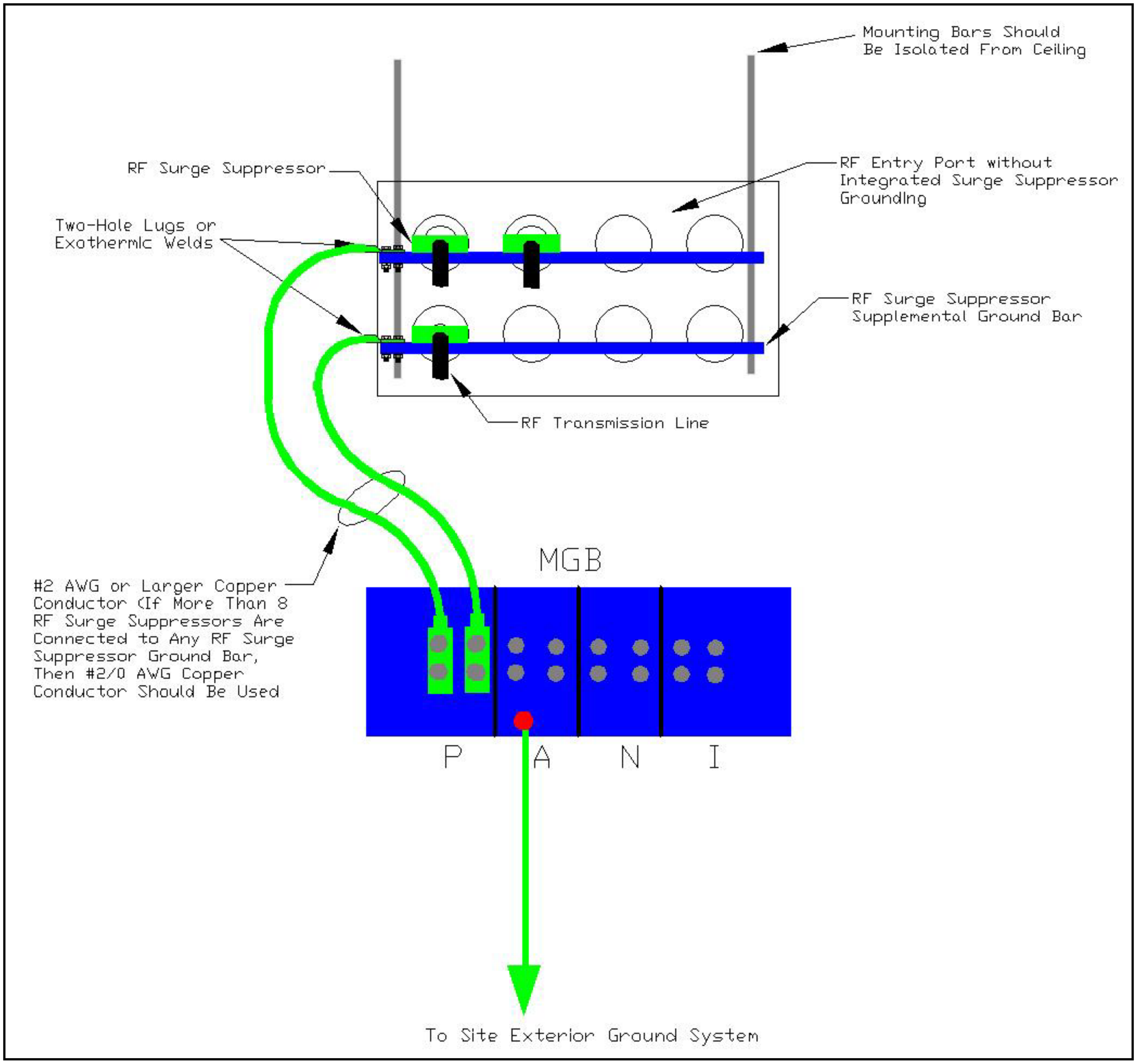



**Figure 5-30: RF Surge Suppressor Mounting to RF SGB Detail**

You should attach RF surge arrestor grounds to the MGB in the PANI Surge Producers section.

Contact Harris Systems Engineering for guidance in selecting recommended RF entry port or bulkhead products.

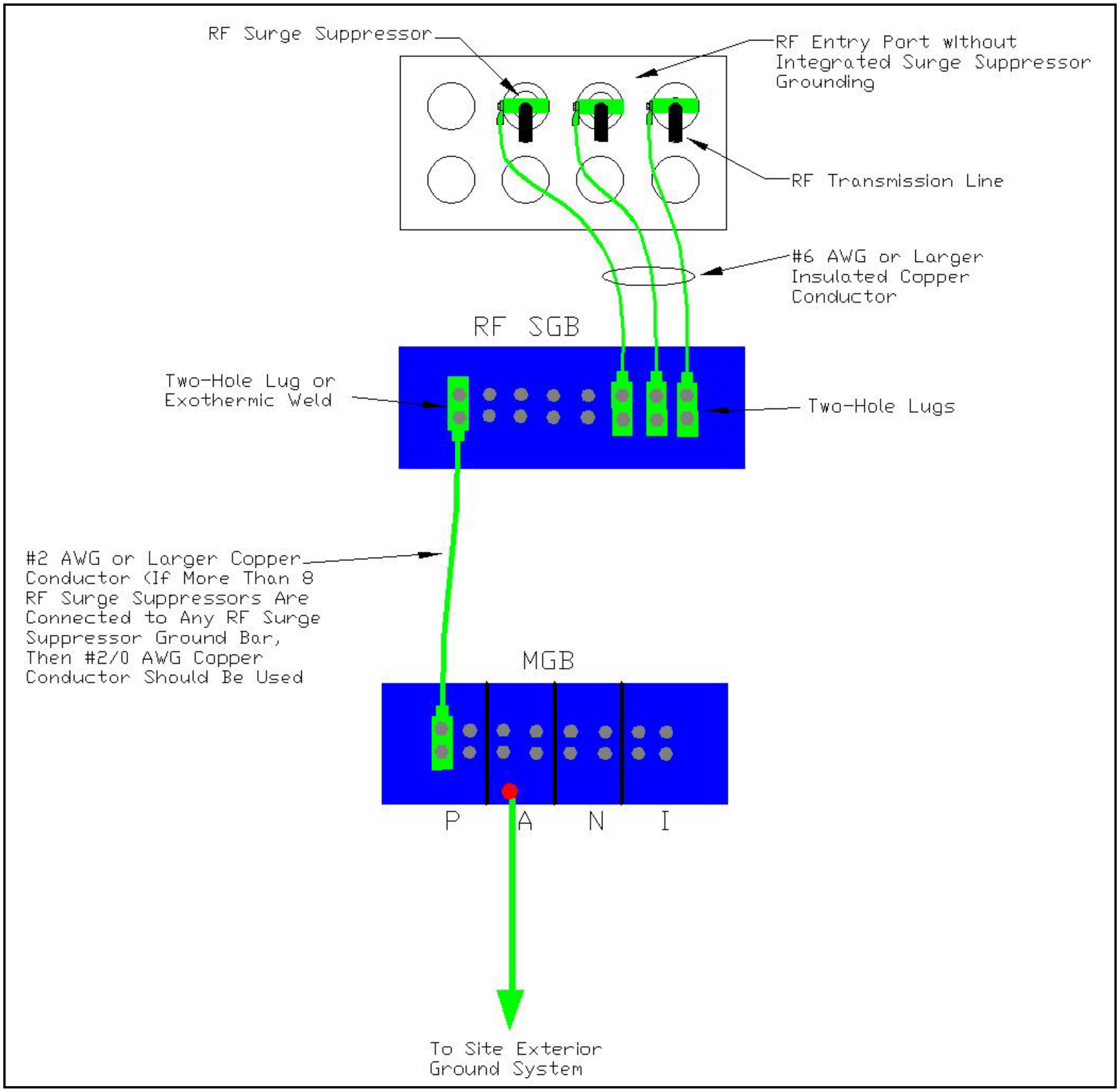



**Figure 5-31: RF Surge Suppressor Bonding to RF SGB Detail**

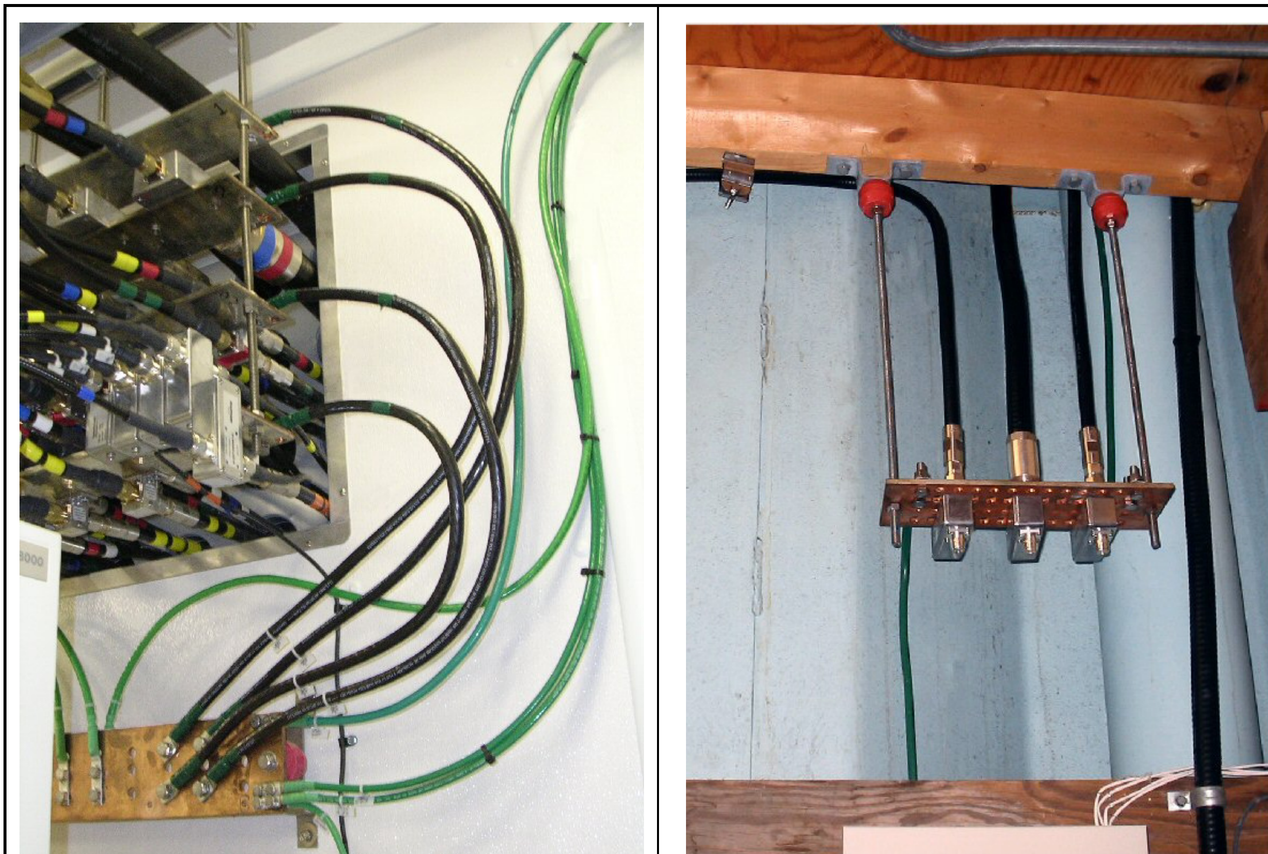


**Figure 5-32: Examples of RF Surge Suppressors Grounded to RF SGBs Bonded to MGB**

## 5.4 EQUIPMENT/RACK GROUNDING

Each equipment cabinet, rack, or shelf and its enclosed equipment must be grounded to the MGB. Metallic equipment enclosures used inside of communications shelters must also be connected back to the MGB. Attach equipment grounds to the MGB in the PANI-Isolated Grounds section.

### 5.4.1 Equipment Ground Bus Conductors "Home Runs"

The recommended method of grounding equipment racks back to the MGB is to run one or more equipment ground bus conductors from the MGB along the equipment rows. This ground bus conductor is a #2 AWG, or larger, copper conductor, often called a "home run." It may have branches of similar size conductor coming from the home run to access multiple rows of equipment. This ground bus conductor has equipment grounding drop conductors ("drops") of #6 AWG, or larger, stranded copper conductor going to each rack or cabinet.

We recommend no more than 16 cabinet grounds be connected to each equipment ground bus home run and its associated branches.

The ground bus conductor and its branches are usually installed in the cable ladders or trays either above or below the equipment rows. The conductor should be installed with all bends going toward the MGB with an 8 inch minimum bend radius and angles greater than 90 degrees. The ends of the ground bus conductor and its branches should be left unterminated at the end of the equipment rows. It should never be attached to the cable ladder or tray since this would create a ground loop.

A non-conductive covering, either electrical tape or heat shrink, should be placed over the unterminated ends of the equipment ground bus conductor and any branch connections to avoid incidental ground contact with the cable ladder or tray.

### 5.4.2 Equipment Ground Drop Conductors "Drops"

Most equipment cabinets or racks are equipped with an internal ground bus to which all of its interior components are grounded. This internal ground bus may be a copper bar or a copper conductor.

Each equipment cabinet or rack's internal ground bus should be attached to a drop from the equipment ground bus conductor. This connection should be made at the end of the rack ground bus closest to the ground bus conductor.

Some cabinets or racks may incorporate a single continuous length of conductor that serves as both the drop from the equipment ground bus home run and the internal cabinet ground bus.

Equipment ground drop conductors should be #6 AWG, or larger, stranded copper conductor. They should be attached to the equipment ground bus home run using an irreversible crimp connection and to the cabinet or rack's internal ground bus with an appropriate termination. The length of these connections should be kept as short as possible while maintaining an 8 inch minimum bend radius and angles greater than 90 degrees.

Each equipment cabinet or rack should be connected to the equipment ground bus conductor home run with a separate drop conductor. Equipment cabinets or racks should not be daisy chained together.

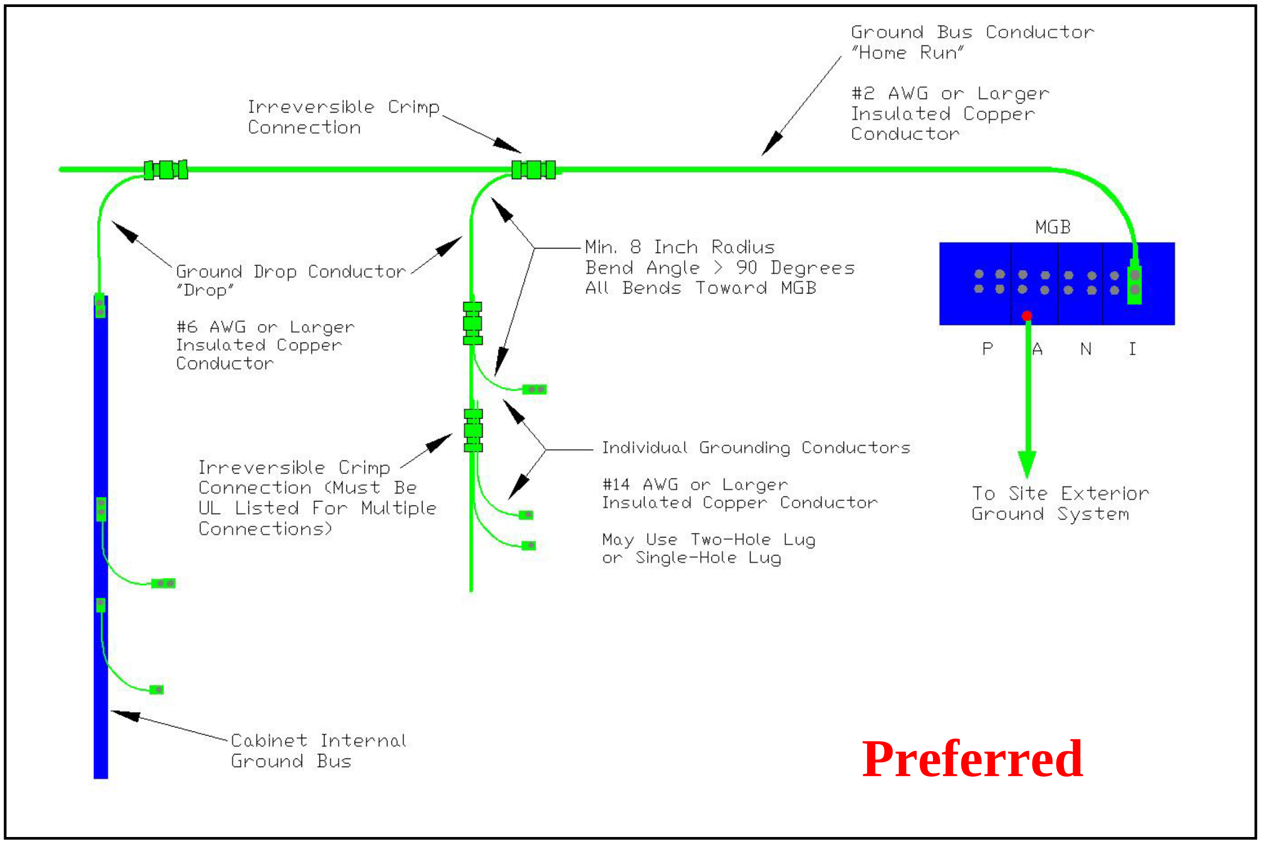



**Figure 5-33: Preferred Equipment Grounding Conductor Practices**

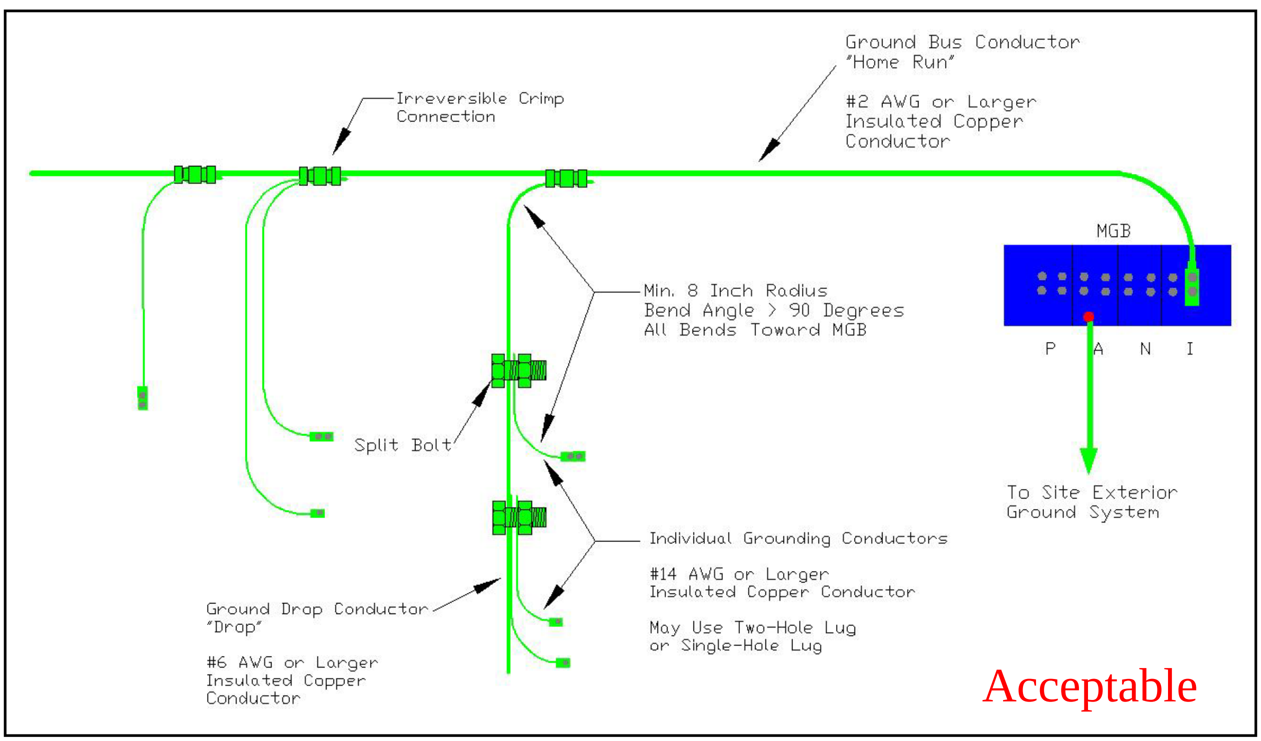



**Figure 5-34: Acceptable Equipment Grounding Conductor Practices**

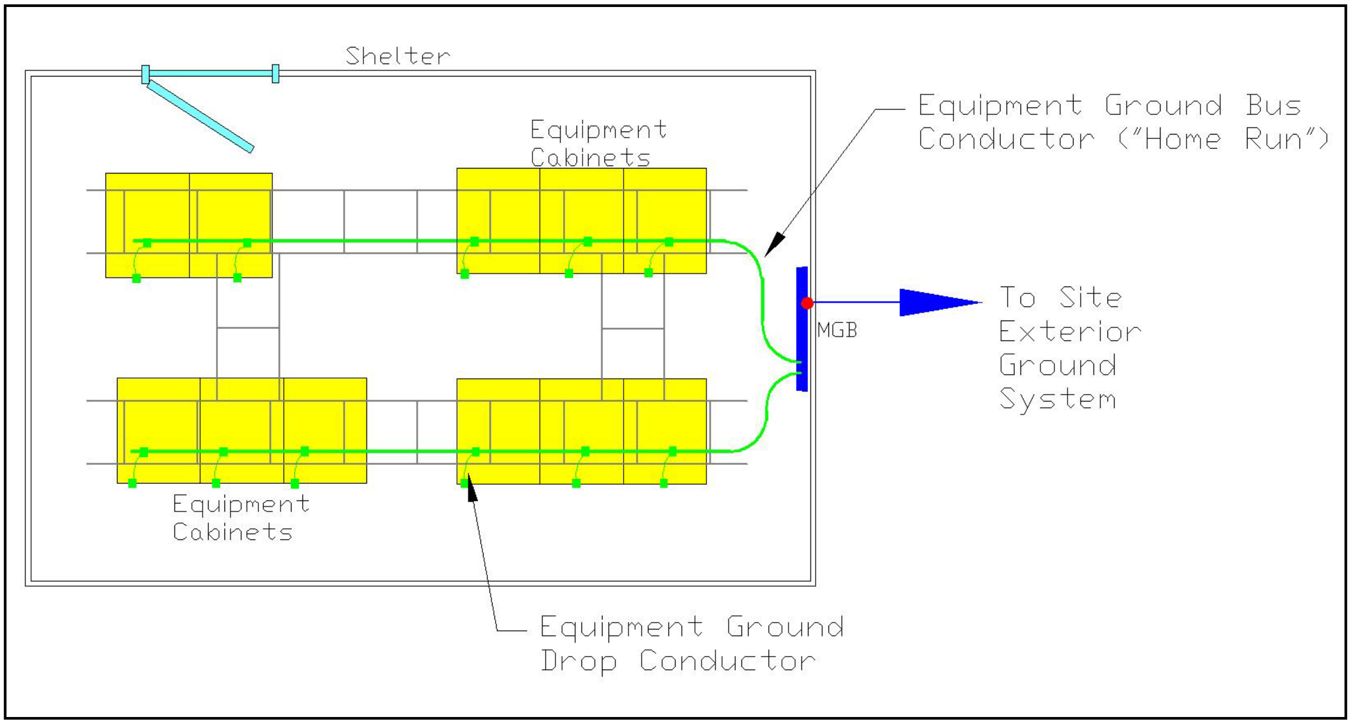



**Figure 5-35: Typical Equipment Ground Bus Conductor Routing**

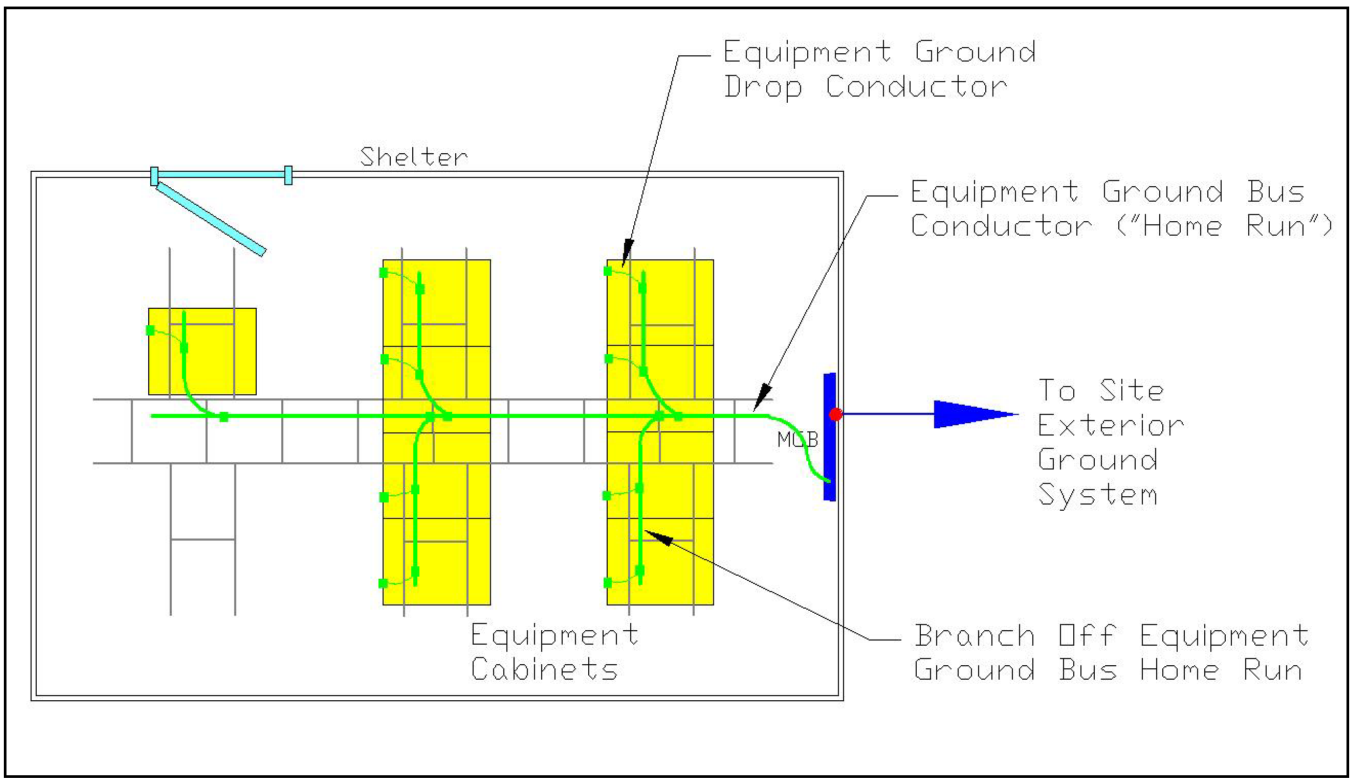



**Figure 5-36: Typical Equipment Ground Bus Conductor Branches**

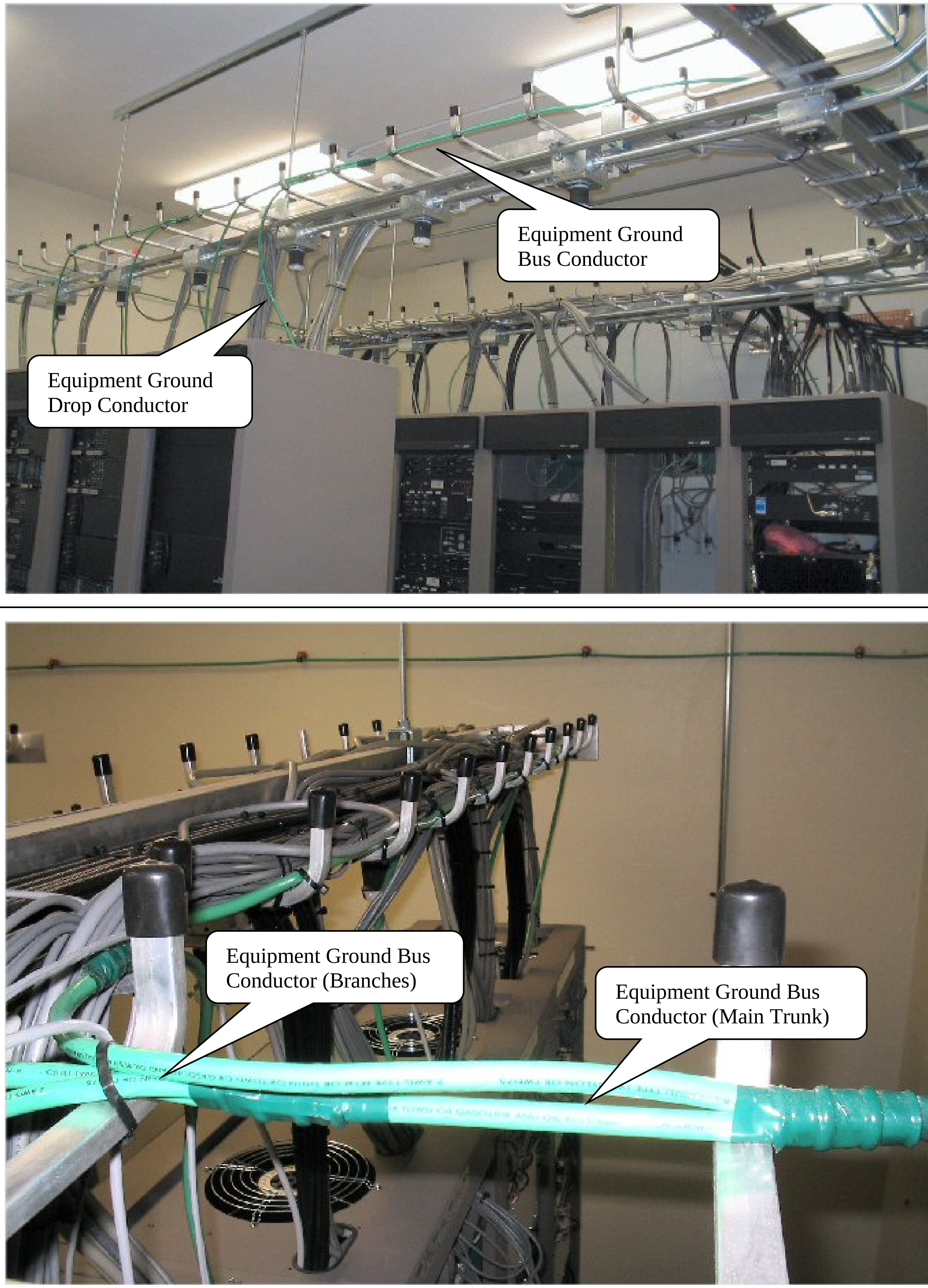



**Figure 5-37: Example Equipment Ground Bus Conductors**

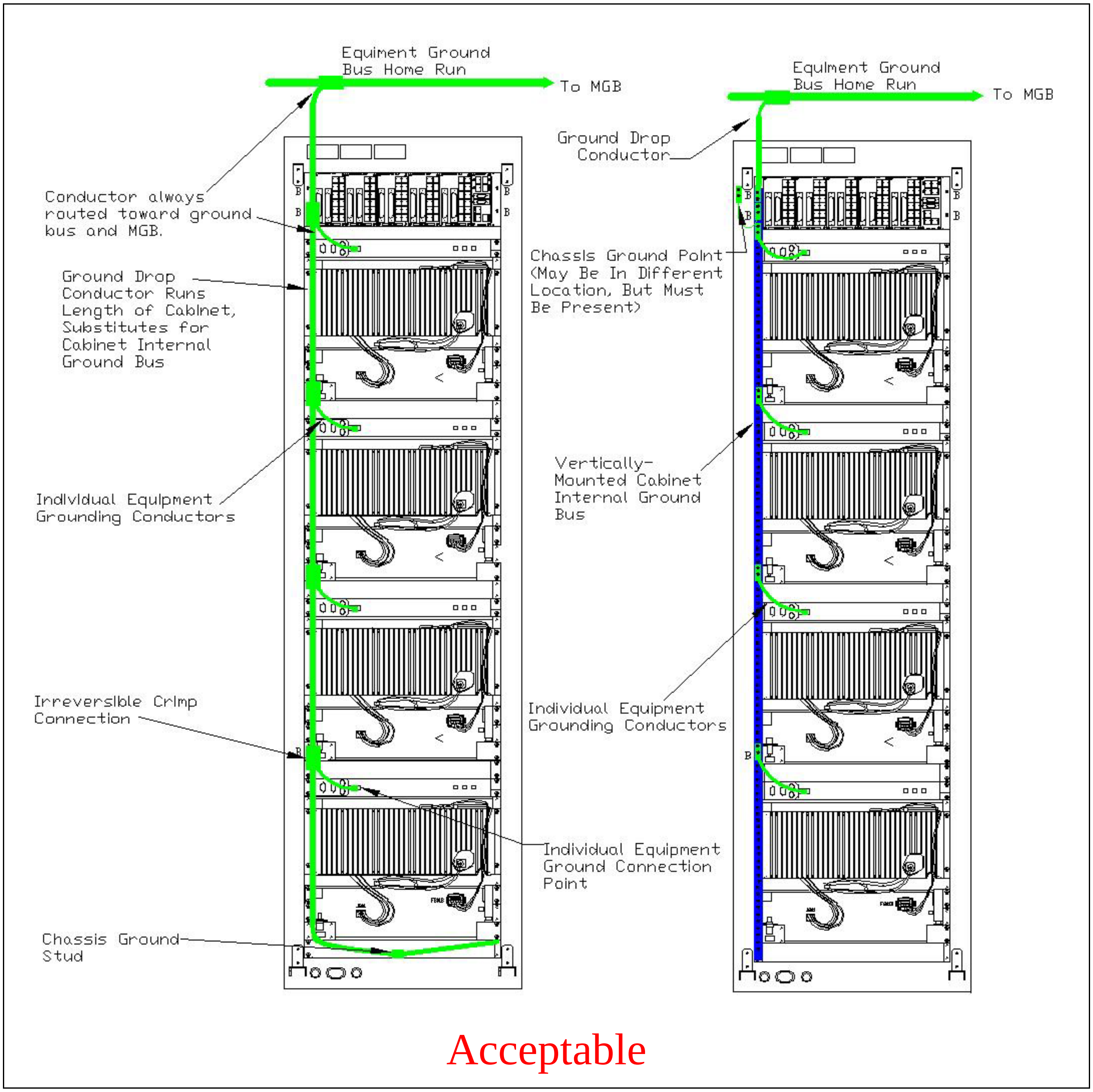



**Figure 5-38: Acceptable Equipment Ground Drop Conductor Applications**

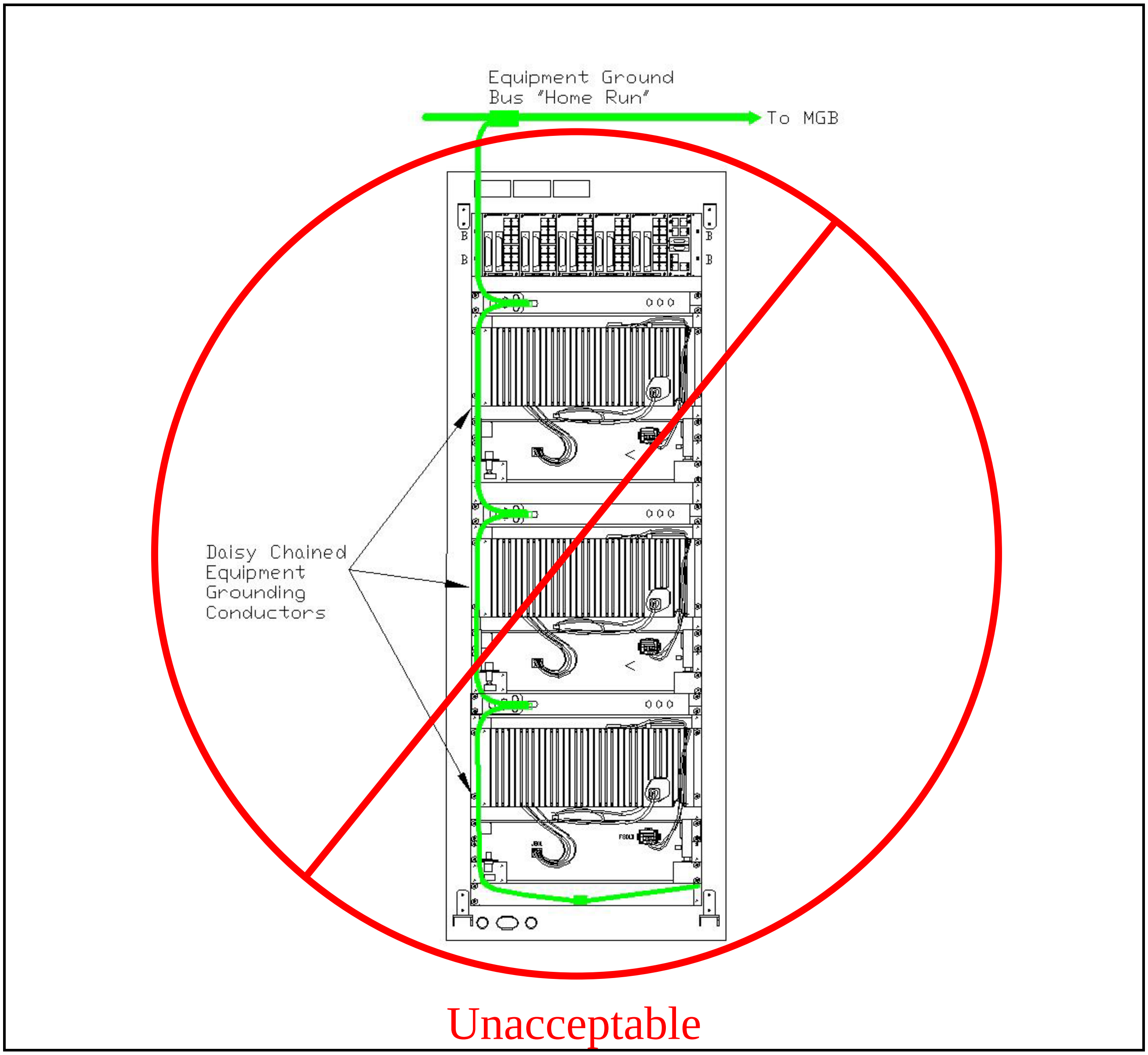
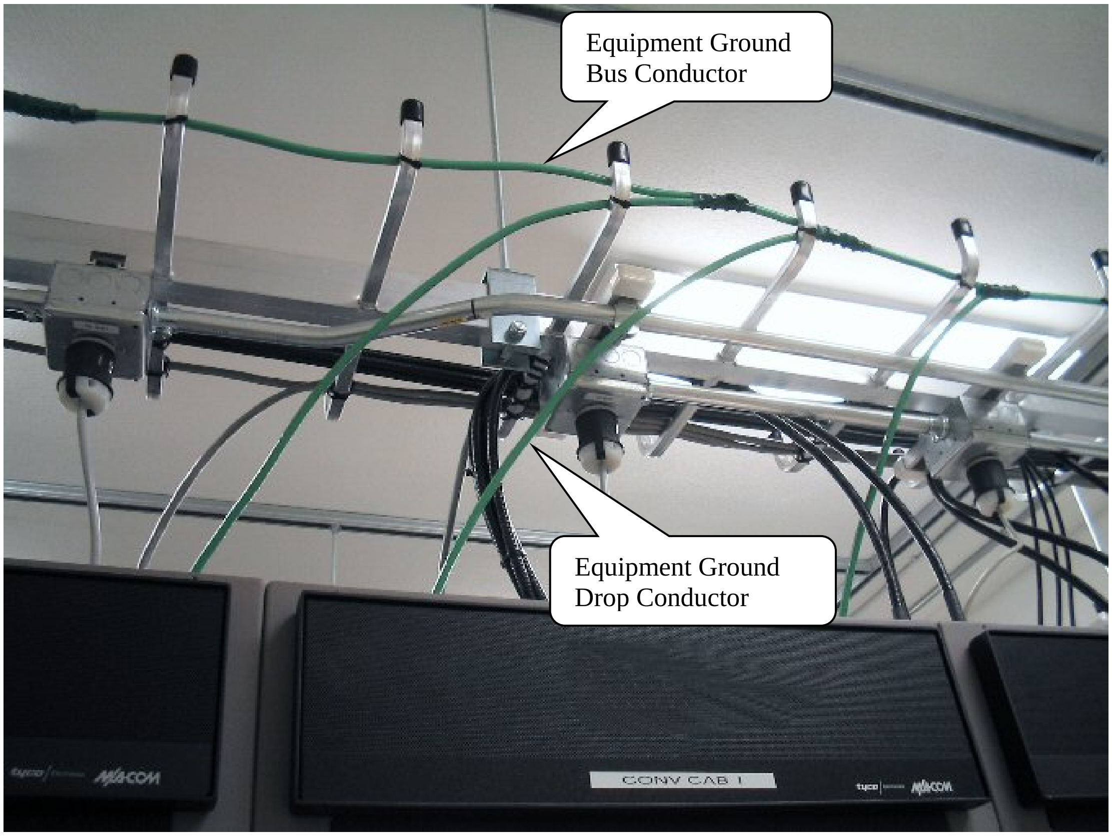



**Figure 5-39: Unacceptable Equipment Ground Drop Conductor Daisy Chaining**



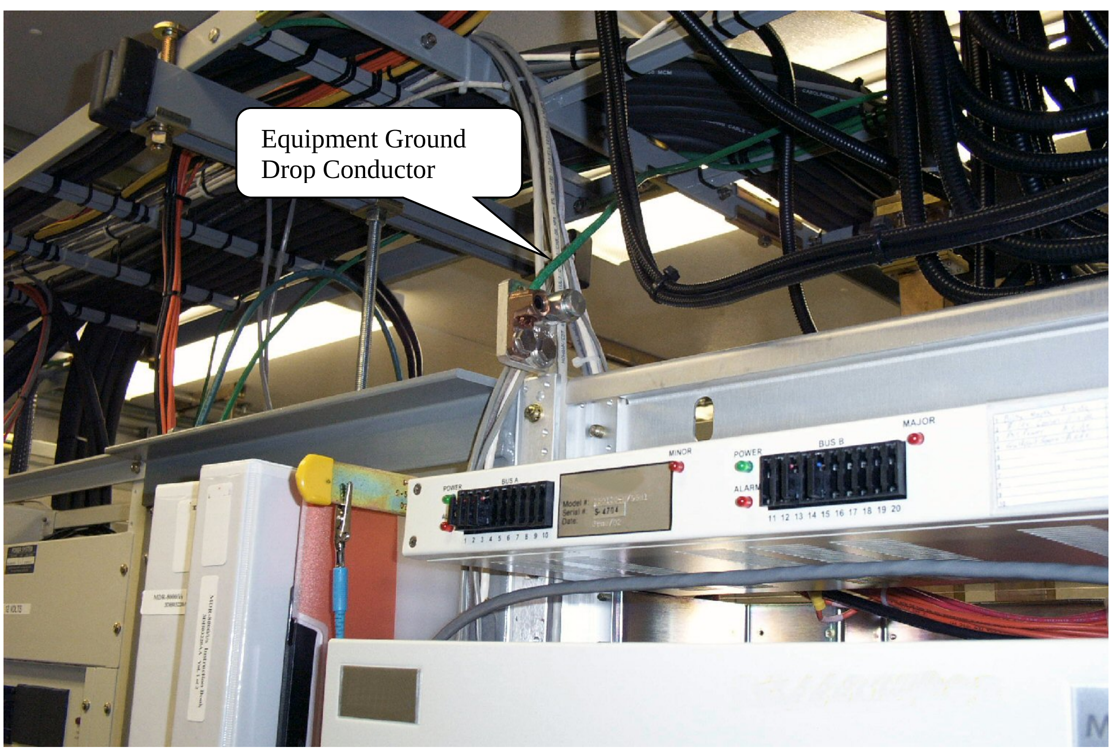




**Figure 5-40: Example of Equipment Ground Drop Conductors**

### 5.4.3 Equipment Individual Grounding Conductors

Each equipment chassis secured in a cabinet or rack must be connected to the cabinet or rack internal ground bus. The framework of the equipment rack or cabinet must also be connected to the rack internal ground bus.

These connections should be made using #14 AWG, or larger, stranded copper conductor and appropriate terminations. (See Section 5.1 for details.) The length of these connections should be kept as short as possible while maintaining an 8 inch minimum bend radius and angles greater than 90 degrees.

NOTE

Do not daisy chain equipment grounds.

Some equipment may not have a dedicated grounding point. In these cases, install a jumper between the cabinet or rack rails, to which the equipment is mounted, and the cabinet's internal ground bus. These jumpers should be #6 AWG insulated copper conductor.

**Figure 5-41: Example of Bonding Cabinet Rails Together**

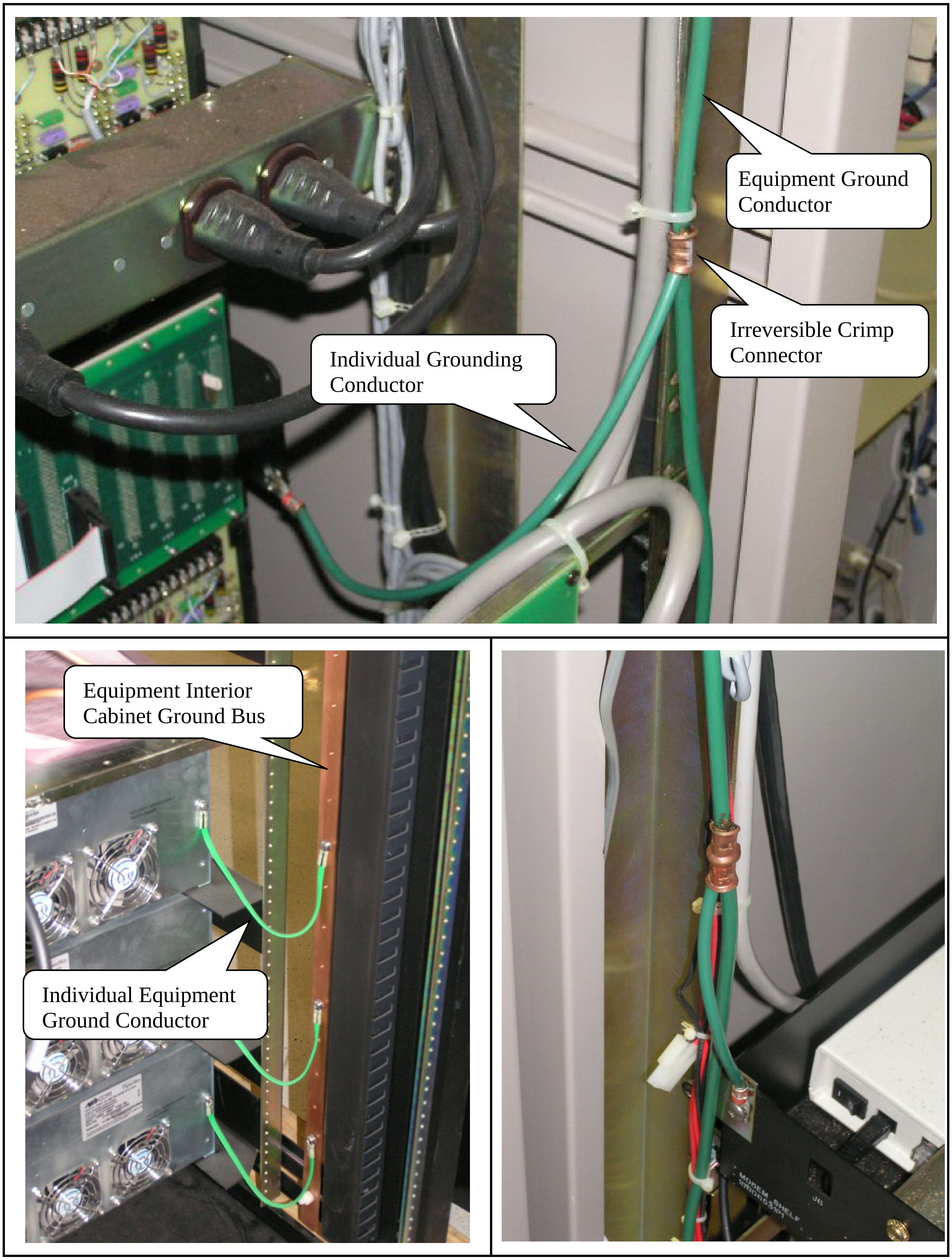



**Figure 5-42: Example of Individual Equipment Ground Conductor Attachments**

### 5.4.4 Cabinet/Rack Isolation from Cement or Conductive Floor

It is recommended that all cabinets and racks be isolated from a cement or conductive floor (including raised floors), especially in areas highly prone to lightning. This is to avoid possible sneak path current flow through the equipment during a lightning event.

Isolation is accomplished through the use of non-conductive pads or a platform under the cabinet or rack and non-conductive shoulder washers to isolate the floor anchor hardware from the cabinet. We recommend using non-conductive materials including polypropylene or phenolic materials. Contact Harris Systems Engineering for guidance in selecting specific products.

Seismic mounting requirements may require using more anchors or different mounting methods. Refer to the applicable Harris system (OpenSky®, EDACS®, P25, Simulcast, etc.) installation manuals for details on cabinet or rack mounting.

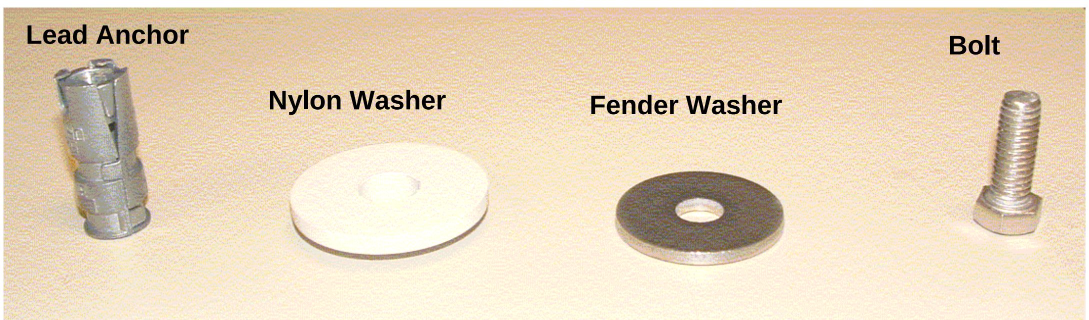



**Figure 5-43: Bolt Assembly Hardware**

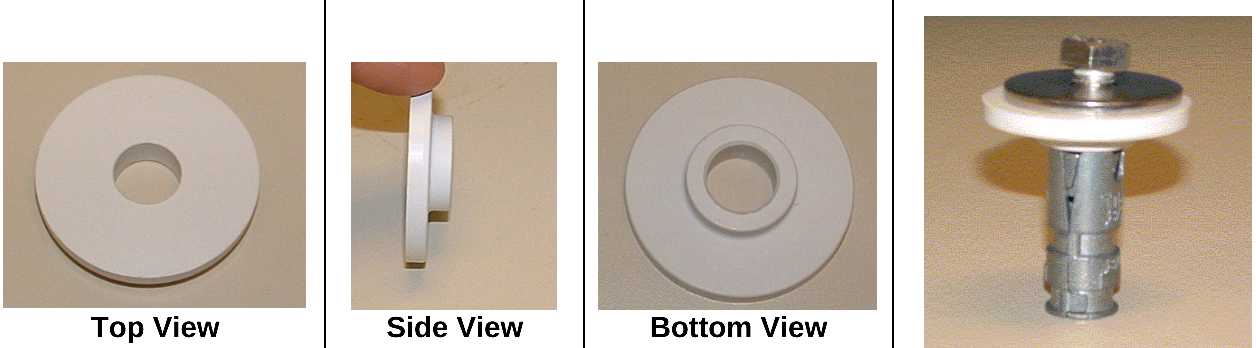



**Figure 5-44: Nylon Washer and Bolt Assembly**

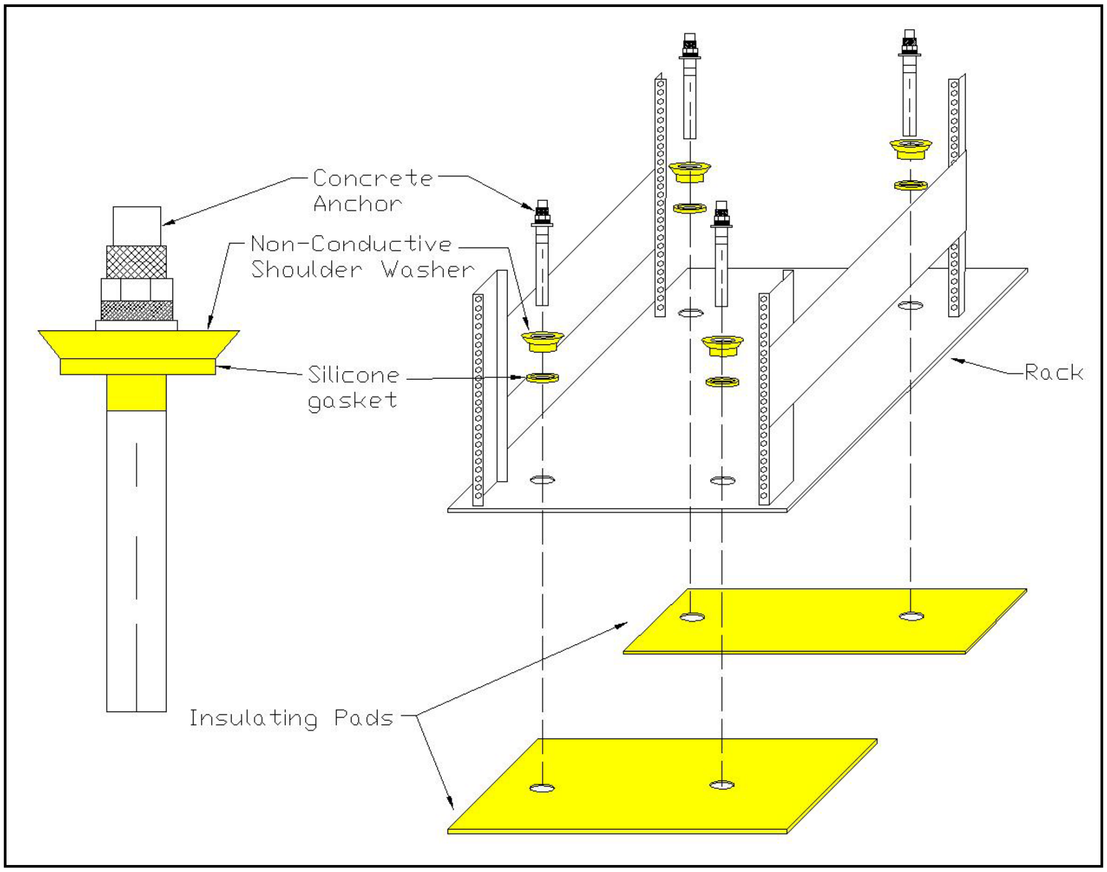



**Figure 5-45: Example of Isolated Cabinet Mounting**

## 5.5 CABLE LADDERS AND TRAYS

Cable ladders and trays should be bonded to MGB using a #2 AWG, or larger, stranded copper conductor at a single point closest to the MGB. Each individual section of the cable ladder or tray must have a jumper connecting the sections together. Use a #6 AWG, or larger, copper conductor on both sides of the ladder or tray to ensure a good electrical ground connection.

Exercise care to ensure the cable ladder or tray is not grounded in any other location. This includes through any uninsulated C-taps on any ground bus conductors running through the cable ladder.

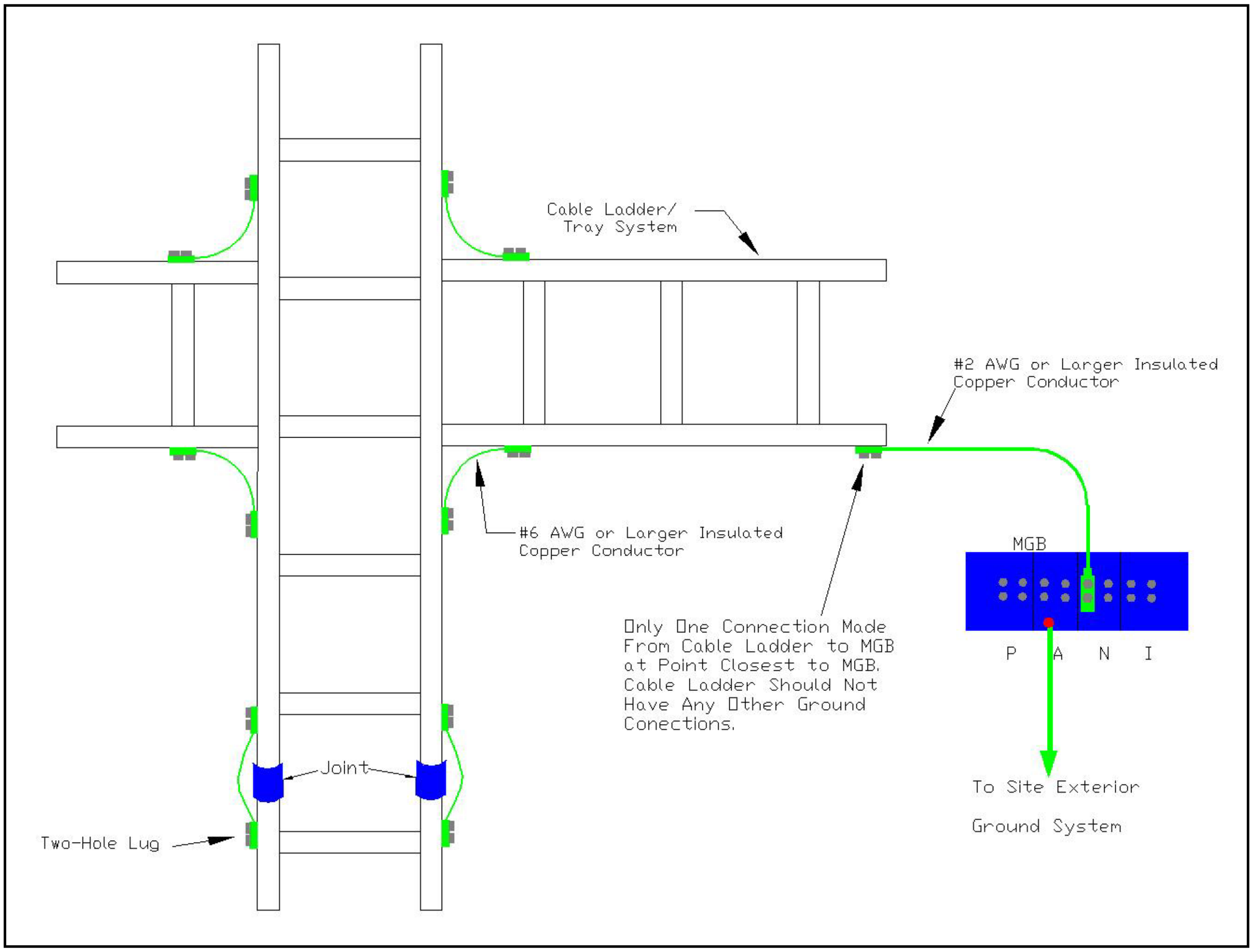



**Figure 5-46: Cable Ladder/Tray Grounding Detail**

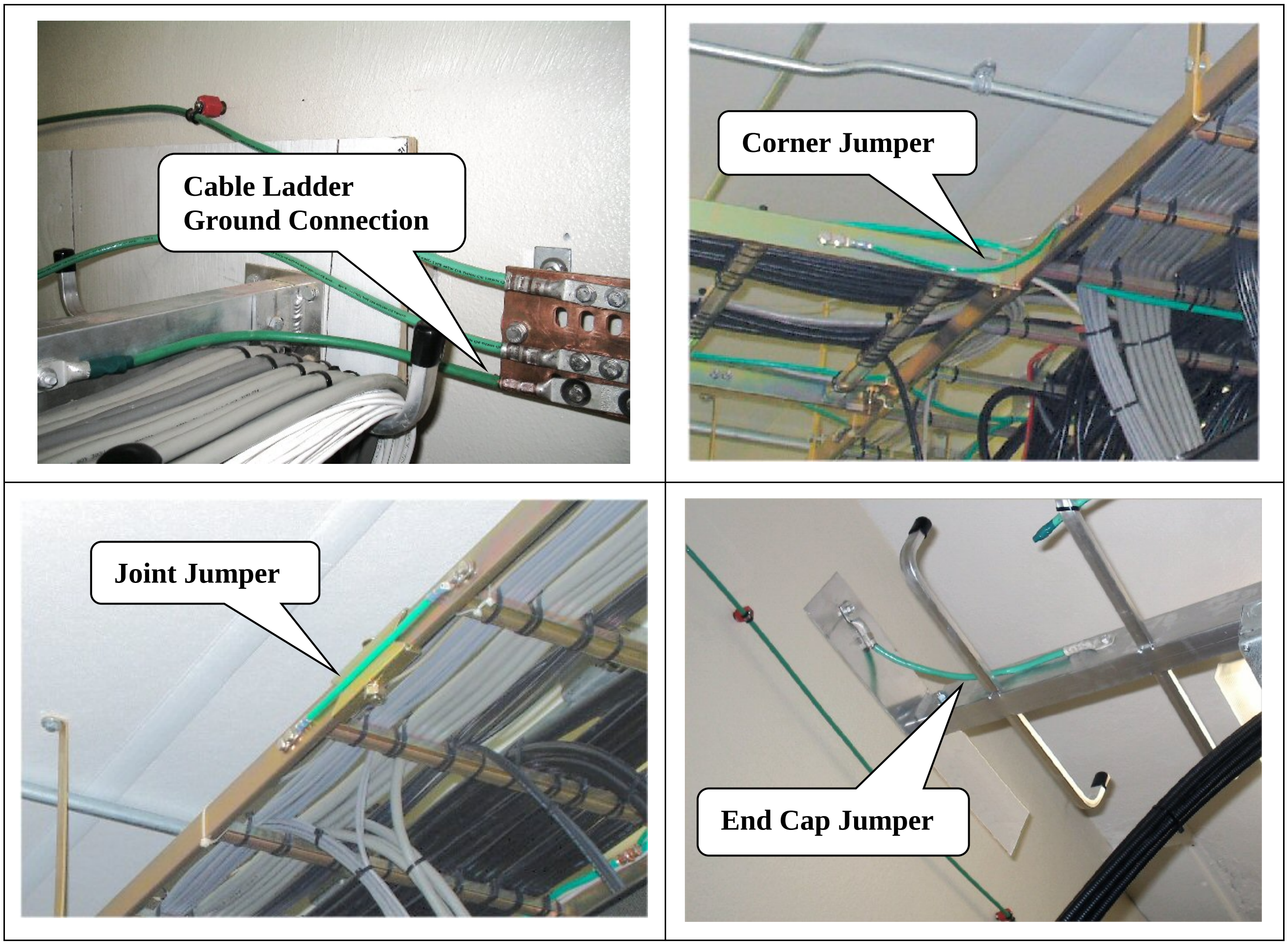



**Figure 5-47: Example of Cable Ladder Grounding and Jumpers**

## 5.6 AC UTILITY ENTRANCE

### 5.6.1 AC Entrance Neutral-To-Ground Bond

The neutral-to-ground bond is established at the first main AC service disconnecting means of an electrical distribution system (*Refer to NFPA 70, NEC code, Article 250*). The main AC service disconnecting means should be located as close to the shelter as possible, and preferably inside the shelter.

The neutral conductor is grounded at the shelter service entrance disconnecting means, and must never be grounded again at another location. This is to avoid 60 Hz return current passing through conduit, framework, etc., possibly posing life safety concerns or causing noise in susceptible electronic circuits.

**All site grounding and electrical installation must comply with all applicable NEC and local codes. If a conflict exists between this document and any of these applicable codes, then the codes shall take precedence over the guidelines in this document.**

NOTE

At a shared tower site where multiple shelters may receive power from a single AC utility feed brought to a multiple-meter base located away from the shelters, the Harris shelter's first service disconnect should be established at the shelter. The shelter neutral-to-ground bond is located at this disconnecting means. This is allowed by *NEC Article 250.32(B)(1)*, even if a neutral-to-ground bond is also present on the load side of the AC meter located away from the shelter. However, the following conditions must be met:

(1) There is no AC ground conductor (NEC calls this an equipment grounding conductor) brought from the meter base to the shelter disconnecting means;

(2) There are no continuous metallic paths (conduit) bonded to the grounding system at both locations;

(3) Ground fault protection has not been installed on the supply side of the feeder(s) (meter base); and

(4) The neutral conductor (NEC calls this the grounded conductor) is properly sized, labeled, and terminated.

Locating the neutral-to-ground bond directly at the shelter isolates the shelter's AC electrical power from noise and possible surge currents from neighboring site equipment.

### 5.6.2 AC Entrance Grounding

The AC ground should be connected to the MGB in the PANI-Surge Energy Absorbers section with a #2 AWG, or larger, stranded copper conductor.

If the only AC electrical service ground connection is made through the MGB, then this conductor shall be sized per *NEC Table 250.66 (see Appendix F)* or applicable local code based on the size of the largest incoming service entrance conductors. This conductor then becomes the AC Grounding Electrode Conductor, and no separate AC grounding electrode is required.

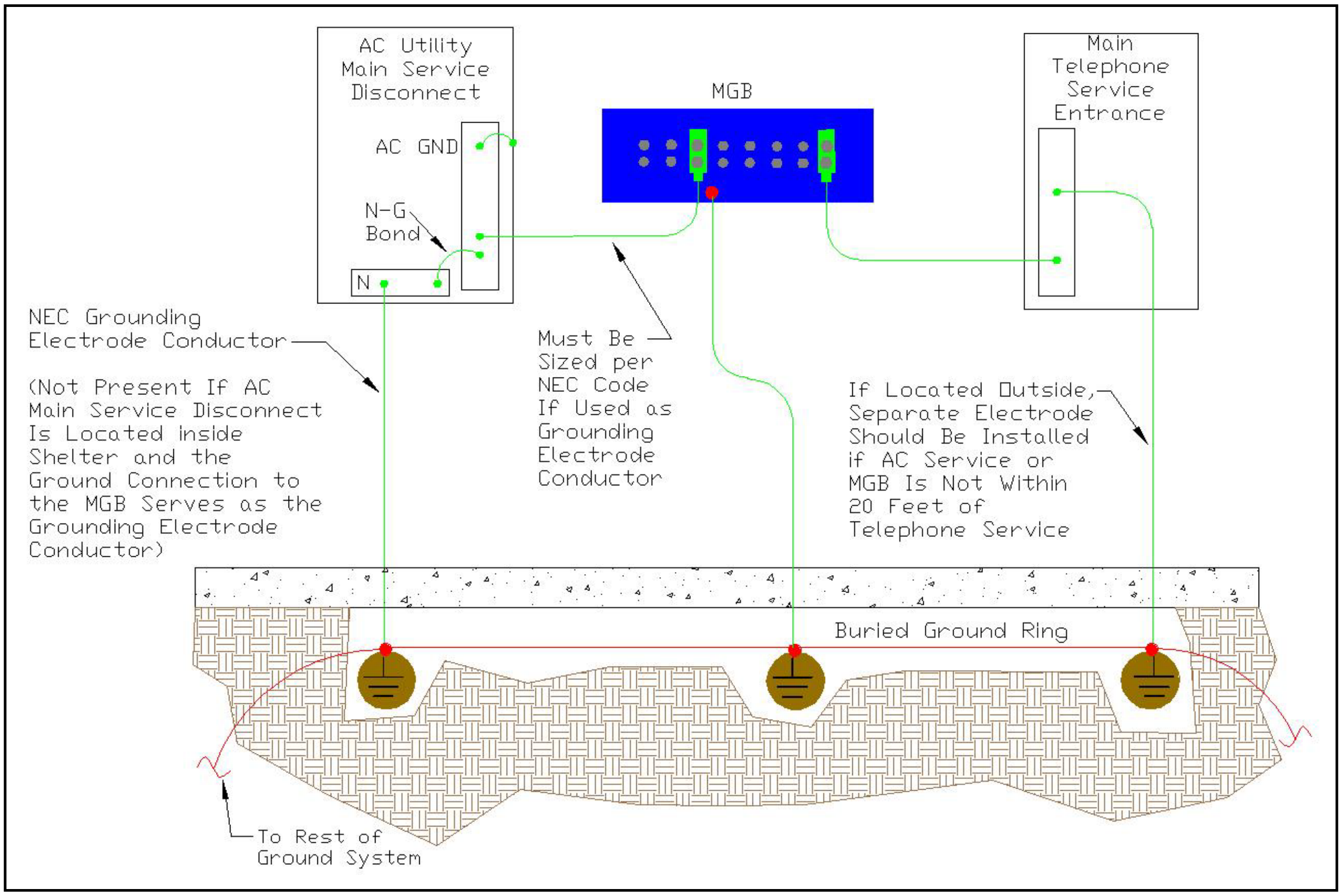



**Figure 5-48: AC Utility Main Service Disconnect and Telephone Service Entrance Grounding Detail**

## 5.7 TELECOMMUNICATIONS SERVICE ENTRANCE

The shielding of each telephone cable entering the building, through underground or aerial entrances, must be bonded to the site single point ground. This entry point should be as close to the AC entry point and MGB as possible.

If the MGB is close to the telecom cable entrance, the cable shields should be bonded to the MGB (PANI - Surge Energy Producers section) using a #6 AWG stranded copper conductor. If the MGB is not nearby, or is in another part of the building, a telecommunications SGB should be located near the telecommunication line entry point, and the cable shields should be bonded to the SGB using a #6 AWG stranded copper conductor. The telecommunication line SGB is then bonded to the MGB using a #2 AWG, or larger, conductor.

The primary telephone surge suppressor should be grounded to the same location and in the same manner discussed previously.

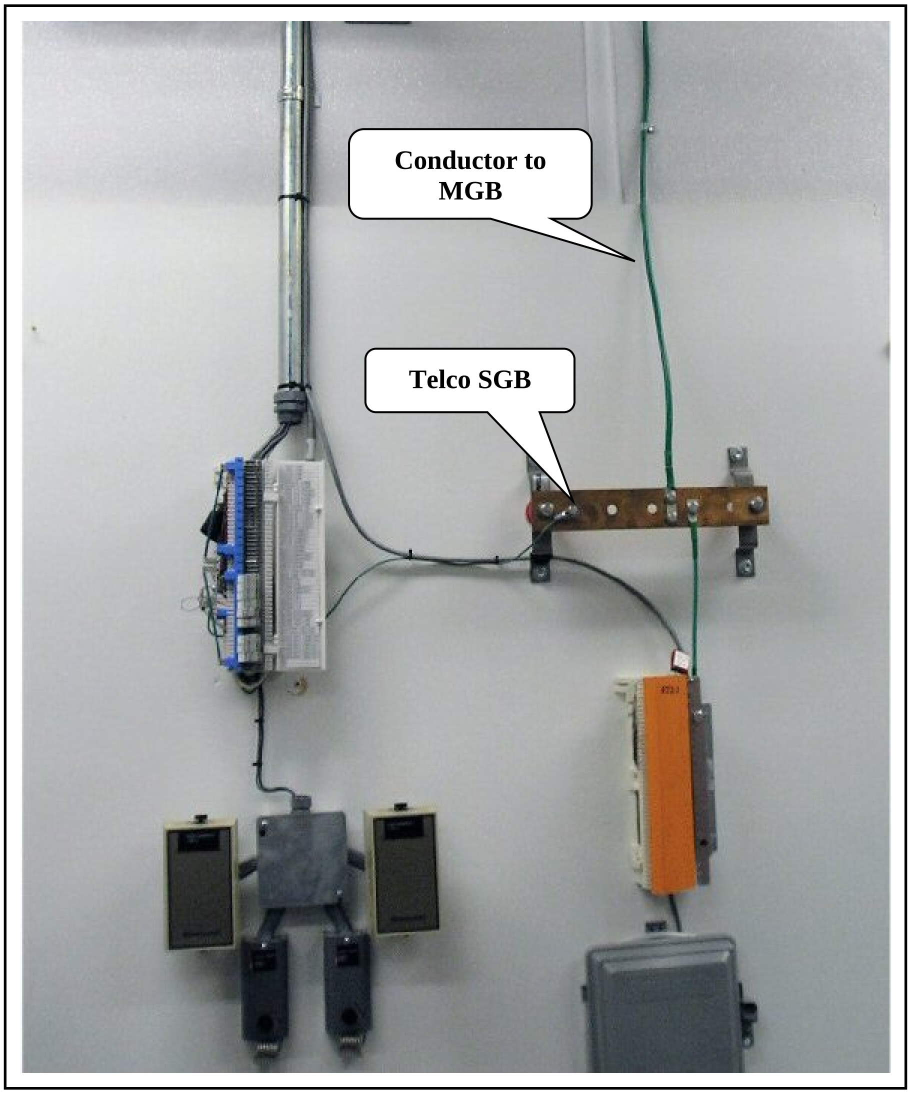



**Figure 5-49: Telecommunications Entrance SPD Grounding Overview**

NOTE

Unused pairs in an incoming telecommunications cable should be grounded to the Telecommunications SGB also. Contact the Telco provider to verify this will not disturb their equipment.

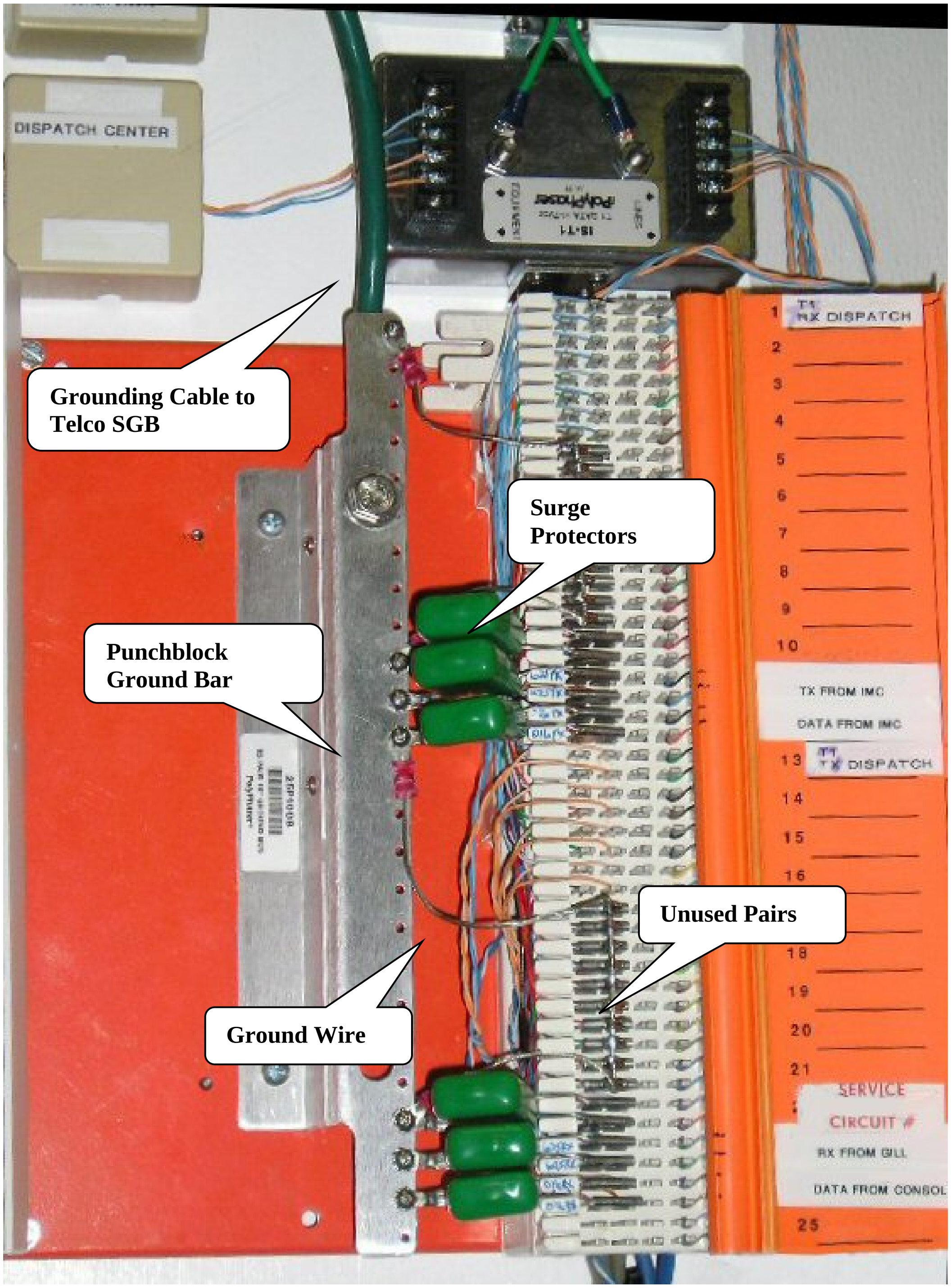



Figure 5-50: Example of Grounding Unused Telco Pairs

## 5.8 DC POWER PLANT

The main DC power plant return bus bar should be connected to the MGB (PANI - Non-Isolated Grounds section) with an appropriately sized dedicated grounding conductor. The size of this conductor is dependent on the current capability of the DC power plant. It should be sized per NEC Article 250.166, but a 350-750 MCM AWG conductor is typically used. See Section F.1.3 for details.

The battery cabinet frames must also be connected to the MGB (PANI - Non-Isolated Grounds section) using a #2 AWG, or larger, conductor.

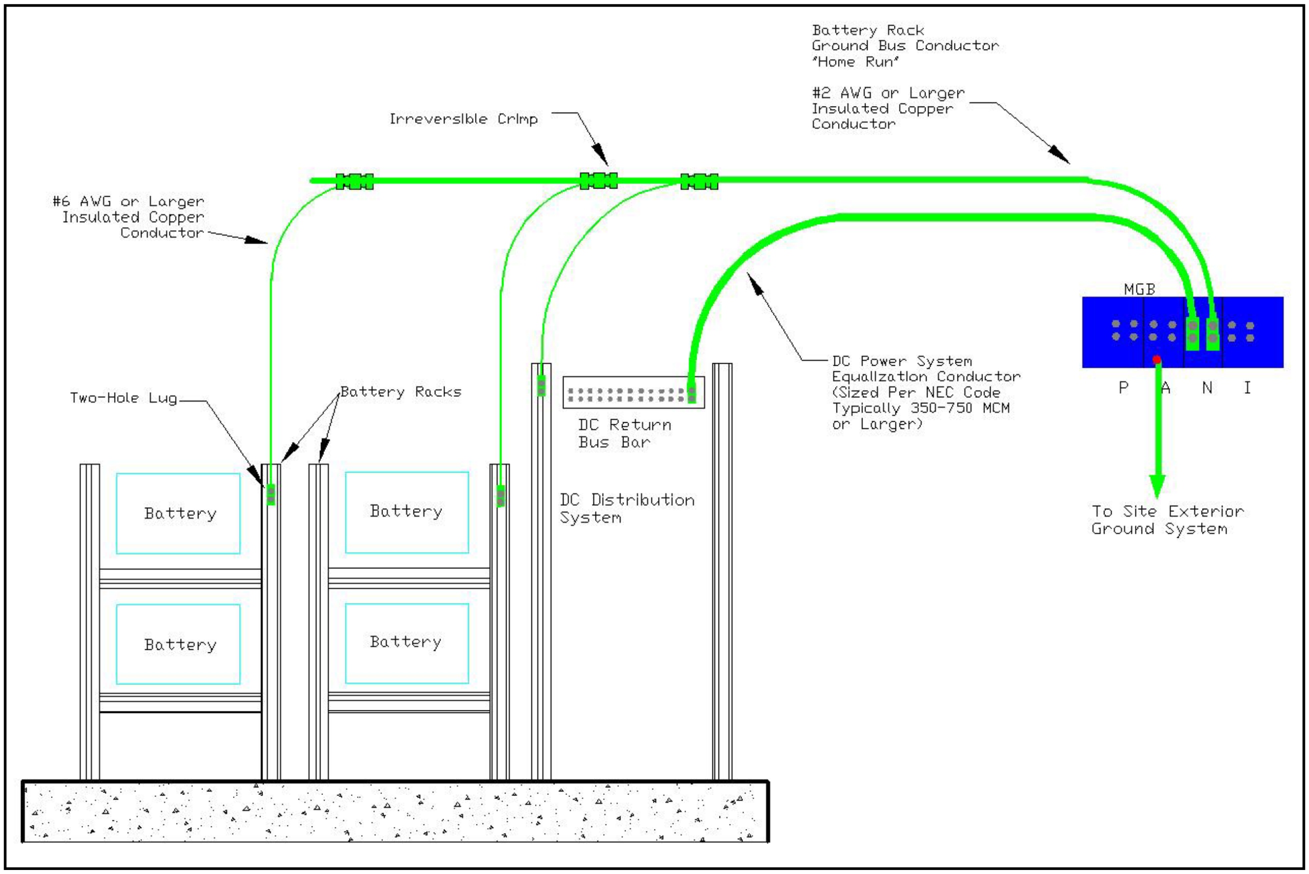



**Figure 5-51: DC Power System Grounding Detail (Note preferred method of grounding battery racks.)**

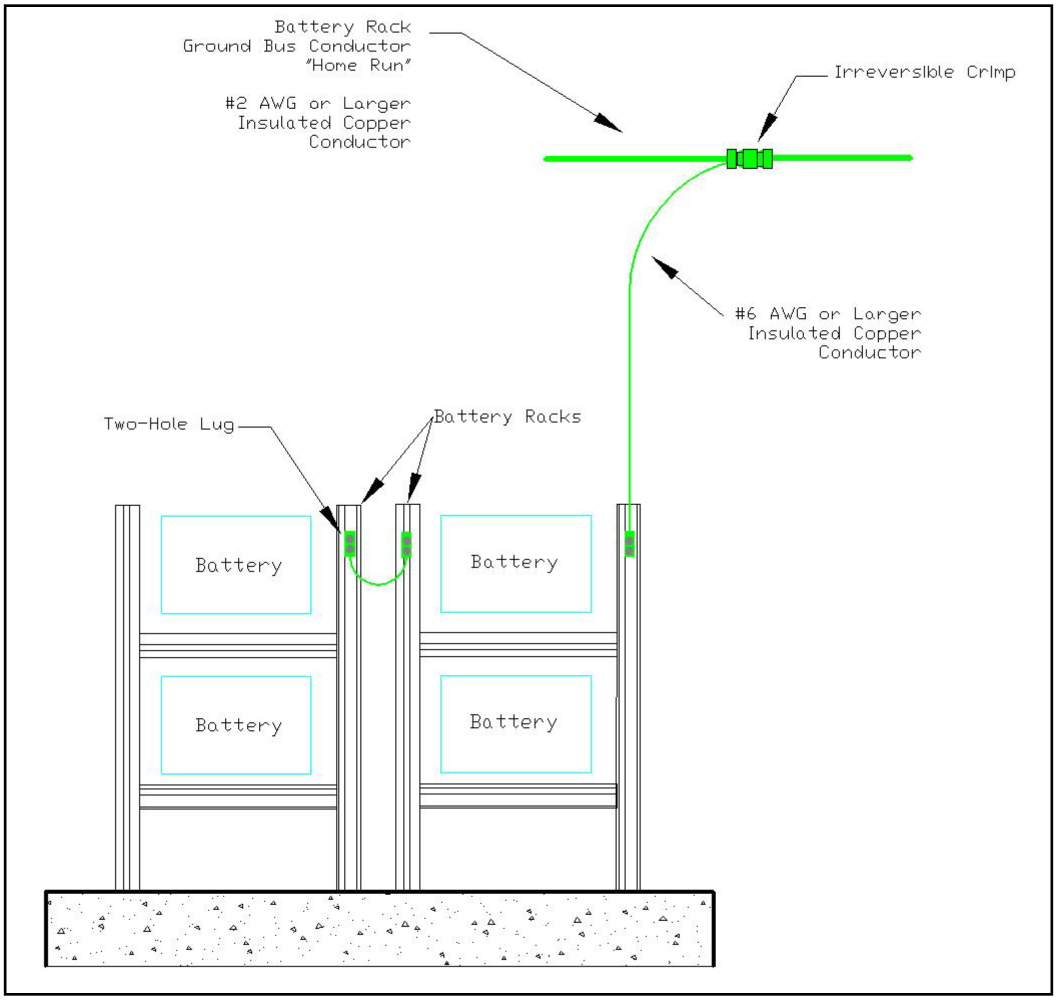



**Figure 5-52: Acceptable Method of Jumpering Battery Rack Grounds**

**Figure 5-53: Example of a Jumper between Battery Racks**

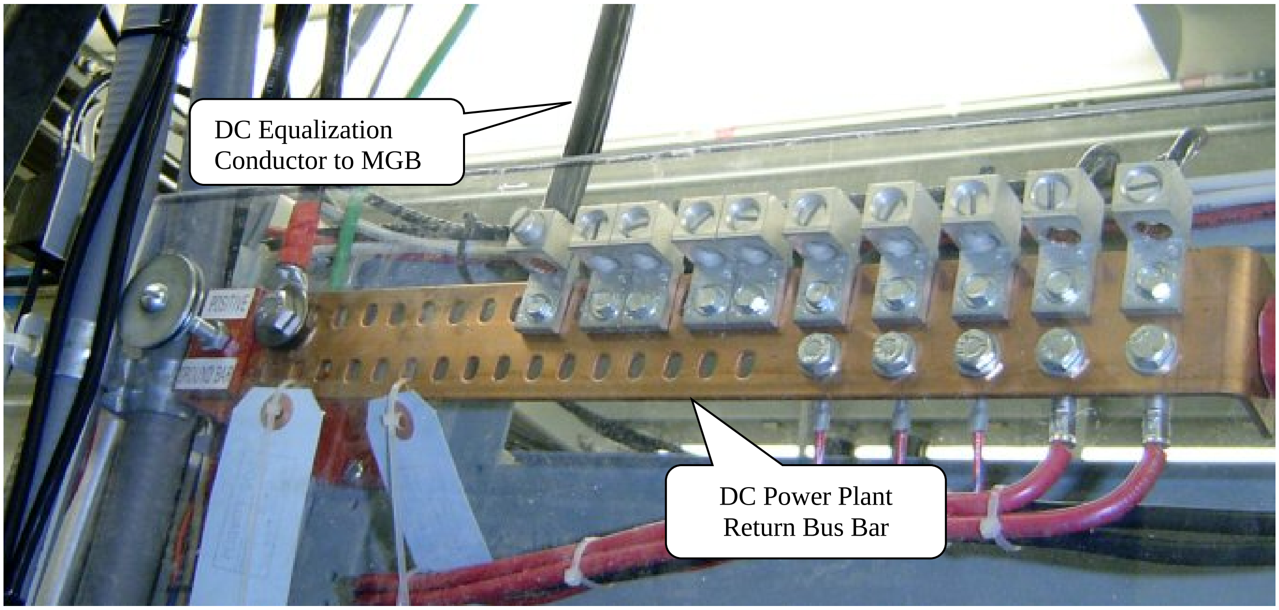



**Figure 5-54: Example of DC Equalization Conductor on -48V DC Power System**

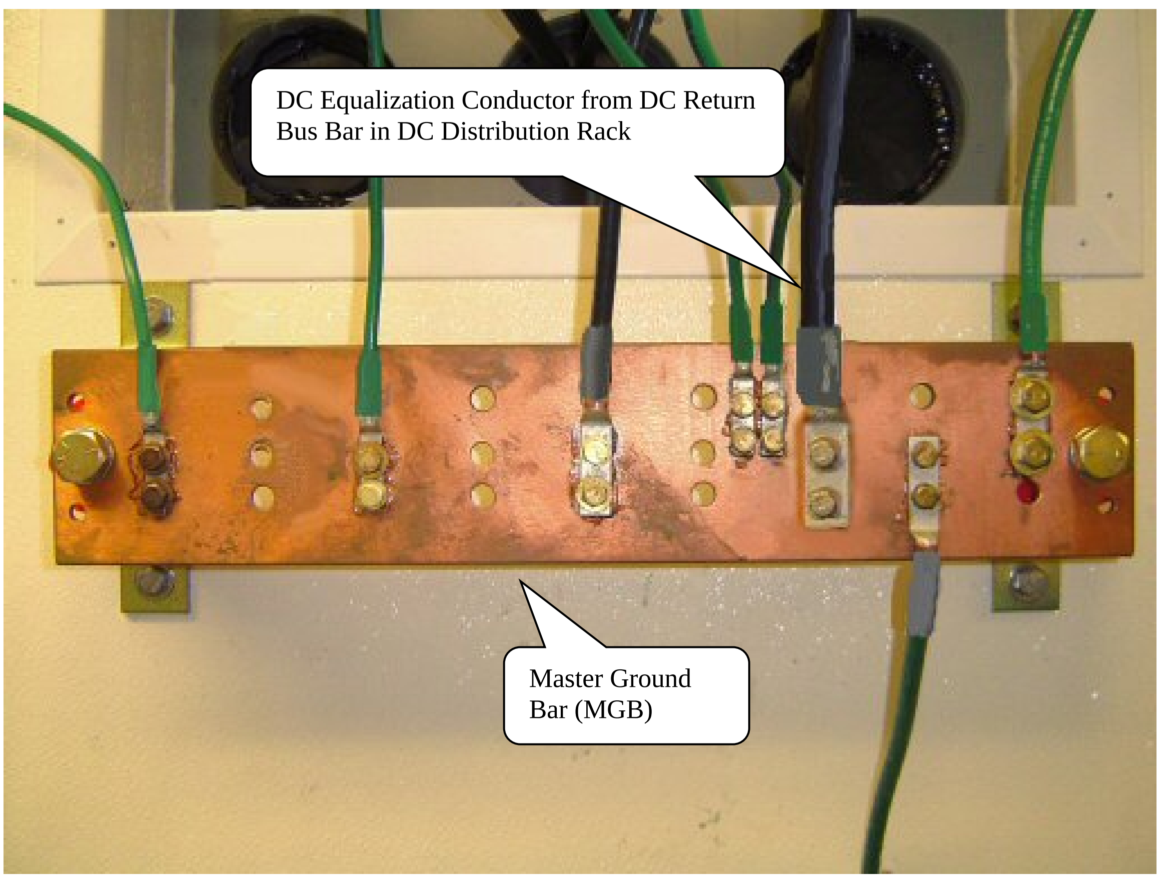



**Figure 5-55: DC Equalization Conductor Connection to MGB**

## 5.9 SEPARATELY DERIVED AC SYSTEMS

In a separately derived AC system, its neutral is separate from the neutral for the incoming AC power source. A separately derived AC system is typically an inverter powered from a battery bank, a transformer isolated AC system, a generator wired as a separately derived AC system, or an Uninterruptible Power Supply (UPS) wired as a separately derived AC system.

If a separately derived AC system exists, its grounding conductor should be connected to the MGB (PANI – Non-Isolated Grounds section) using a #2 AWG, or larger, stranded copper conductor. Again, if the only ground is made through the MGB, then the grounding electrode conductor should be sized per NEC Table 250.66 (see Section F.1.2) or applicable local code based on the size of the largest phase conductor. NEC or applicable local codes may require a separately derived AC system to have its own grounding electrode which would have to be bonded to the site's grounding electrode system.

The separately derived AC system will have its own neutral-to-ground bond.

A generator, where the neutral is switched on the load side of the generator transfer switch, is considered a separately derived source, and the generator must have its own neutral-to-ground bond. This would require a 4-pole transfer switch as opposed to the 3-pole transfer switch used if the neutral is not switched.

**Many generators ship with a neutral-to-ground bond installed at the manufacturer. If the generator is not used as a separately derived AC source, this neutral-to-ground bond must be removed.**

NOTE

At the majority of Harris site installations, the generator is not designed to be a separately derived AC system. The neutral is not switched in the generator transfer switch, and it should not have a neutral-to-ground bond.

## 5.10 SURGE SUPPRESSION GROUNDING

See Section 5.3 (RF Surge Protector Grounding) for details on grounding RF surge suppressors.

All other primary and secondary surge suppressor grounds should be connected to the MGB PANI-Surge Energy Producers section with a #6 AWG, or larger, conductor. If an SGB is used to gather multiple primary surge suppressor grounds, it should be connected back to the MGB using a #2 AWG, or larger, conductor to the MGB PANI-Surge Energy Producers section.

Secondary surge arrestors located in equipment cabinets may be grounded directly to the cabinet/rack ground bus.

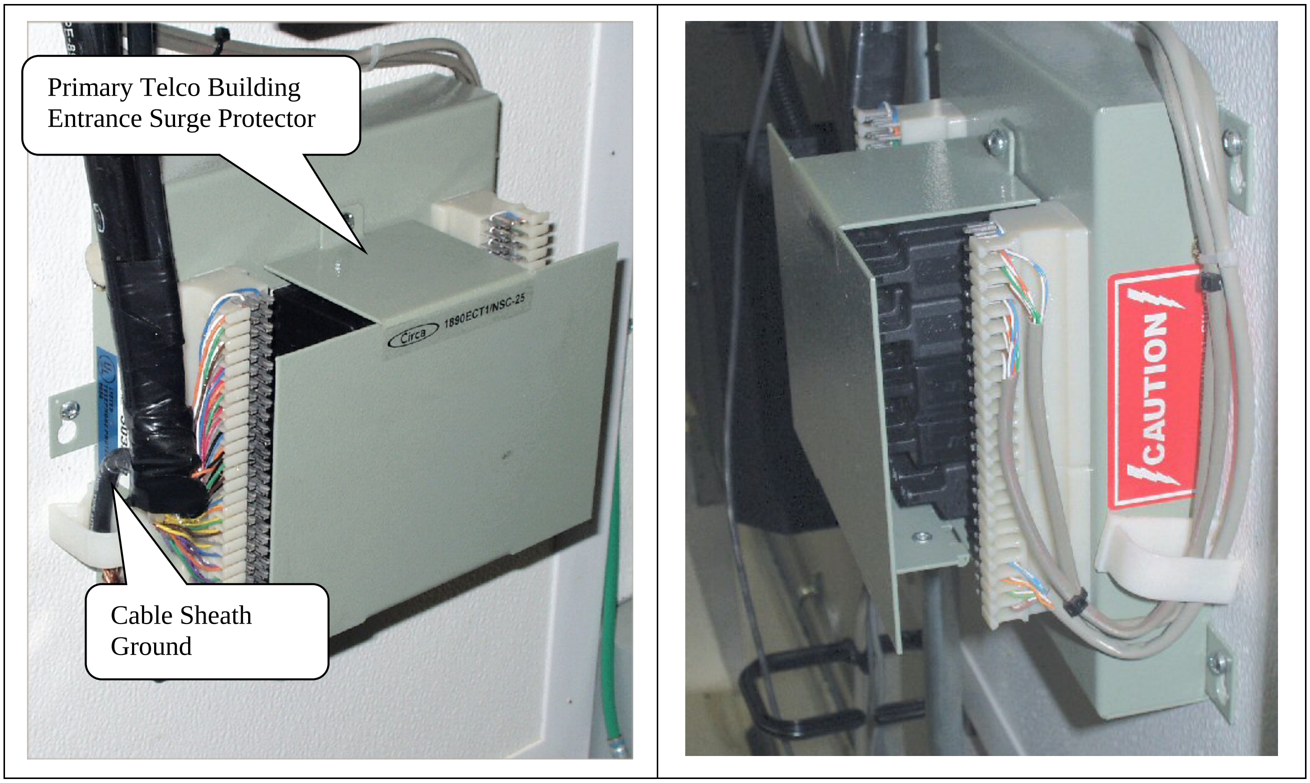



**Figure 5-56: Example of Primary Telco Building Entrance Surge Protection**

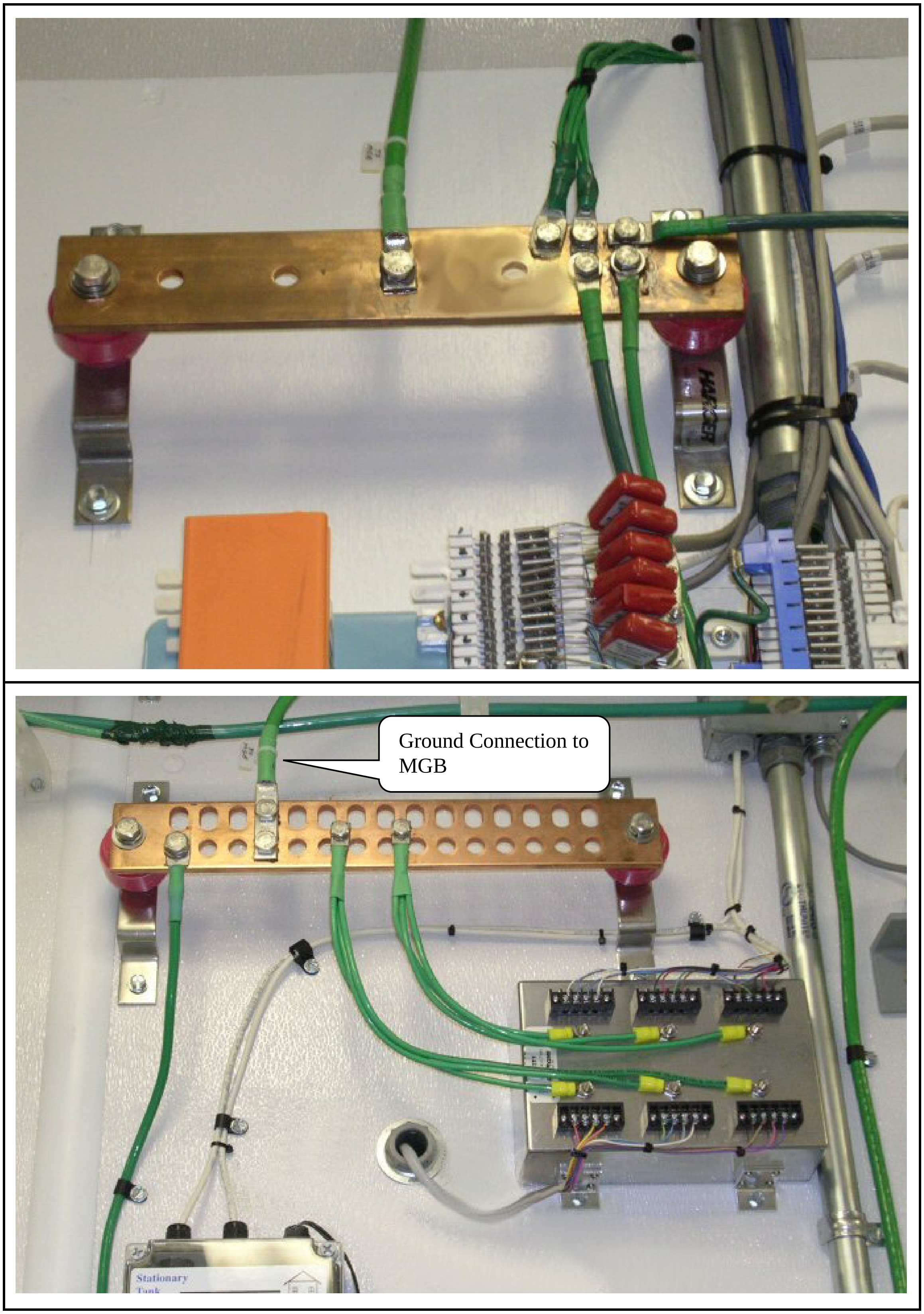



**Figure 5-57: Examples of Surge Protection Grounding**

# 5.11 MISCELLANEOUS INTERIOR METALLIC OBJECTS

In the equipment room, all current-carrying components are bonded to the MGB, as detailed in the previous sections. All remaining non-current-carrying ancillary support equipment and conductive objects in the equipment room must also be grounded to keep to reduce possible shock hazard to personnel. This means bonding all ancillary equipment and any miscellaneous metallic housings, frames, conduit, piping, or surfaces (often called "dirty grounds") to the MGB. In the process, it is also important to avoid developing any ground loops.

## 5.11.1 Horseshoe Halo Ground Bus

The easiest way to ground miscellaneous objects is to install two ground bus conductors stretching in opposite directions from the MGB. This type of ground is referred to as a "horseshoe halo ground" or "split halo ground" as shown in Figure 5-58.

Each ground bus is routed around one-half of the equipment room's perimeter. The two ground bus conductors do not connect at the end of the room opposite the MGB; otherwise, a ground loop would exist. Each ground bus conductor provides a convenient, low impedance bonding point for any miscellaneous non-isolated grounds.

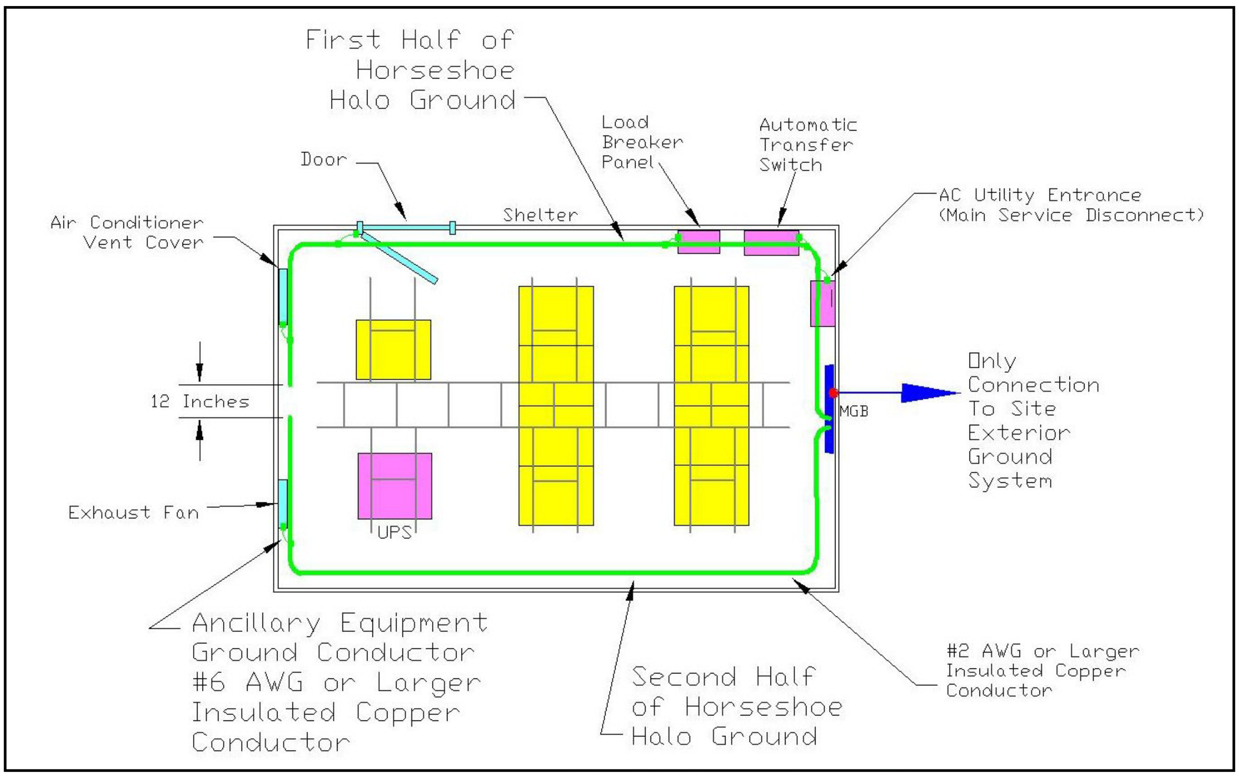



**Figure 5-58: Horseshoe Halo Ground Bus Detail**

NOTE

Each horseshoe halo ground bus conductor is bonded to the MGB directly. No other interior connections to the exterior ground system should be made, i.e. corner downrunners.

Each of the two independent ground bus conductors should originate at the MGB (PANI - Non-isolated grounds section) using #2 AWG, or larger, copper conductor. From the MGB each ground bus conductor should be routed toward the ceiling then around one-half of the room. The conductor should be mounted on evenly spaced, insulated standoffs that maintain a straight run at about 8 feet above the floor and at least 2 inches out from the wall. At the opposite end of the room from the MGB, each ground bus conductor should end leaving at least 12 inches of space between the two opposing ground bus conductors or any objects tied to the opposing ground bus conductors.

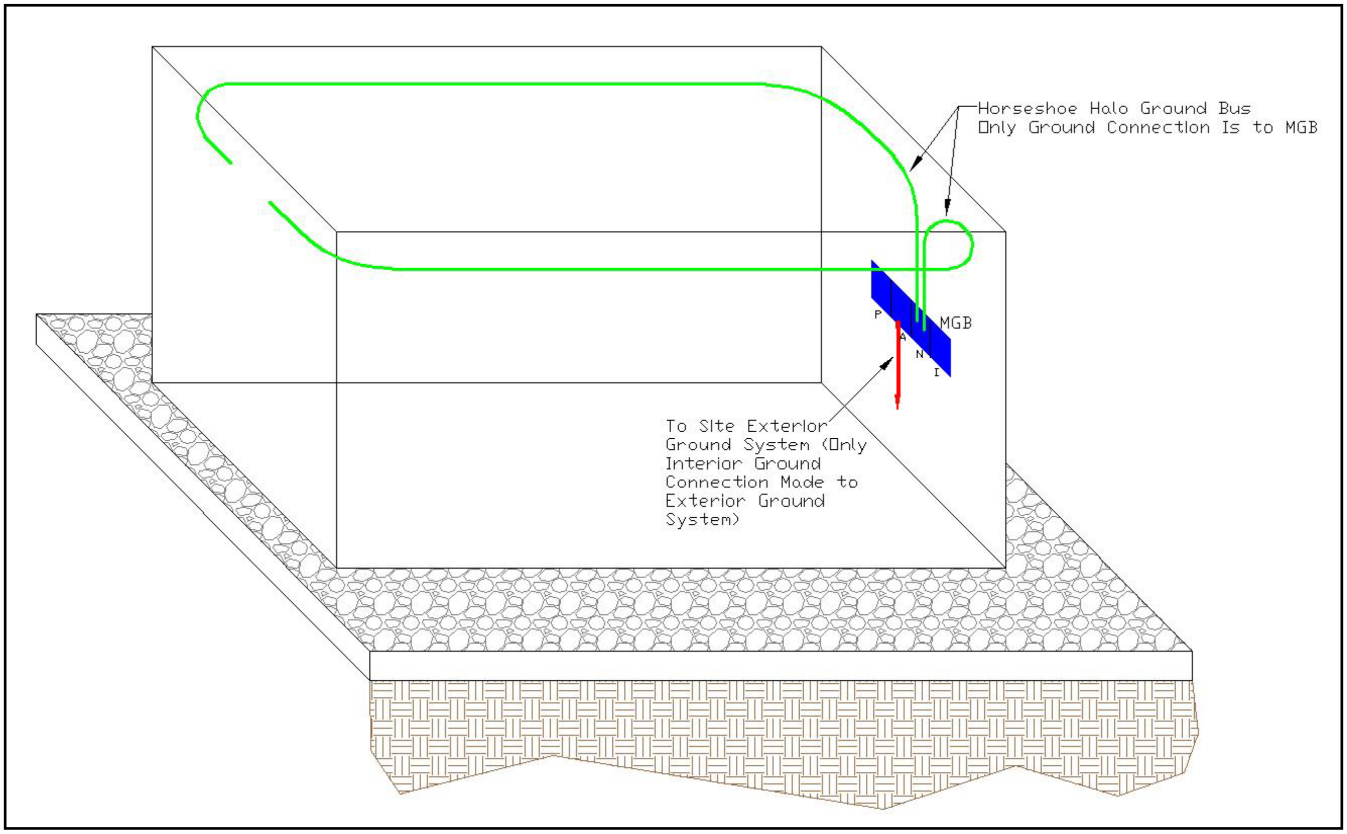



**Figure 5-59: Horseshoe Halo Ground Bus Location in Shelter**

### 5.11.2 Ancillary Support Equipment

Ancillary support equipment and any miscellaneous non-current carrying conductive objects not already bonded to the MGB should be bonded to the horseshoe halo ground bus using a #6 AWG, or larger, copper conductor. These objects may include; metallic housings, doorframes, conduit, piping, vent covers, exhaust fans, fire suppression systems, metal cabinets or desks, etc. (See examples in Figure 5-60.)


**Figure 5-60: Examples of Ancillary Equipment that should be Bonded to Horseshoe Halo Ground Bus**

Install a jumper, using a flexible stranded or short braided conductor, between entry doors and their doorframes, on the hinge side.

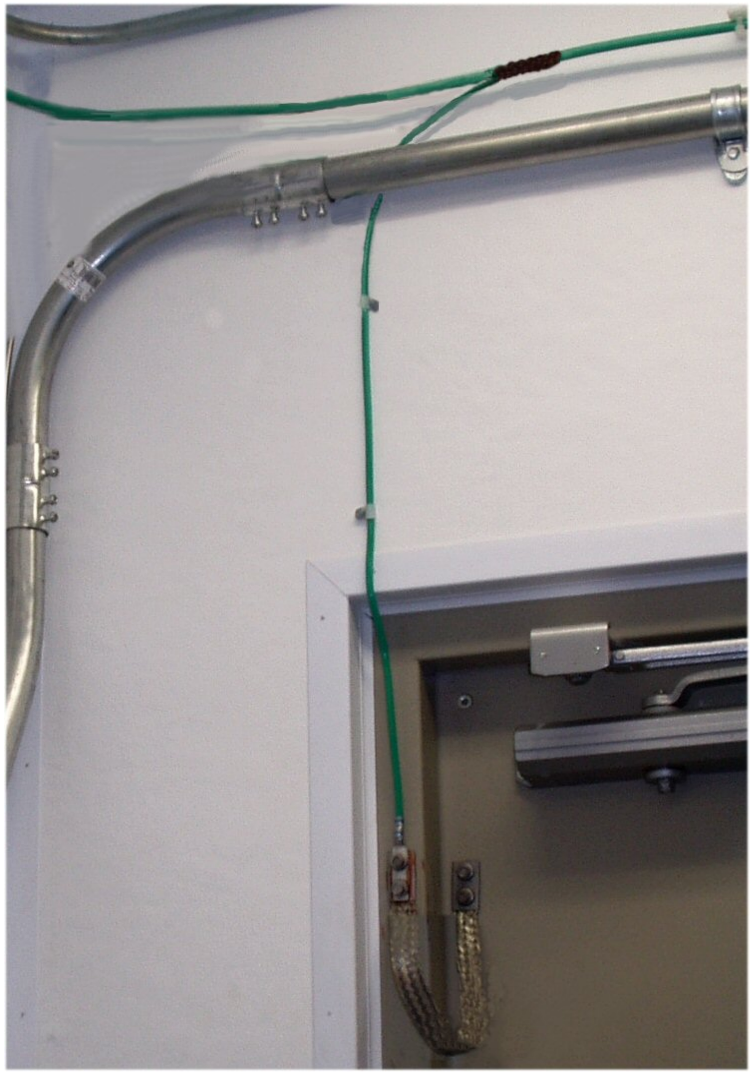


**Figure 5-61: Example of Door Frame Grounding to Horseshoe Halo and Jumper to Door**

### 5.11.3 Electrical Conduit

Each continuous run of metallic conduit that passes within 6 inches of the horseshoe halo ground bus should have a single ground connection to the horseshoe halo ground bus. The most convenient location is usually where the conduits leave the breaker box. Connect the conductor at a point where the conduit passes near the horseshoe halo ground. A single conductor may be used to attach multiple conduit runs, but connections should be made such that removing one clamp does not disconnect other conduits on the run, as shown in Figure 5-62.

As long as UL-listed couplings are used that maintain electrical continuity, no additional bonding jumpers are required around junctions. If non UL-listed couplings are used, such as set screw couplings, then jumpers should be installed around any junction boxes or joints using #6 AWG, or larger, copper conductor and UL-listed clamps.

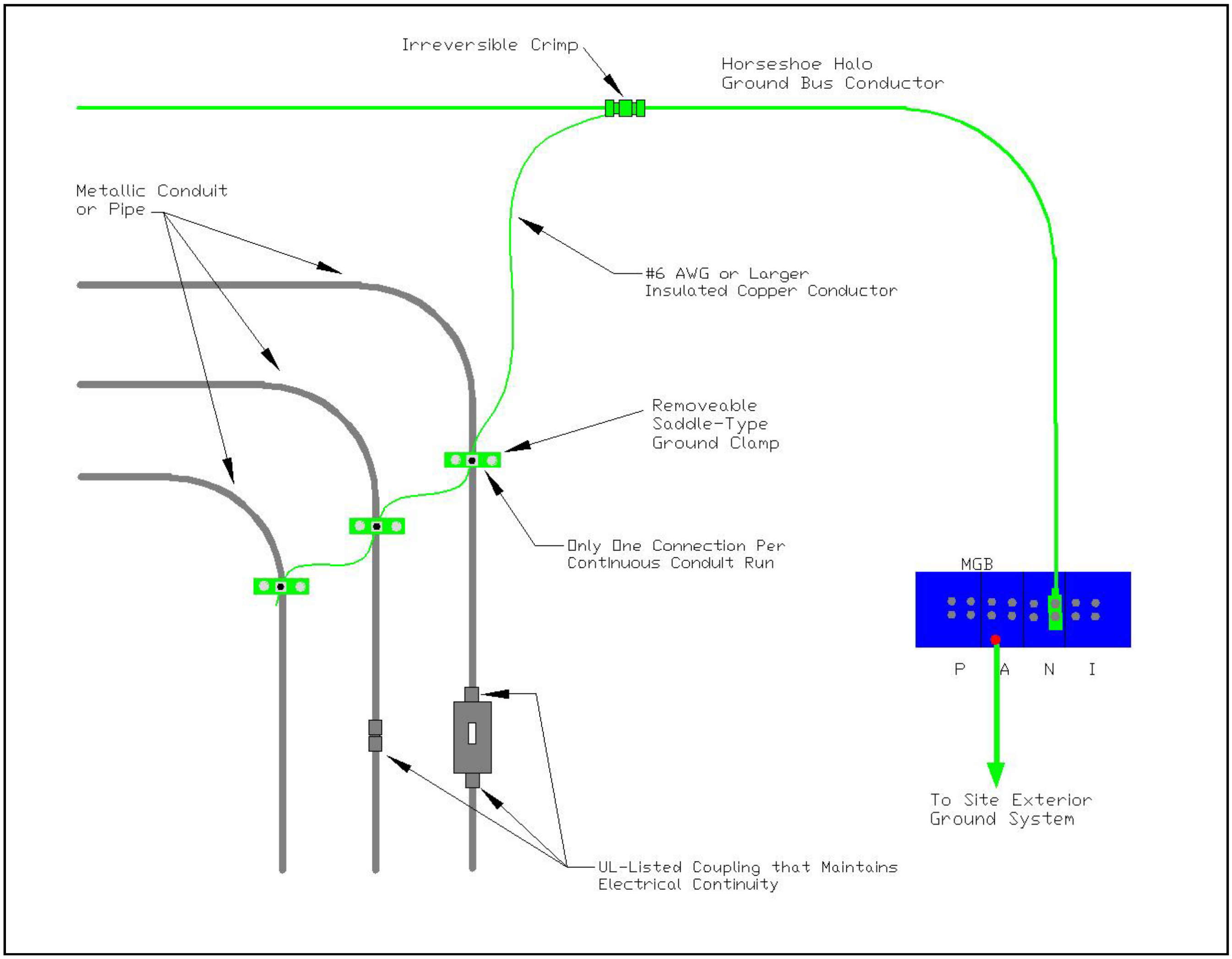



**Figure 5-62: Conduit Jumpers and Bonding to Horseshoe Halo Ground Bus Detail**

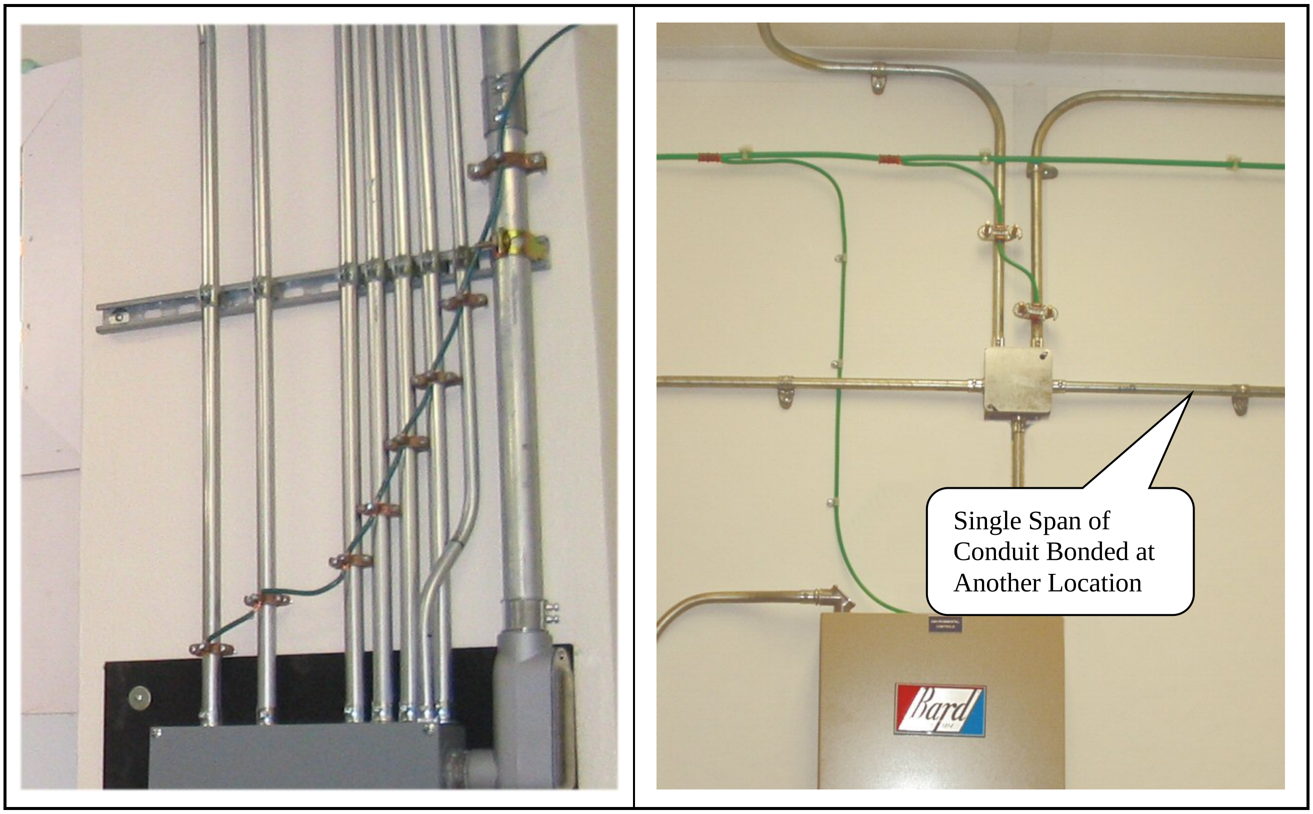



**Figure 5-63: Examples of Electrical Conduit Bonding**

### 5.11.4 Raised Floors

Raised floors should be grounded, as shown in Figure 5-64, to the MGB in the PANI-Non-Isolated Grounds section. A #2/0 AWG insulated copper conductor should be run from the MGB to a supplemental ground bar (sometimes called a "floor splice") placed under the raised floor. If needed, you should use PVC or non-conductive conduit to run this conductor through a wall or floor panel.

Install a clamp on the pedestal nearest the SGB under the raised floor. Install a #2/0 AWG insulated copper conductor between the pedestal and the SGB. Then run a #2/0 AWG insulated copper conductor under the raised floor and connect it to this bonded pedestal and every tenth pedestal, as shown in Figure 5-65, being sure the distance between bonds is less than 20 feet. The overall conductor length between the SGB and the furthest pedestal should not exceed 100 feet, maximum. Multiple conductor runs may be required for large rooms, to ensure the conductor length does not exceed the 100 feet limit.

The pedestal ground clamps should be UL-listed and positioned 6 inches above the sub-floor. On all conductors, you should maintain a minimum-bending radius of 8 inches, and the angles of the bends should be greater than 90 degrees.

You should also bond any metallic handrails or stairs near the raised floor to the raised floor grounding system.

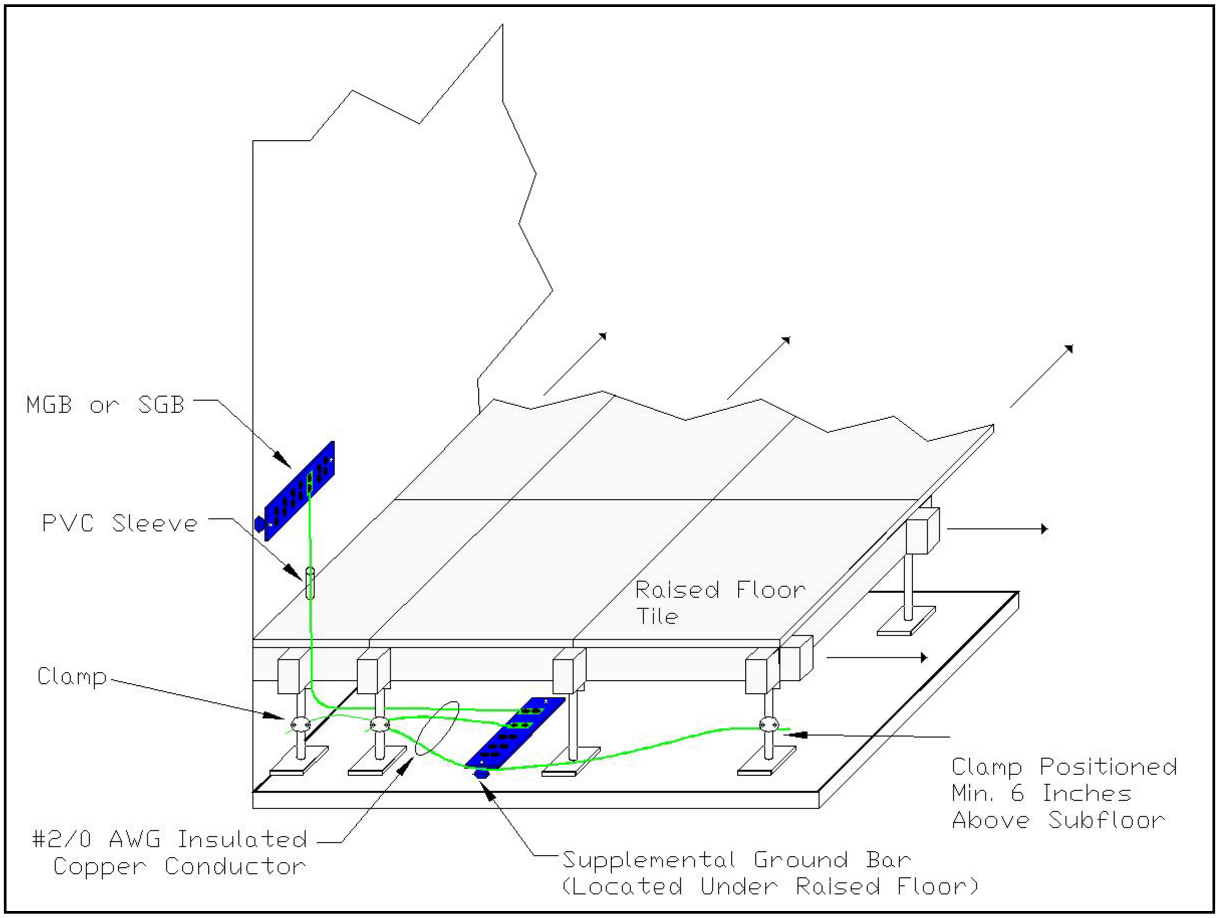



**Figure 5-64: Raised Floor Grounding Detail**

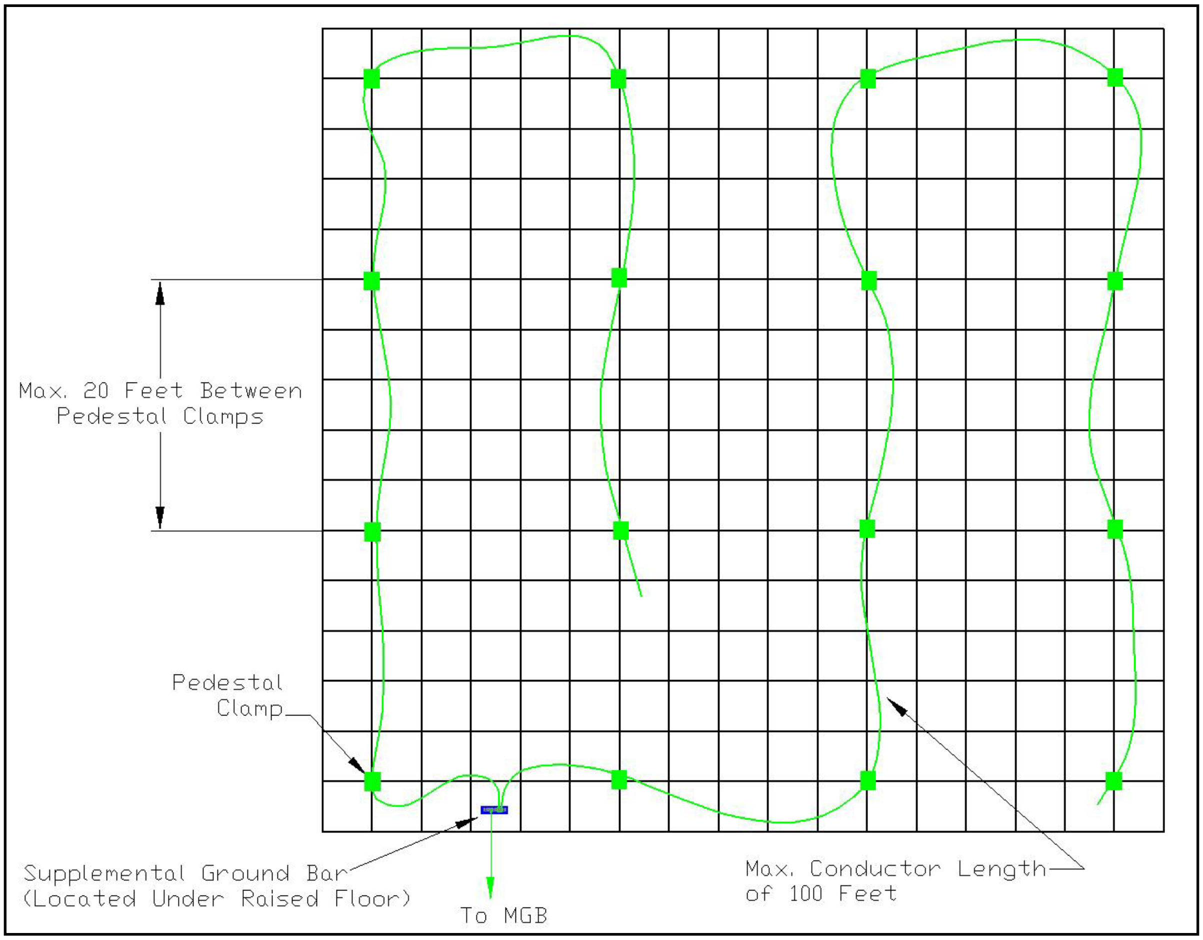



**Figure 5-65: Raised Floor Ground Conductor Routing Detail**

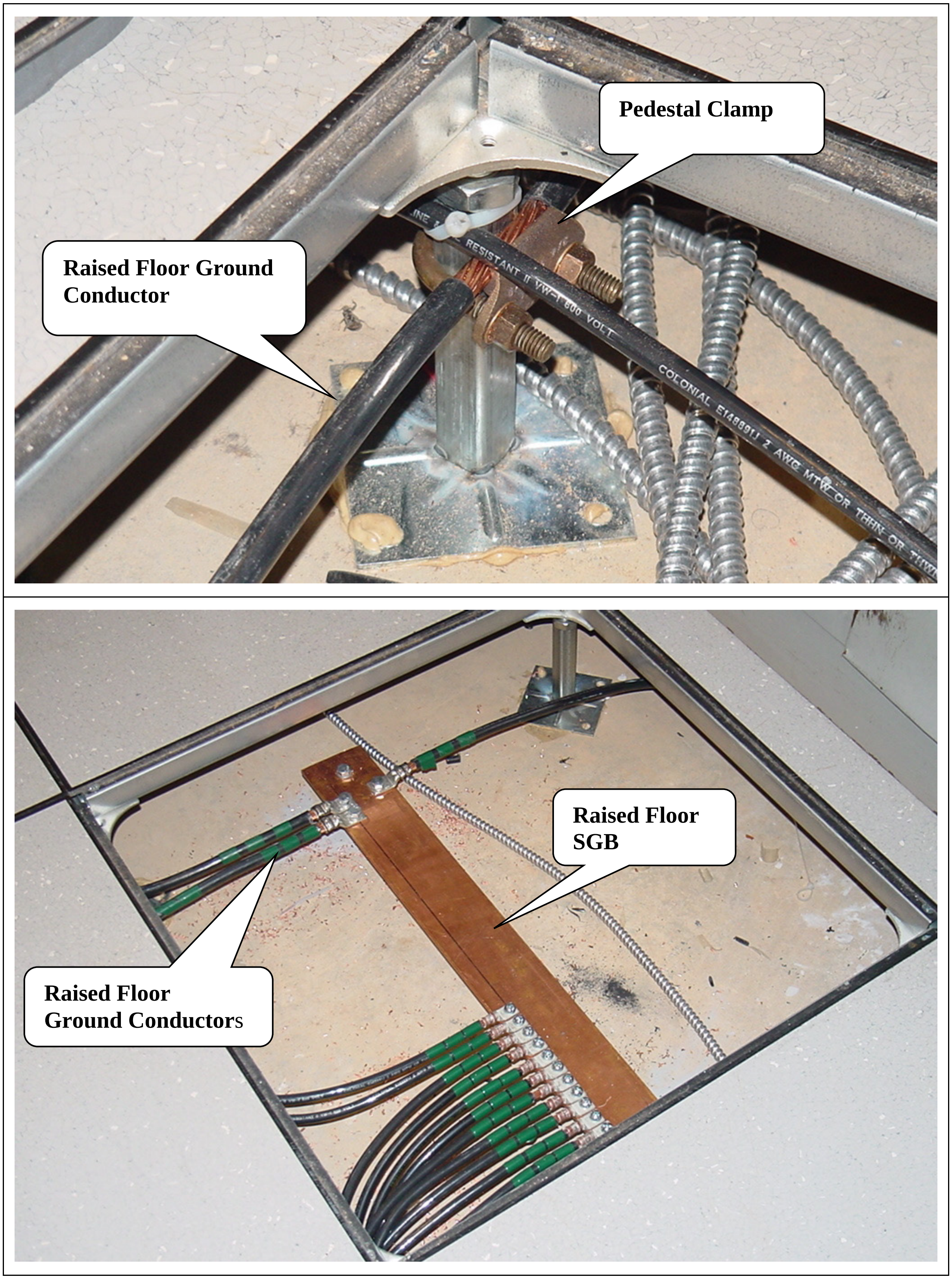



**Figure 5-66: Example of Raised Floor Grounding Components**

### 5.11.5 Antistatic Flooring

Antistatic floors should be grounded to the horseshoe halo ground bus. Typically, copper straps or tape is installed under the antistatic flooring and brought out at several locations along each wall. A #6 AWG, or larger, insulated copper conductor should be run from the horseshoe halo ground bus to at least one copper strap along each wall. If a wall is longer than 20 feet, then a second copper strap should be connected along that wall.

Connections between the #6 AWG copper conductor and the floor's copper strap may be made by sandwiching the copper strap between two pieces of ¼ inch copper bar that are bolted together and attaching the #6 AWG conductor's lug to this copper bar, as shown in Figure 5-67.

Securely attach the ¼ inch copper bar assembly and the #6 AWG drop from the horseshoe halo ground to the wall to protect them from damage.

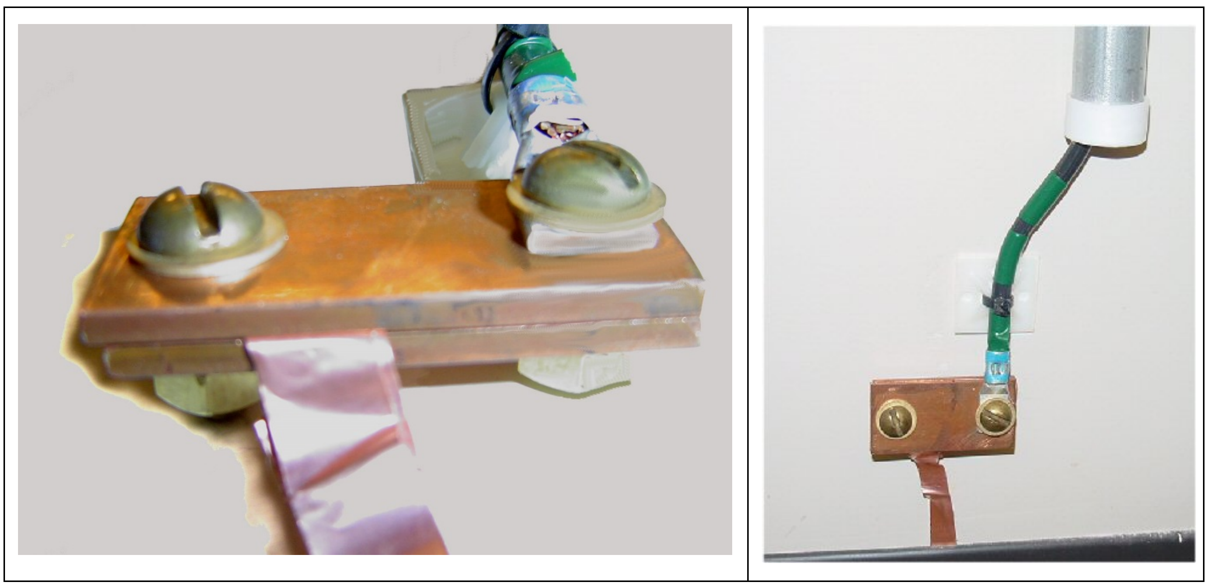


**Figure 5-67: Antistatic Floor Grounding Strap Connection Detail**

### 5.11.6 Avoiding Accidental Multi-Point Grounding

When grounding miscellaneous metallic objects in the shelter, exercise special care to avoid accidental multi-point grounding. For example, exhaust fans and AC vent covers must be isolated from any metallic contact with any outside units that are bonded directly to the exterior ground ring. Incidental electrical contact will also produce a multi-point grounding situation.

# 6. SURGE PROTECTION

Even the most effective low impedance grounding system will not entirely protect a site from damage due to lightning, surges, and transients. For maximum protection, it is also necessary to install surge protection devices on all metallic conductors coming into a facility.

A Surge Protection Device (SPD) is intended to either limit transient (short duration) overvoltages or divert surge currents. It is a package containing at least one nonlinear component such as a gas discharge tube, Metal Oxide Varistor (MOV), or a Silicon Avalanche Diode (SAD). An SPD may also be referred to as a lightning arrestor, surge suppressor, or Transient Voltage Surge Suppressor (TVSS).

Protection from voltage transients on AC power, signal/data lines, and RF transmission lines is critical to Harris installation sites to avoid damage to electronic equipment. Damage from voltage transients may appear immediately or present itself as a "blue sky" failure much later.

All metallic conductors entering or exiting a Harris equipment room (AC, RF, telephone, LAN, signal/data, and alarm/control) require SPDs, except for ground conductors. This protection is vital to reduce the risk of personal injury, equipment damage, and equipment downtime. In addition to the primary surge protection at the building entrance or for a long cable runs between two pieces of equipment, it may also be necessary to install secondary surge protection on equipment.

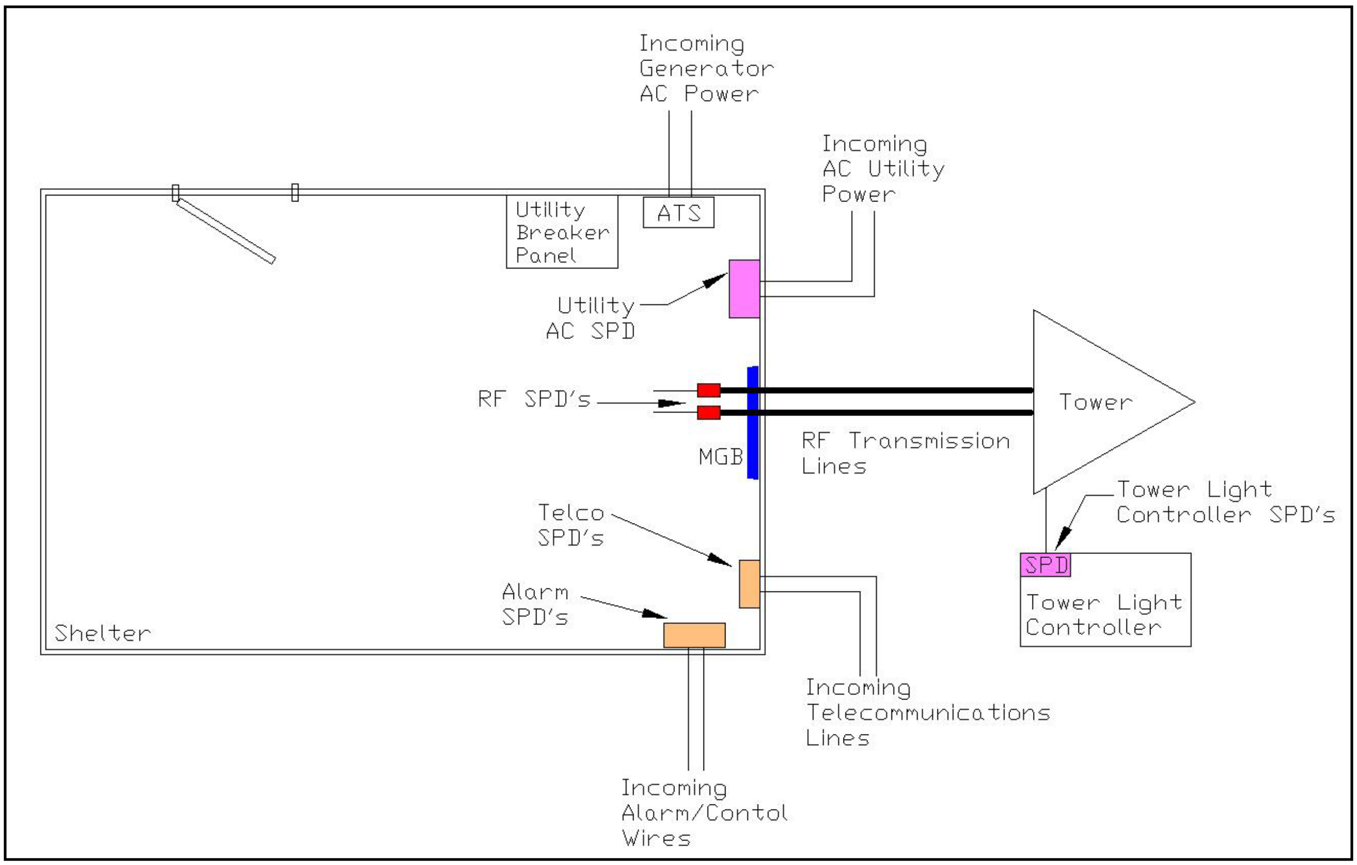



**Figure 6-1: Surge Suppression Locations Overview**

# 6.1 SOURCES OF TRANSIENT VOLTAGES

## 6.1.1 External Transient Overvoltage Sources

Nearby lightning activity can induce high-energy transients on incoming metallic conductors through inductive or capacitive coupling. Direct lightning strikes to antenna towers, incoming AC power conductors, or telephone cables can cause the most dramatic damage, but they are not the predominant cause of transient overvoltages.

The most common source of transient overvoltages (surges and spikes) is the AC power conductors from power line distribution and load switching.

Installing SPDs on incoming metallic conductors can offer protection against both types transient overvoltages.

## 6.1.2 External Transient Undervoltage/Outage

Undervoltage and low-voltage (brown out or sag) conditions and power outages are two other types of AC power line disturbances. Installing SPDs will not offer protection from these disturbances. To protect against undervoltage conditions or outages, it is necessary to install an on-line (double conversion) UPS or use batteries to power inverters to produce site AC power.

## 6.1.3 Internal Transient Overvoltage Sources

Internal load switching, fluorescent lighting, power overloads, short circuits, and induced lightning energy are internal sources of AC power transient overvoltages. Installing SPDs to protect against external transient overvoltages may not protect against these internal transient overvoltages.

To protect against these internal transient overvoltages, secondary SPDs may be installed, as close to the equipment as possible.

The high energy of a direct or nearby lightning strike can also couple onto a long cable runs inside an equipment room. To protect against this, cable runs should be as short as possible. If long data cable runs are necessary, use shielded cable and install SPDs on both ends of the cable to provide protection for the equipment inputs.

For long AC or DC power cable runs, you should install SPDs at the load end, as close to the equipment input as possible.

# 6.2 REDUCING NUMBER OF SURGE PATHS INTO SHELTER/EQUIPMENT ROOMS

The most obvious way to minimize the risk of damage to electronic equipment at a site is to reduce the number of surge paths coming into the site. This especially applies to metallic telecommunications and data lines.

In lightning prone areas, Harris highly recommends using fiber optic data links rather than metallic telecommunications and data conductors. This applies to communications paths between RF sites, between central switches and RF sites, and between central switches and remote dispatch console locations.

This concept becomes even more important in the case of two buildings located near one another but on different AC feeds and with separate ground systems. In lightning prone areas, Harris recommends not running copper conductors between the two buildings. If copper conductors are used, then you must pay special attention to the cable shield grounding and the SPD type, location, quality, and maintainability. Section 7.8.3 provides additional information for installing copper conductors at remote dispatch centers. This also applies to other situations using copper conductors between two co-located buildings.

Contact Harris Systems Engineering for guidance in selecting recommended fiber optic transmission products.

## 6.3 SURGE SUPPRESSION TECHNOLOGIES

When selecting an SPD, you need to consider several characteristics, such as:

- let-through voltage (voltage protection level)
- surge current capacity (energy dissipation capability)
- response time
- disturbance-free operation
- reliability
- operating life
- maintainability

The following sections discuss some of the technologies used in SPDs. An SPD device may consist of one or more components from a single technology or mix of technologies to maximize protection and power dissipation to overcome the deficiencies of a single technology.

NOTE

The SPD device design and construction can influence the effect its basic component advantages or disadvantages have on its overall performance.

All SPD devices used at Harris installations **shall** be UL-listed or approved for the country in which they are being used. Components within the SPD should not be encapsulated.

### 6.3.1 Gas Discharge Tubes

Gas discharge tubes are tubes with two metal plates separated by gas. They are shorting devices. When the voltage rises above a set breakdown level, the gas turns to plasma, and current flows between the two metal plates shunting the fault current.

AC SPDs with gas discharge tubes **shall not** be used in a Harris installation’s AC surge protection scheme. However, SPDs using gas discharge tubes may be used in RF or primary telco SPDs.

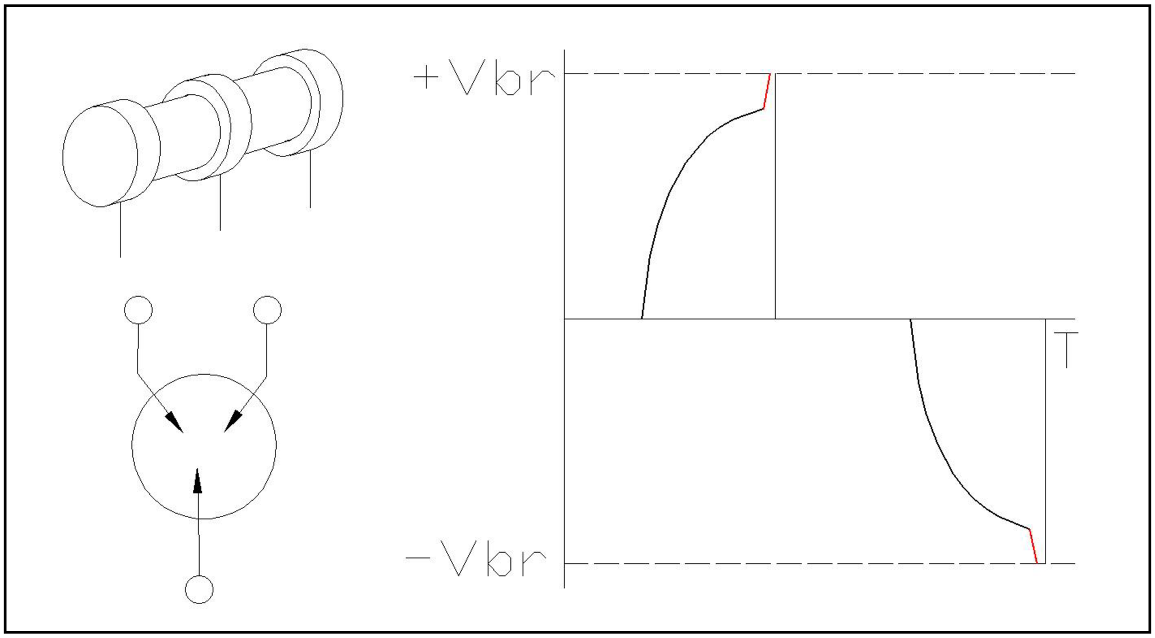



**Figure 6-2: Gas Discharge Tube Clamping Curve**

#### 6.3.1.1 Gas Discharge Tube Advantages

- Gas discharge tubes have a higher surge current dissipation capability than metal oxide varistors or silicon avalanche diodes.
- They are physically small.

#### 6.3.1.2 Gas Discharge Tube Disadvantages

- Gas discharge tubes short or "crowbar" until the voltage drops below its set level so they are not recommended for Harris low voltage (<1000 V) power applications.
- Their response time is slowest, in the low microseconds range.
- Their let-through voltages are high.
- They also have unpredictable repetitive behavior since the breakdown voltage is increased each time the device fires.
- Their operating life is relatively short, anywhere from 25-2500 surges.

### 6.3.2 Metal Oxide Varistors

An MOV is a non-linear voltage variable resistor made of zinc oxide. They are clamping devices, but the let-through voltage and the power dissipation level are interrelated. The let-through voltage rises when suppressing high surge current transients.

Multiple MOVs are often connected in parallel to partially overcome the disadvantages of a single device.

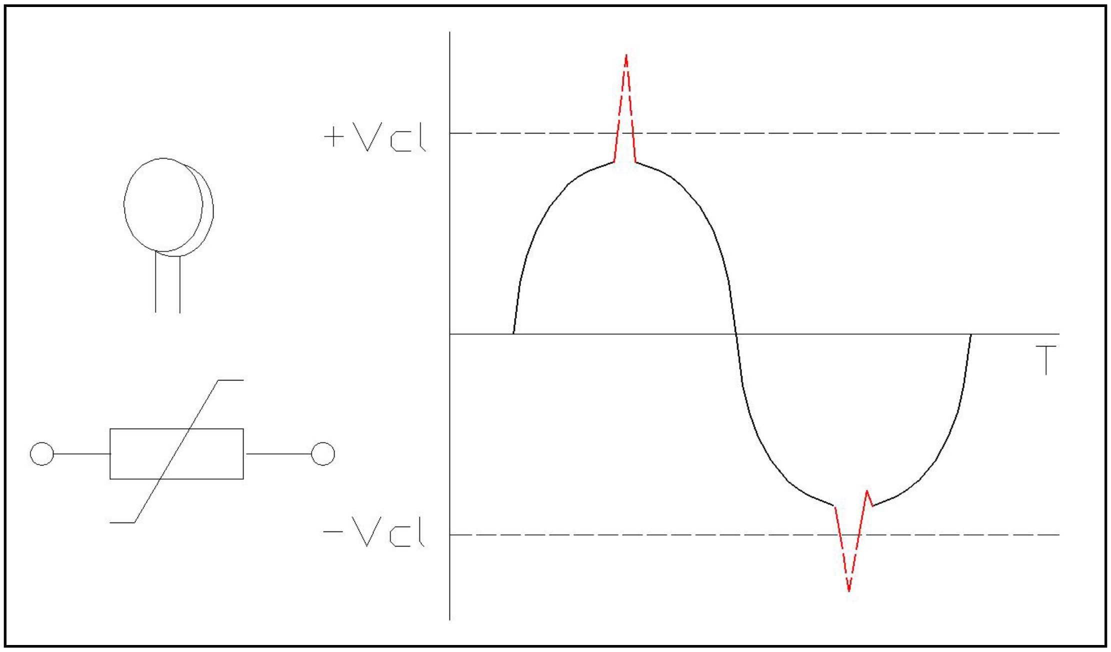



**Figure 6-3: Metal Oxide Varistor Clamping Curve**

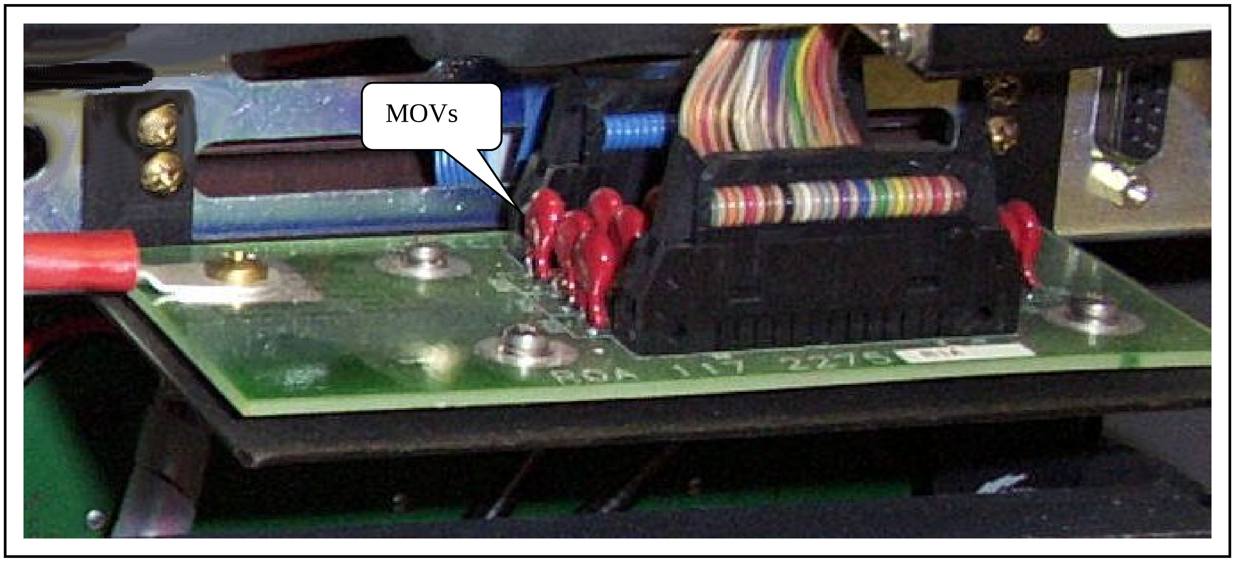



**Figure 6-4: Example of MOV Devices Used to Protect Data Lines**

### 6.3.2.1 MOV Advantages

- MOVs have a relatively fast response time, around 20-50 nanoseconds.
- They have a higher surge current disspation capability than silicon avalanche diodes, but not gas discharge tubes.
- They have consistent performance characteristics.

#### 6.3.2.2 MOV Disadvantages

- MOVs have a non-linear clamping curve. The let-through voltage rises when suppressing higher surge current transients.
- The let-through voltage selected for an MOV should be twice the peak voltage level being protected. The voltage limiting level cannot be selected too close to the protected conductor's normal peak voltage level or small transients cause leakage current to pass through the MOV causing it to overheat.
- They experience rapid fatigue at long, high surge current levels.
- Their reliability and operating life can degrade with use.
- They can have some capacitive problems at higher frequencies.

### 6.3.3 Silicon Avalanche Diodes

An SAD is a silicon crystal formed in a precise manner such that when a certain number of electrons attach to the silicon, the electrons "avalanche" through the crystal. A SAD is a non-shorting, non-linear device that conducts only the current contained in the transient above the let-through voltage. This allows continuity of the supply voltage or data to the protected equipment.

SADs are often connected in parallel to partially overcome the power dissipation limitation of a single component.

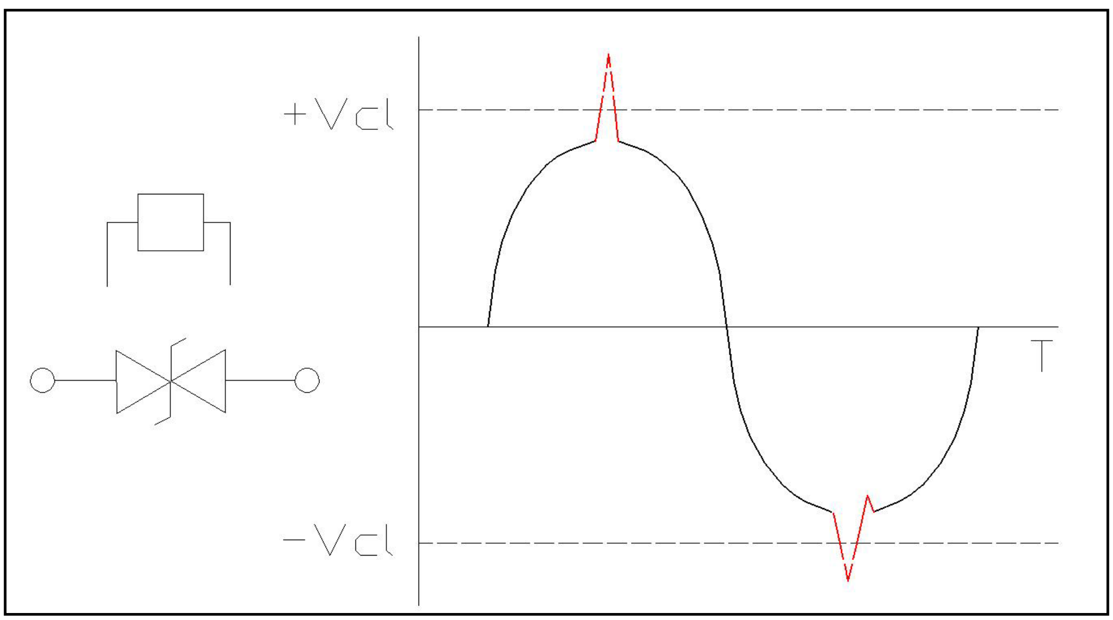



**Figure 6-5: Silicon Avalanche Diode Clamping Curve**

#### 6.3.3.1 SAD Advantages

- SADs have the fastest response time, around 5 nanoseconds.
- The design voltage limiting level can be chosen closer to the peak voltage level being protected. The voltage limiting level remains constant offering better protection.
- SADs have consistent performance characteristics.
- They do not degrade with use.

#### 6.3.3.2 SAD Disadvantages

- SADs have lower surge current dissipation capability.
- They can have some capacitive problems at higher frequencies.

## 6.4 AC SURGE SUPPRESSION

When installing AC surge suppression devices at a Harris site, the devices **shall** be UL 1449-Third Edition Listed or later and installed according to the manufacturer's recommendation. They should be normal mode devices. The equipment location and configuration will determine the type of AC SPDs required. Note that the "let-through voltage" of an AC SPD is more commonly referred to as the "voltage protection level."

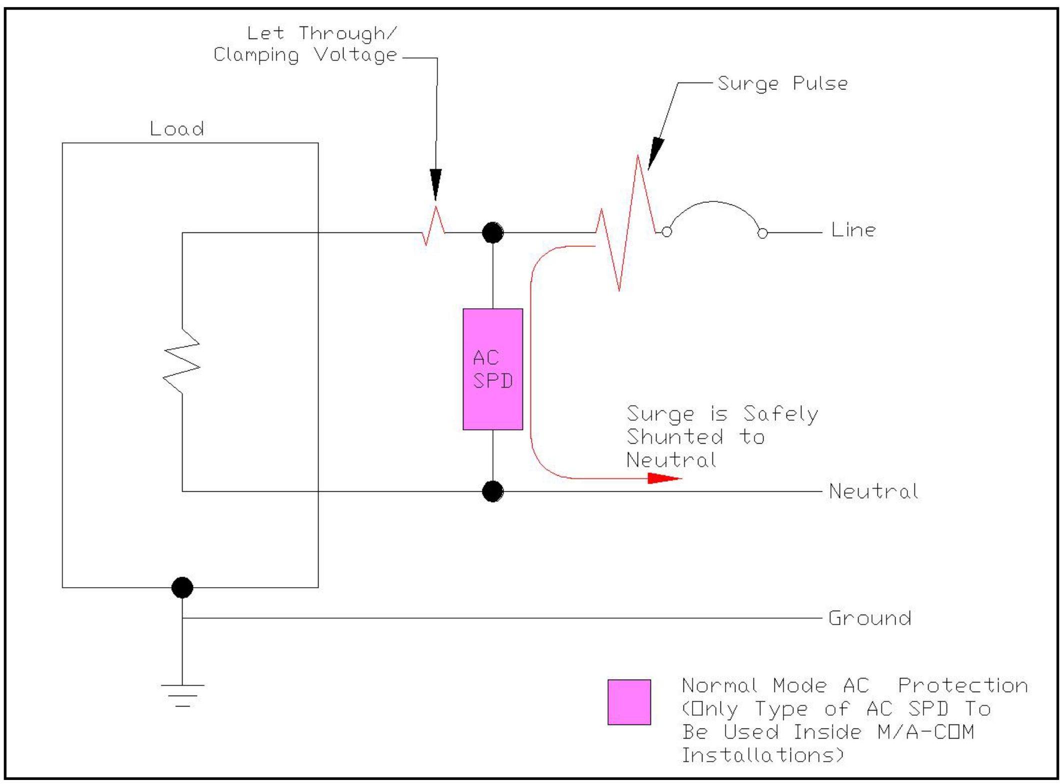



**Figure 6-6: AC Normal Mode Suppression**

### 6.4.1 Normal Mode vs. Common Mode Protection

Always use normal mode protection devices, which are installed between the current-carrying conductors (Line-Neutral or Line-Line) of the incoming AC power circuit (see Figure 6-6). Do not use common mode protection devices, devices installed between the current-carrying conductors and the equipment-grounding conductor (Line-Ground), as they could present a personnel safety hazard.

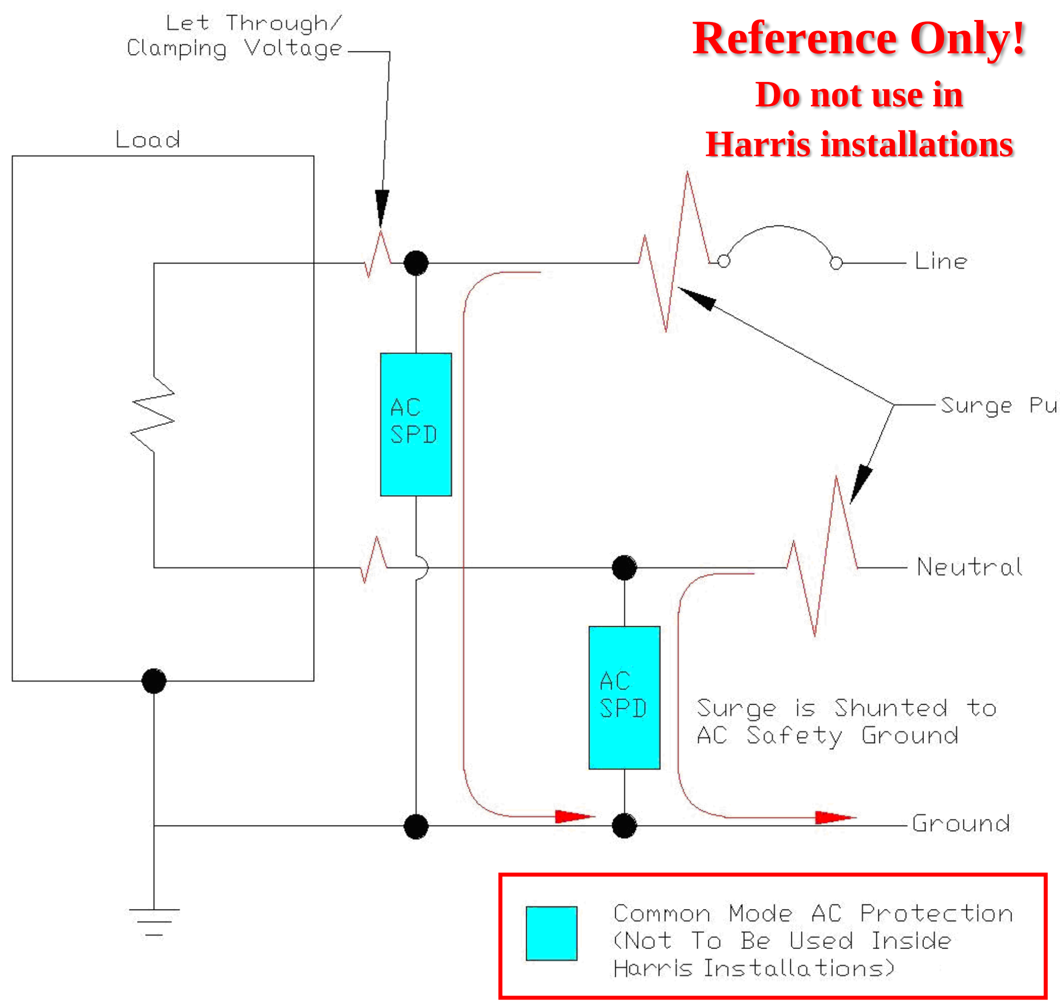



**Figure 6-7: AC Common Mode Suppression**

### 6.4.2 Importance of AC Entrance Neutral-to-Ground Bond Location

Make the AC utility entrance neutral-to-ground bond as close to the shelter as possible. This helps minimize AC transients entering the shelter. This is especially important at shared tower locations. See Section 5.6.1 AC Entrance Neutral-to-Ground Bond for more details.

### 6.4.3 Typical Site AC Surge Suppression Needs

The following sections describe the AC surge suppression needs recommended for typical Harris installation. Figure 6-8 shows the locations of these devices.

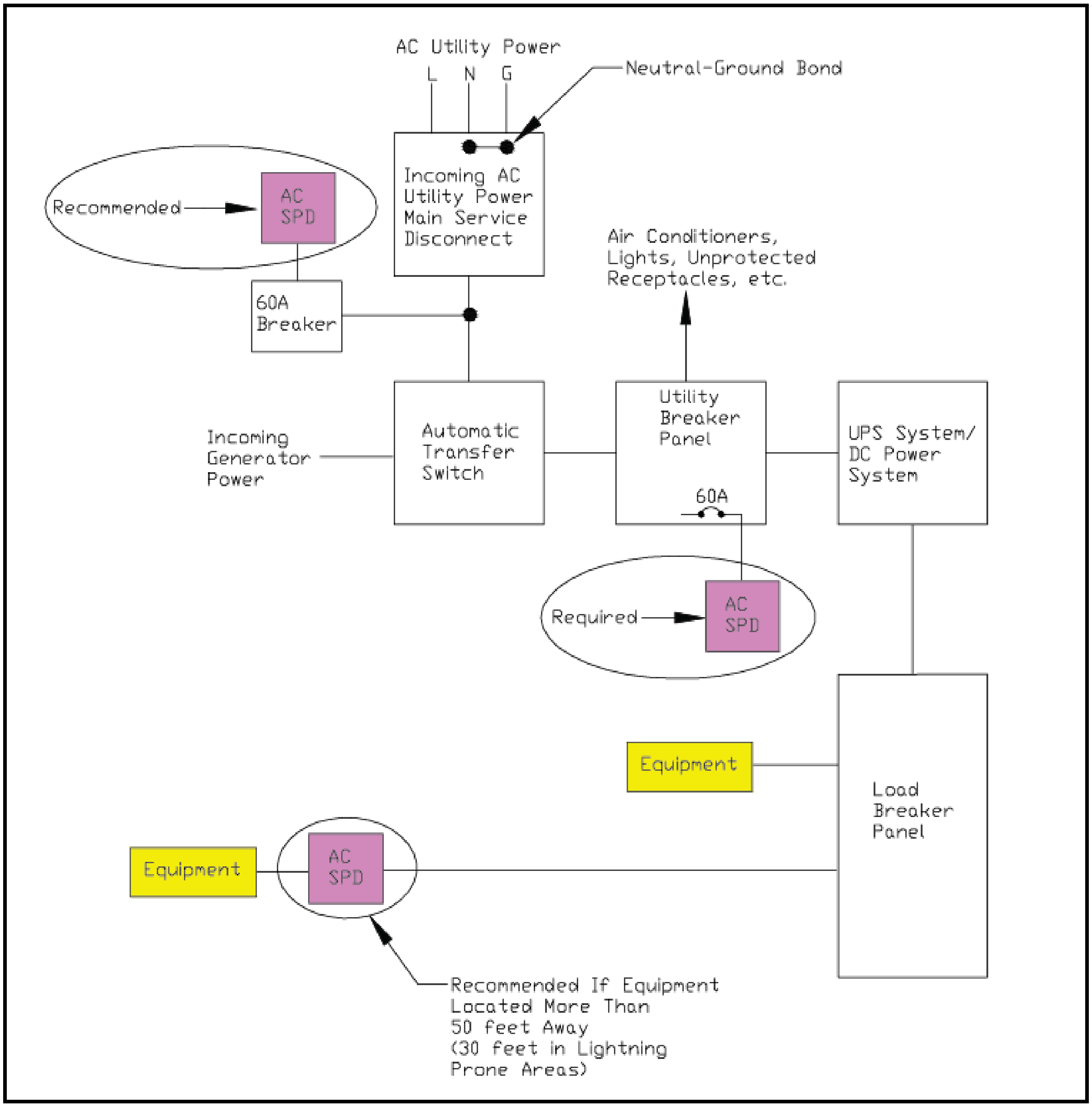



**Figure 6-8: AC Surge Suppression Locations**

### 6.4.3.1 AC Service Entrance - Utility Breaker Panel

The minimum requirement at a Harris installation is to have a UL 1449 defined Type 1 or Type 2 panel-type AC surge protector installed at the Utility Breaker Panel. This surge suppression protects the site equipment from either incoming AC utility surges or surges from a generator. (“Site equipment” refers to either the equipment directly, the UPS to which the equipment is connected, or DC battery plant rectifiers and to all AC ancillary equipment like air conditioners, lights, unprotected AC receptacles, etc.)

The AC SPD installed on the utility breaker panel actually provides surge protection for a limited distance both upstream and downstream of the device location. This is because a parallel (shunt) connected AC SPD is a bi-directional device which provides protection up to 50 feet in either direction. The bi-directional protection provided by the utility breaker panel SPD may eliminate the need to install an additional panel-type AC SPD on the Utility Entrance before the Automatic Transfer Switch (ATS). See Section 6.4.3.2 AC Service Entrance – Utility Entrance before Automatic Transfer Switch for additional details.

NOTE

An AC SPD installed on the shelter's AC utility breaker panel does not provide AC utility surge protection for the ATS if the ATS is switched to the generator input.

If a generator ATS is not used, it is possible to install the AC SPD on a separate breaker or switch right after the shelter AC utility service disconnect if it is within 25 feet of the utility breaker panel.

Site equipment containing sensitive electronics requires the highest level of surge protection. Choose the AC SPD based on the following:

- the AC service entrance configuration
- the number incoming AC power phases
- a Maximum Continuous Operating Voltage (MCOV) of 25 % above nominal service voltage
- the voltage protection level
- the maximum surge current capability

The site's exposure level determines the maximum surge current capability that should be chosen. Exposure level is determined by the site's location, the probability of lightning activity, and its criticality to users.

If you install an additional AC SPD before the ATS, the surge current capacity of that AC SPD should be greater than, or equal to, the surge current of the utility panel AC SPD.

See Section 6.4.3 for more details and refer to the AC service entrance information contained in Table 6-2.

The AC SPD should be a normal mode device and be UL 1449-Third Edition Listed or later defined Type 1 or Type 2 device (per NEC code). It should have an Amperes Interrupting Capacity (AIC) or fault current rating equal to or greater than the panel. It should also be a modular unit with either primary and secondary protection modules or redundancy built into the protection modules. If primary and secondary modules are used, they may use the same SPD technology.

Each of the SPD modules should have visual indicators on the front to indicate that power is applied and the module's protection is operational. The SPD should also have an isolated alarm contact closure to indicate an incoming power failure or a failing module. This alarm information, if properly connected to a system management device, enables remote fault monitoring.


**Figure 6-9: Utility Breaker Panel-Type AC Surge Suppression Example**

### 6.4.3.2 AC Service Entrance – Utility Entrance before Automatic Transfer Switch

At high exposure sites, we recommend installing an additional panel-type AC SPD on the utility entrance before the ATS. This surge suppressor protects the ATS control circuitry from incoming AC utility surges. A damaged ATS control circuit could leave the site without power. This AC SPD also provides additional protection to the site equipment as long as the ATS is switched to the AC utility input.

In low exposure areas, we recommend installing this additional AC SPD if the utility breaker panel SPD is more than 25 feet away from the ATS. We also recommend installing this AC SPD if the shelter's neutral-to-ground bond is located more than 30 feet from the shelter.

If used, this AC SPD should be installed after the AC utility service main disconnect on a separate breaker or switch before the ATS input.

Again, the AC SPD should be chosen based on the AC service entrance configuration, the number of phases of the incoming AC power, an MCOV of 25 % above nominal voltage, the voltage protection level, and the maximum surge current capability.

The ATS is not as sensitive as the site equipment to short duration large overvoltages. This allows using a 20% higher voltage protection level at this location compared to the AC SPD located on the Utility Breaker Panel. (Using a higher voltage protection level is optional. An AC SPD with the same specifications as the SPD used at the Utility Breaker Panel may also be used.)

The site's exposure level determines the maximum surge current capability. Exposure level is determined by the site's location, the probability of lightning activity, and its criticality to user. The surge current capacity of the AC SPD in front of the ATS should be greater than, or equal to, the surge current capacity of the AC SPD on the utility power panel. See Section 6.4.3 for more detail and refer to the AC service entrance information in Table 6-1.

The AC SPD should be a normal mode device and be UL 1449-Third Edition Listed or later defined Type 1 or Type 2 device (per NEC code). It should have an AIC or fault current rating equal to, or greater than, the Utility Breaker Panel. It should also be a modular unit with either primary and secondary protection modules or redundancy built into the protection modules. If primary and secondary modules are used, they may use the same SPD technology.

Each of the AC SPD modules should have visual indicators on the front to indicate that power is applied and the module's protection is operational. The SPD should also have an isolated alarm contact closure to indicate an incoming power failure or a failing module. This alarm information, if properly connected to a system management device, enables remote fault monitoring.

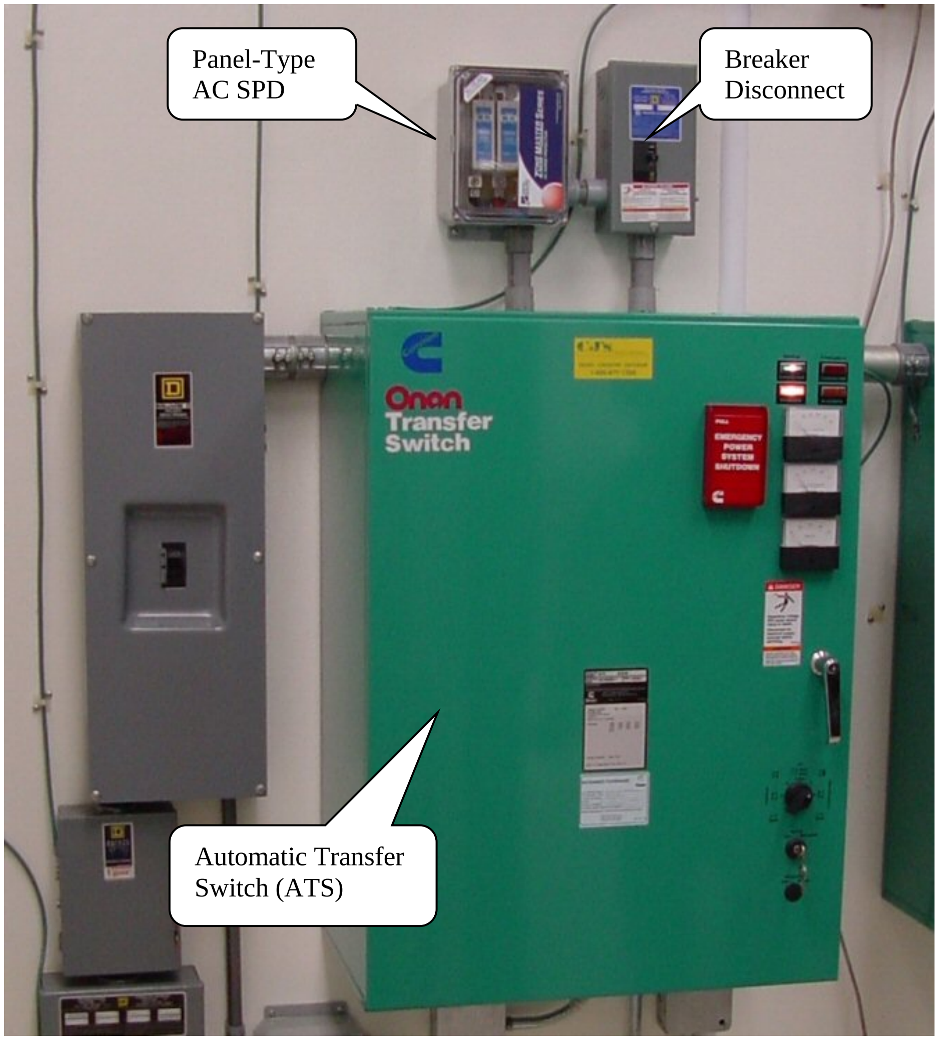



**Figure 6-10: Example of Panel-Type AC Surge Suppression Installed on Utility Entrance before ATS**

#### 6.4.3.3 Branch Breaker Panels

Equipment located inside a larger building is often supplied AC power from a branch breaker panel. If this branch breaker panel is located within 40 feet of the AC service entrance (with an appropriate AC SPD installed), then no additional panel-type AC SPD is required.

If the branch breaker panel (subpanel) is located more than 40 feet away from the Utility Breaker Panel or the AC service entrance does not have an appropriate AC SPD installed, then we recommend installing a panel-type AC SPD at the branch breaker panel. This AC SPD protects against internally produced surges and any residual external surge current that may get past the AC entrance SPDs.

NOTE

> If an appropriate AC SPD is located on the AC service entrance utility breaker panel, an alternative to installing an AC SPD on the branch breaker panel is using individual equipment AC SPDs at the equipment powered by the branch panel.

Again, choose an AC SPD based on the panel's electrical configuration, the number of phases of the incoming AC power, an MCOV of 25 % above nominal voltage, the voltage protection level, and the maximum surge current capability.

Since an AC SPD on a branch panel is also protected by the AC service entrance SPD (upstream protection), it requires a lower surge current capability unless it is located in an industrial location.

Using an SPD with a lower voltage protection level will provide more protection for the equipment on the branch panel.

See Section 6.4.5 Selecting Panel-Type AC Surge Suppression Devices for more detail and refer to the branch service information in Table 6-2.

The AC SPD should be a normal mode device and be UL 1449-Third Edition listed or later defined Type 2 device (per NEC code) and have an AIC or fault current rating equal to or greater than the panel.

Each AC SPD should have visual indicators on the front to indicate that power is applied and the module's protection is operational. The SPD should also have an isolated alarm contact closure to indicate an incoming power failure or a failing module. This alarm information, if properly connected to a system management device, enables remote fault monitoring.

If a modular unit is used, each of the SPD modules should have visual indicators on the front showing that power is applied and that the module's protection is operational.

#### 6.4.3.4 Individual Equipment

In lightning prone areas, we recommend installing individual equipment AC SPDs for each critical load located more than 30 feet in conductor length from its breaker panel and any non-critical load located more than 40 feet in conductor length from its breaker panel. We also recommend installing individual equipment AC SPDs at any site where equipment is located more than 50 feet in conductor length from its breaker panel. This surge suppression protects the equipment itself from any induced lightning AC transient overvoltages.

The AC SPD should be a normal mode device and be UL 1449-Third Edition listed or later defined Type 3 device.

Protection from the induced transient overvoltages on cabling between the individual equipment and its breaker panel requires much lower surge current dissipation than the panel-type AC SPDs previously described.

See Section 6.4.8 Selecting Individual Equipment AC Surge Suppression Devices.


**Figure 6-11: Individual Equipment AC Surge Suppression Example**

### 6.4.4 Special Installation AC Surge Suppression Needs

#### 6.4.4.1 Stand-Alone Base Station or Cell Site

At a minimum, the base station or cell site equipment should be plugged into an individual equipment AC SPD protected receptacle, as detailed in Section 6.4.3.4.

In areas prone to lightning or for critical applications, a panel-type AC SPD, similar to that described in Section 6.4.3.2, should be installed at the Utility Breaker Panel.

In addition to the AC power SPD, an appropriate SPD should also be installed on any other RF, data, or telecommunication lines that are connected to one of these devices. See the appropriate sections for details on selecting these devices.

#### 6.4.4.2 Radio Control Station, Remote Console or System Management Device

At minimum, equipment should be plugged into an individual equipment AC SPD protected receptacle, as detailed in Section 6.4.3.4.

In lightning prone areas or for critical applications, a panel-type AC SPD, similar to that described in Section 6.4.3.2, should be installed at the Utility Breaker Panel.

In addition to the AC power SPD, an appropriate SPD should also be installed on any other RF, data, or telecommunication lines that are connected to one of these devices. See the appropriate sections for details on selecting these devices. See the appropriate sections in Chapter 7 - Special Installation Situations for more details.

### 6.4.5 Selecting Panel-Type AC Surge Suppression Devices

A logical approach to defining a site's AC surge suppression needs involves defining what device or equipment needs protection. Then determine its AC service configuration, nominal AC service voltage, and the maximum transient overvoltage allowed before damage occurs or its operation is interrupted. It is important to choose the correct Voltage Protection Level (VPL) for the piece of equipment being protected, or the SPD protection may be compromised.

Next, it is necessary to determine the amount of surge current dissipation needed based on the site and equipment's exposure level.

Finally, determine the form factor and desired AC SPD features.

**WARNING**

**Any AC SPD used at a Harris installation shall be UL 1449 – Third Edition Listed or later (per NEC code) for safety.**

There are many different ways of selecting performance parameters for AC panel-type SPDs.

All AC SPDs used at a Harris installation should have performance parameters (voltage protection levels and surge current capacity) established from actual test results using waveforms specified in UL 1449-Third Edition or later. UL 1449-Third Edition and later strengthened conformity of testing among different manufacturers providing better comparative results. SPD manufacturers may also use IEEE Standard C62.41.2™-2002 and testing methods specified in IEEE Standard C62.45™-2002 for duty cycle and additional surge impulse testing. (See Section F.2.4 for more details on these specifications and their applicability.)

UL 1449-Third Edition and later introduced SPD "Type" ratings that define specific locations where an SPD is allowed to be installed based on product design, safety and performance testing. This contrasts to IEEE Standard C62.41.1™-2002 that defined the surge environment as comprised of location categories. In specifying AC SPDs for Harris installations, only the first three UL 1449 types are of concern.

**Table 6-1: AC SPD's for Harris installations**

| UL 1449-Third Edition or later "Type" | Definition | IEEE C62.41.1™-2002 "Category" |
|---|---|---|
| Type 1 | Permanently connected SPDs installed between the secondary of the service transformer and the line side of the service equipment overcurrent device, as well as the load side, including watt-hour meter socket enclosures and intended to be installed without an external overcurrent protective device. | Category C – High Exposure |
| Type 2 | Permanently connected SPDs intended for installation on the load side of the service equipment overcurrent protective device; includes SPDs located at branch panels. | Category B – Medium Exposure and Category C – High Exposure |
| Type 3 | Point of utilization SPDs, installed at a minimum conductor length of 30 feet from the electrical service panel, i.e., surge protected outlet strips. | Category A – Low Exposure |

Figure 6-12 shows the equivalent installation locations of AC SPDs between UL 1449-Third Edition and the IEEE Category.

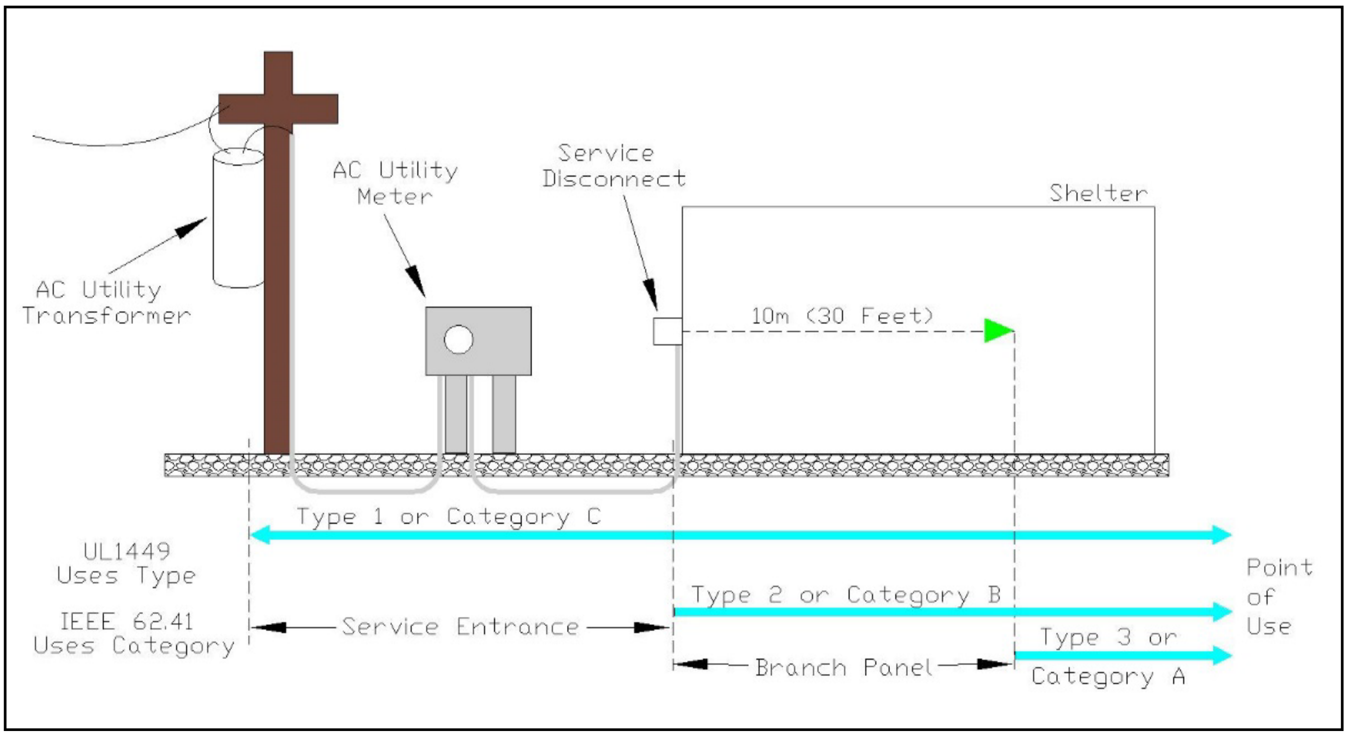



**Figure 6-12: AC SPD UL 1449 Type Locations vs. IEEE Category Locations**

Table 6-2 provides the recommended voltage protection levels for various surge current waveforms and the recommended minimum single pulse surge current capacity based on AC SPD location and exposure level.

Contact Harris Systems Engineering for guidance in selecting specific recommended AC surge suppression products.

### 6.4.5.1 Site AC Power Configuration and Maximum Voltage Protection Levels

The first step in selecting an AC Power SPD is determining the site's AC service configuration, nominal AC service voltage, and maximum transient overvoltage allowed before damage occurs or operation is interrupted for the equipment being protected.

NOTE

It is important to choose the correct voltage protection level for the equipment being protected, or the SPD protection may be compromised. The VPLs specified in Table 6-2 are suitable for most Harris site equipment.

The AC service configuration determines the nominal service voltage. An MCOV of 25% over the nominal service voltage should then be used.

The maximum voltage protection level is chosen based on the equipment being protected. The levels shown in Table 6-2 are recommended to protect Harris site equipment. UL 1449-Third Edition and later specifies an impulse test performed with a surge waveform of 6kV/3000A to obtain a Voltage Protection Rating (VPR) for each protected mode. All levels should be specified by protection mode, i.e., line-to-neutral (L-N) or line-to-line (L-L).

The measured VPR is rounded up to the next highest VPR assigned level. The UL listing label should indicate this level. (See Section F.2.1 for a list of these levels.)

Table 6-2 provides common AC service configurations, nominal service voltages, MCOV, and the maximum recommended voltage protection levels for various representative surge current waveforms for an AC SPD location in that configuration.

NOTE

The effective VPL may be affected by the installation method.

- Table 6-2 provides the maximum recommended voltage protection levels. Using an AC SPD with a lower VPL than that recommended will increase the protection level.
- Poor installation techniques can reduce the effective protection of even the best AC SPD.

The voltage protection level of a device at the various surge current levels is the most important parameter in protecting equipment. The most common surges seen on AC utility entrances are 3 kA or less. Careful attention to choosing a device with a low voltage protection level (600V-700V) at this surge current level will provide maximum protection for the equipment. For high exposure sites, attention to the VPL at the higher surge current levels is also important.

### 6.4.5.2 Site AC Power Minimum Surge Current Dissipation Level

The next step in selecting an AC power SPD is determining the minimum amount of surge current dissipation needed. This parameter is mostly dependent on the site's exposure level. The site's exposure level consists of three elements: the site's physical location, its probability of lightning activity, and the criticality of the site.

Several factors need to be taken into consideration when choosing the level of surge current dissipation protection needed for a device:

- The sources of transient overvoltage to which a device may be exposed. (The device being located at a site in a lightning prone area or near a manufacturing/industrial complex.)
- The device being located at a critical site.
- The device's criticality to site operation.
- The surge current capacity should be specified per protection mode, i.e., line-to-neutral (L-N) or line-to-line (L-L).

AC power SPDs must be capable of withstanding many surges over their service life. Ensure their performance parameters, especially the number of impulses the SPD can handle, are acceptable. Compare the manufacturer's pulse life test results with those described in Section 6.4.5.4 and Table 6-3.

Table 6-2 provides recommended minimum single pulse surge current capacities for panel-type AC SPDs based on location and exposure level. It also provides common AC service configurations, nominal service voltages, MCOV, and the maximum recommended voltage protection levels for various representative surge current waveforms for an AC SPD location in that configuration.

#### 6.4.5.3 Recommended AC Power Surge Suppression Performance Parameters

Table 6-2 provides recommended performance parameters for panel-type AC power SPDs used at the AC service entrance and branch breaker panels in Harris installations. The table shows the most common AC entrance configurations. If information is needed for an AC service configuration not shown, please contact Harris Systems Engineering.

Additional general information for each type of AC SPD is available in the preceding sections.

NOTE

The VPL of a device at the various surge current levels is the most important parameter in protecting equipment. Table 6-2 lists the maximum VPLs and minimum current ratings recommended for Harris installations. However, AC SPDs with lower VPLs and higher surge current ratings may be used.

NOTE

The recommended AC SPD parameters are for North America TN grounded sites (neutral grounded at the facility) only. For the recommended AC SPD parameters in countries with TT ground systems (no neutral-to-ground bond at the facility), contact Harris Systems Engineering

### 6.4.5.4 AC Surge Protection Device Nominal Discharge Current Test ($I_n$)

AC power SPDs must be capable of withstanding many surges over their service life. To ensure the AC SPD's surge suppression performance is maintained over its service life, UL 1449-Third Edition and later require AC SPDs to remain fully operational after being subjected to 15 impulses, one minute apart with less than 10% difference in the VPR measured between the first and the last impulse. The value of the nominal discharge current ($I_n$) impulse value is selected by the manufacturer and must be marked on the label of the device as ($I_n$). For Harris installations, SPDs should be chosen with minimum nominal discharge current ($I_n$) rating of 10kA with 20kA recommended for high exposure sites. Table 6-3 lists the test requirements according to the device's location and exposure level.

**Table 6-2: Recommended Panel-Type AC Surge Protection Performance Parameters**

| Location | Exposure Level (Location and Criticality) | IEEE C62.41.2-2002 Category/ Exposure Level | Service Type | Service Configuration | Nominal Service Voltage $V_{RMS}$ (L-N) | MCOV $V_{RMS}$ (L-N) | Maximum Voltage Protection Level V (L-N): 6kV/ 3kA UL1449-3rd Edition or later VPR | Maximum Voltage Protection Level V (L-N): @ Cat C Low 3kA 8/20µs | Maximum Voltage Protection Level V (L-N): @ Cat C High 10kA 8/20µs | Min. Single Pulse Surge Current Capacity (8/20µs per mode) |
|---|---|---|---|---|---|---|---|---|---|---|
| **AC Service Entrance** (IEEE C62.41.2-2002 Category C) | High | C High Scenario II, Exposure 3 100kA 8/20µs | Split Phase/ Single Phase | 1Ø, 240/120V, 3-Wire+Gnd | 120-127 | 150 | 700 | 600 | 800 | 100kA |
| | | | Grounded Wye | 3Ø, 208/120V, 4-Wire+Gnd | 120-127 | 150 | 700 | 600 | 800 | 100kA |
| | Normal | C Low Scenario II, Exposure 2 50kA 8/20µs | Split Phase/ Single Phase | 1Ø, 240/120V, 3-Wire+Gnd | 120-127 | 150 | 700 | 600 | 800 | 50kA |
| | | | Grounded Wye | 3Ø, 208/120V, 4-Wire+Gnd | 120-127 | 150 | 700 | 600 | 800 | 50kA |
| | | | | | | | | | | |
| **Branch Service** (IEEE C62.41.2-2002 Category B) | Normal | B Scenario II, Exposure 1 20kA 8/20µs | Split Phase/ Single Phase | 1Ø, 240/120 V, 3-Wire+Gnd | 120-127 | 150 | 700 | 500 | 700 | 25kA |
| | | | Grounded Wye | 3Ø, 208/120V, 4-Wire+Gnd | 120-127 | 150 | 700 | 500 | 700 | 25kA |

**Table 6-3: Recommended Panel-Type AC Surge Protection Pulse Life Test Parameters**

| Location | Exposure Level (Location and Criticality) | IEEE C62.41.2-2002 Category/ Exposure Level | Number of Impulses | IEEE C62.41.2-2002 Test Waveform | Percent Change in Voltage Protection Levels |
|---|---|---|---|---|---|
| **AC Service Entrance** (IEEE C62.41.2-2002 Category C) | High | C High | 100 | 10kV / 10kA Combination waveform, Alternating (+/-) at one minute intervals | <10% |
| | Normal | C Low | 100 | 6kV / 3kA Combination waveform, Alternating (+/-) at one minute intervals | <10% |
| | | | | | |
| **Branch Service** (IEEE C62.41.2-2002 Category B) | Normal | B | 100 | 6kV / 3kA Combination waveform, Alternating (+/-) at one minute intervals | <10% |

### 6.4.6 Installation of Panel-Type AC Surge Suppression Devices

You should install panel-type AC power surge suppressors as close as possible to the service entrance breaker panel according to the manufacturer's recommendation. This point cannot be stressed enough. A general rule of thumb is that for each foot of wiring between the AC SPD and the breaker panel, the transient let-through voltage will increase by an additional 165 Volts.

During a surge the self-inductance of the wire connecting the SPD can also significantly increase the residual let-through voltage reaching the equipment being protected. The conductors should be kept as short as possible and twisted together to minimize their self inductance. It is also important to have no sharp bends in the conductors to the SPD.

Conductors to the SPD should be sized as recommended by the manufacturer, but at least #6 AWG should be used. The SPD should be on its own 30A, or larger, breaker after the main breaker to allow for servicing.

**NOTE**

> The largest breaker and connecting conductors allowed by the AC SPD manufacturer should be used. The connecting wires should also be kept as short as possible to minimize increases to the AC SPDs effective voltage protection level.

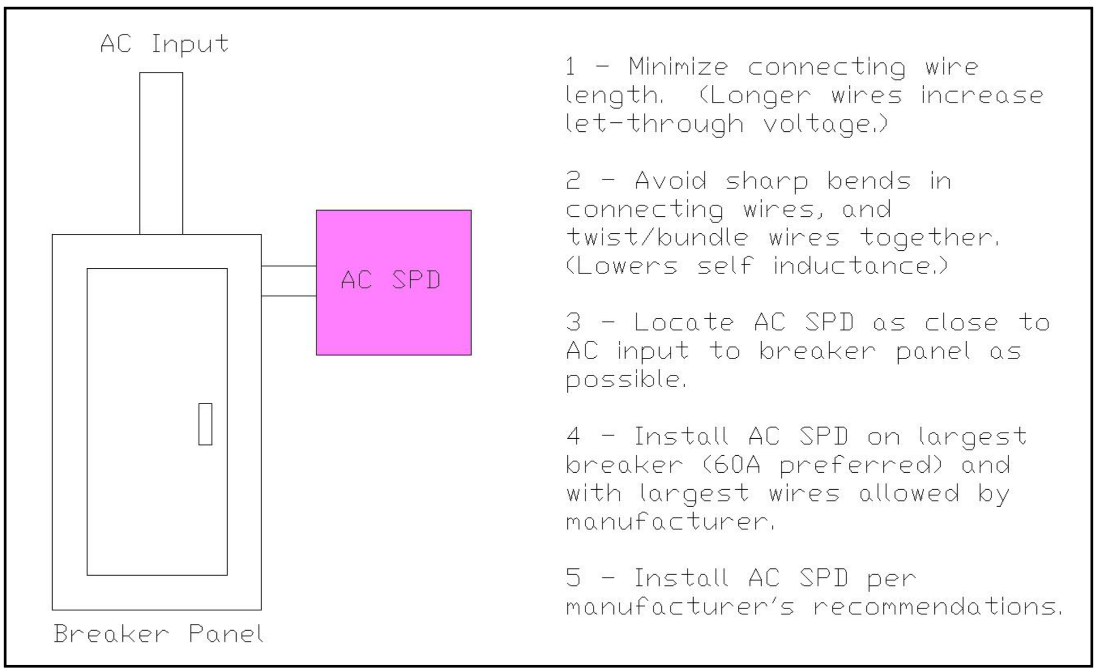



**Figure 6-13: AC Surge Suppression Installation Detail**

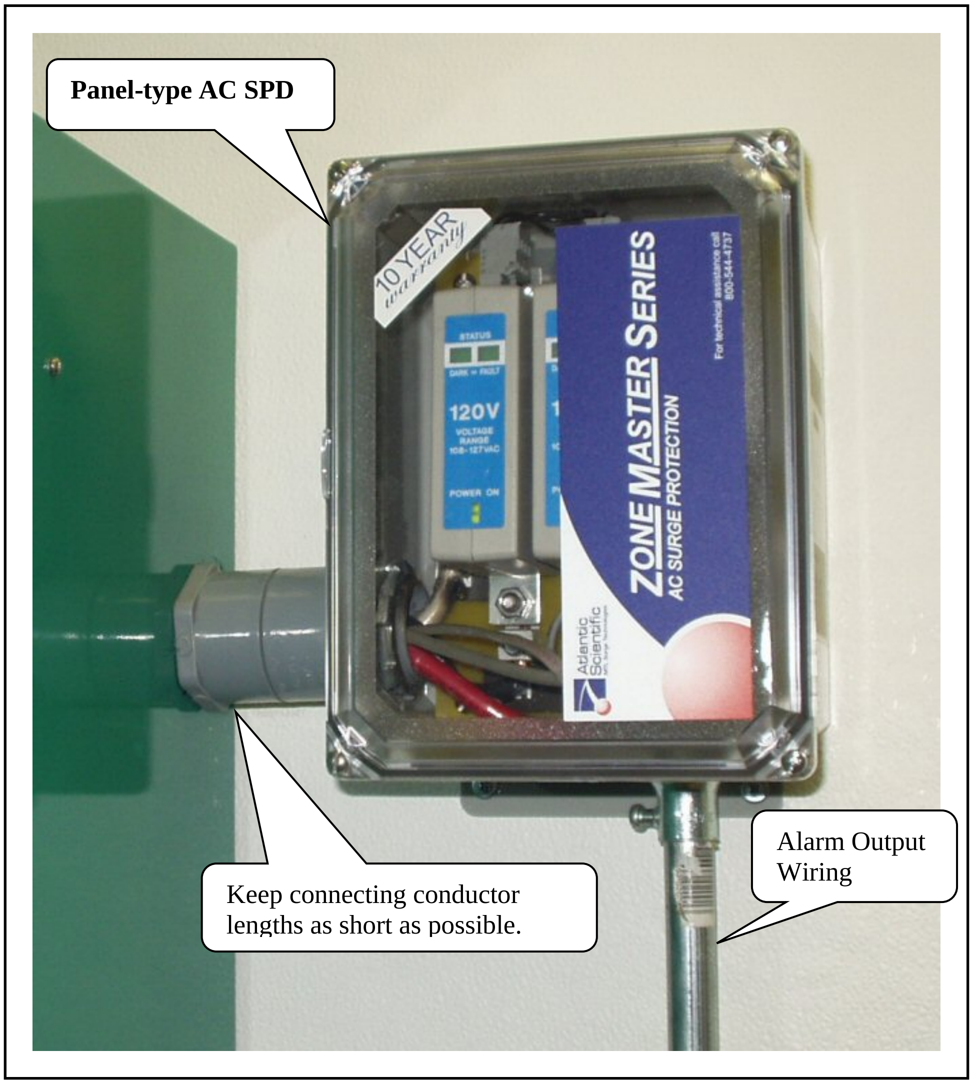



**Figure 6-14: Typical AC Surge Protector Installation**

## 6.4.7 Considerations for AC Surge Suppression Devices Installed Inside Breaker Panels

Some breaker panels allow an SPD to be installed inside the panel. Load centers that include the functionality of a utility breaker panel, generator transfer switch, and surge protection are also available.

Though this would appear to minimize the conductor length therefore minimizing the effective VPL, care should be taken to examine the mounting location and cabling configuration of the SPD inside the panel to verify this is true.

The other consideration is that an SPD installed inside a breaker panel may require removing the breaker panel cover when servicing the SPD. This presents an electrocution hazard and requires a licensed electrician.

NOTE

Servicing AC surge suppression devices installed inside breaker panels may require removing the breaker panel cover. This presents an electrocution hazard and requires a licensed electrician.


**Figure 6-15: Example of Load Center with Integrated AC Surge Suppression**

### 6.4.8 Selecting Individual Equipment AC Surge Suppression Devices

Individual equipment AC SPDs come in many different form factors. They may be a wire-in receptacle outlet, plug-in adapter, or multiple receptacle outlet panel or strip. Multiple receptacle outlet panels or strips may have mounting tabs.

Individual equipment AC SPDs should have visual indicators on the front showing that power is applied and that the module's protection is operational.

They should be at least UL 1449-Third Edition Listed type 3 devices. An AC SPD including telephone and data circuit protection may be used, but it must then also be UL-listed for these applications.

Table 6-3 lists the performance parameters for the recommended individual equipment AC SPDs.

**Table 6-3: Recommended Individual Equipment AC Surge Protection Performance Parameters**

| Parameter | Value |
|---|---|
| Service Voltage/Phase | 120 VAC/Single Phase |
| Maximum Continuous Operating Voltage (MCOV) | 140 $V_{RMS}$ |
| UL 1449-Third Edition or later Type | 3 |
| IEEE C62.41.1-2002 Location Category/Exposure Level | A3 |
| Maximum Voltage Protection Level (L-N)<br>@6kV/3kA 8/20µs (UL 1449-3rd Edition or later VPR) | 330V |


**Figure 6-16: Individual Equipment Surge Protector Examples**

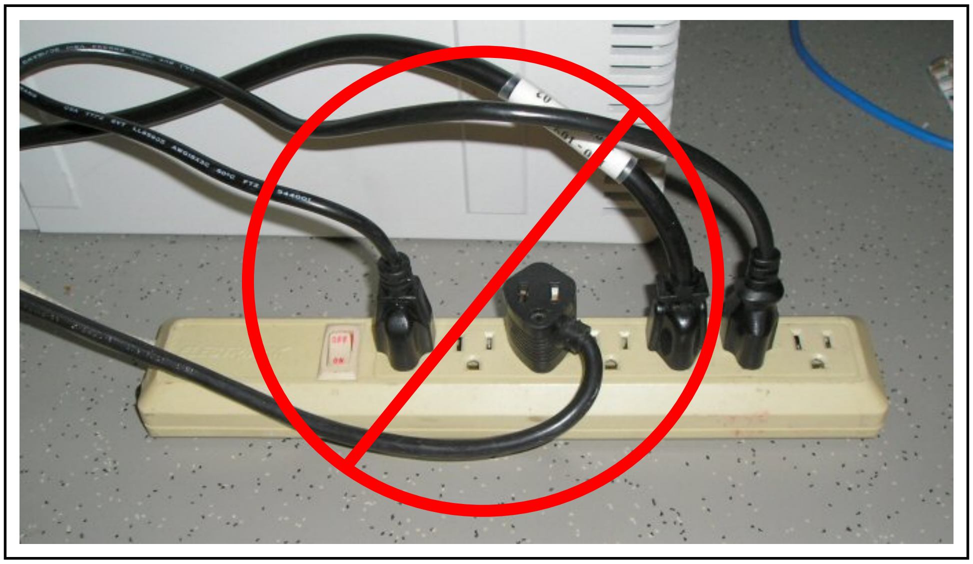


**Figure 6-17: Example of a Multiple AC Receptacles Strip without Surge Protection**

## 6.5 RF SURGE SUPPRESSION

After entering the shelter, all RF transmission lines (including GPS antenna lines) should have a coaxial RF surge protection device (SPD) installed in the line as close as practical to the entry point. The RF SPD must be grounded to either the RF entry port or MGB as described in Section 5.3. These RF SPDs are effective in limiting the amount of lightning surge current that can be transferred to the equipment through the inner conductor of the coaxial or transmission line. All RF transmission lines, including unused lines and test port lines, should have an RF SPD installed.

RF SPDs should be located and grounded within 2 feet of the cable entrance to a shelter. For equipment rooms located within a larger building, this means the RF SPDs should be located at the cable entrance to the building and not inside the equipment room.

All RF transmission lines entering a shelter should also have ground kits installed as described in Section 4.4. While RF SPDs shunt surge current off the inner conductor of the RF transmission line, it is still necessary to install ground kits to shunt surge current off the outer shield of the RF transmission line.

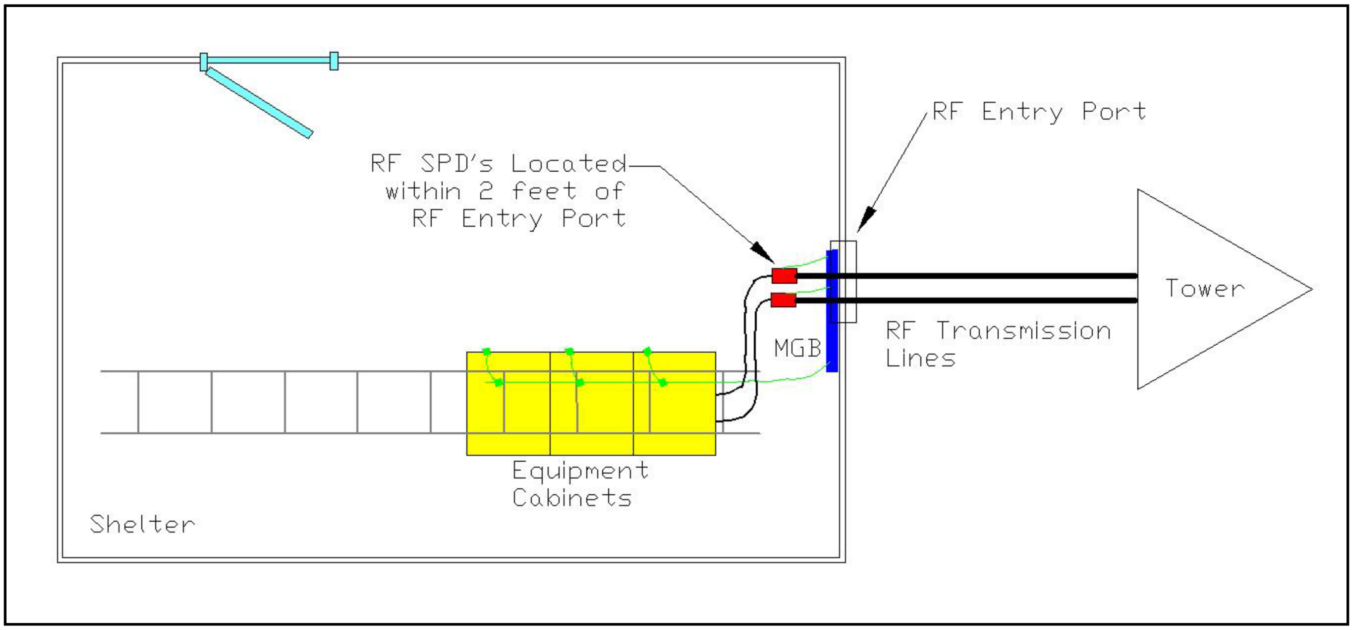



**Figure 6-18: RF Surge Protector Location in Shelter**

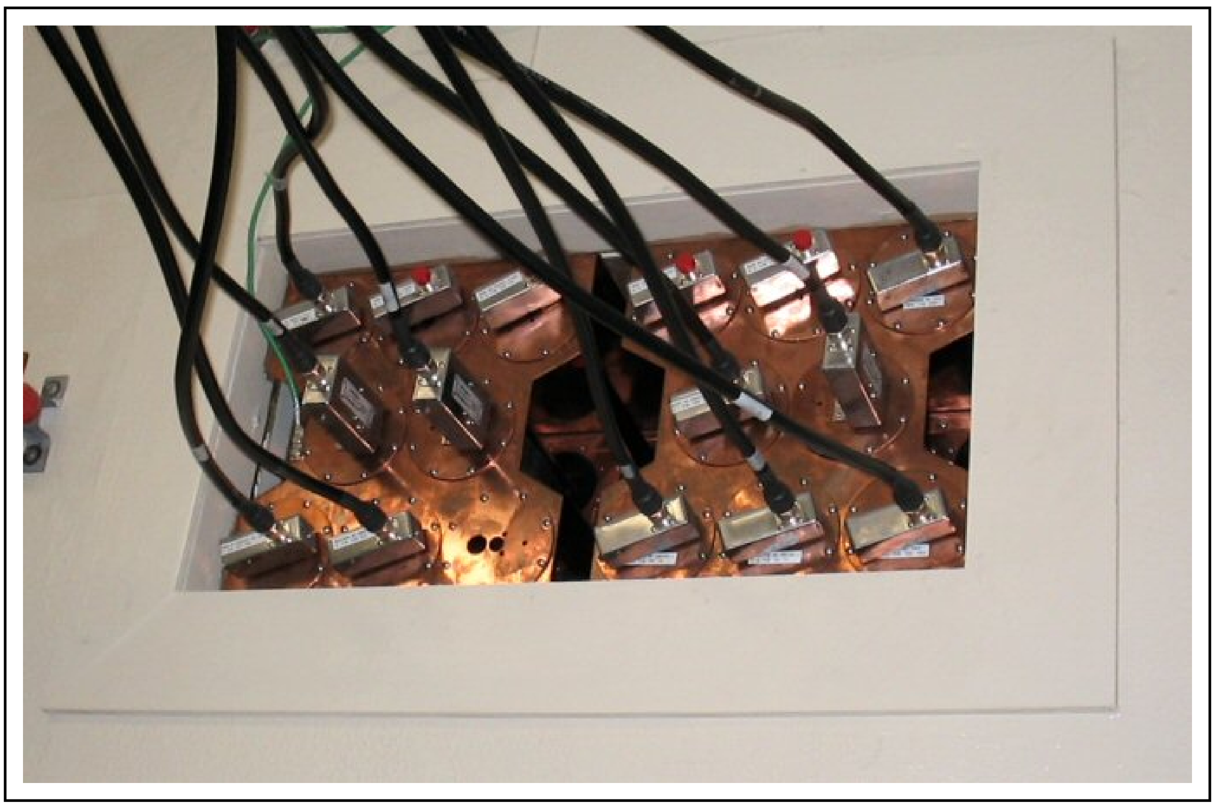


**Figure 6-19: Example of RF Surge Protectors Installed at RF Entry Port in Shelter**

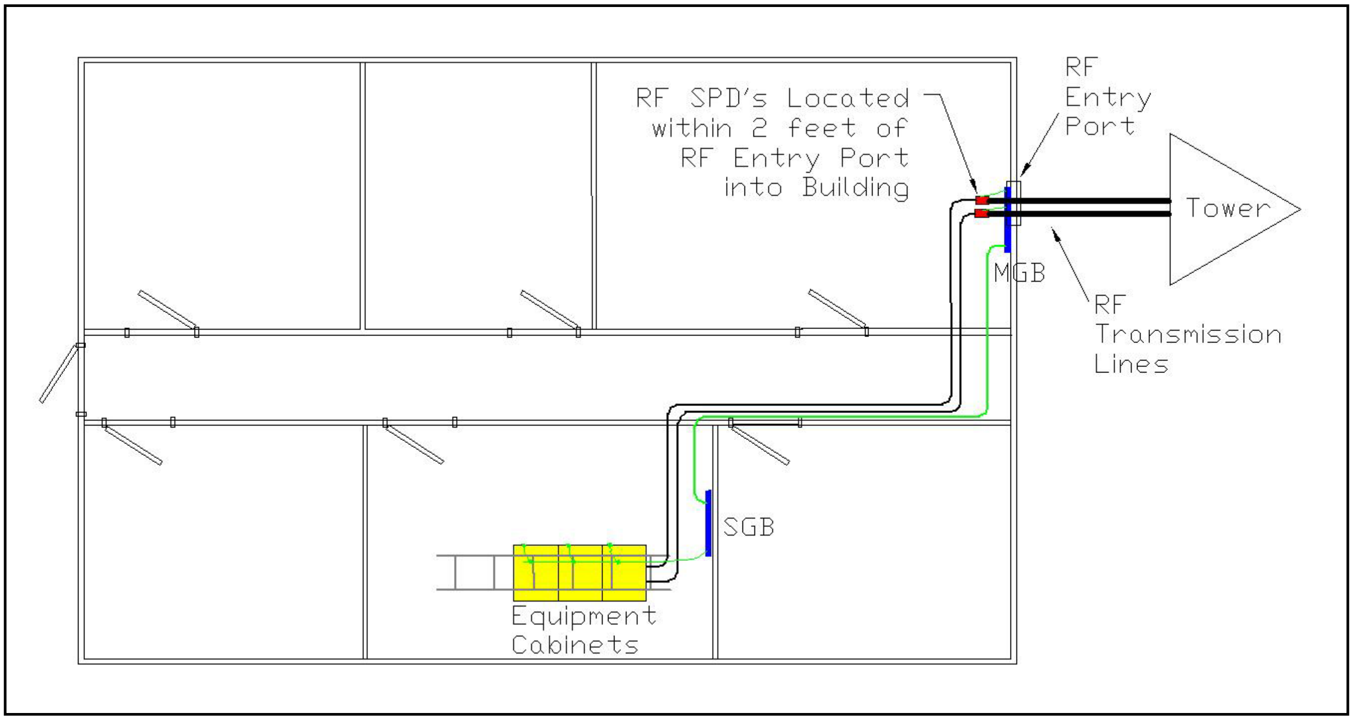



**Figure 6-20: RF Surge Protector Location when RF Entry Port Located in Different Room in Larger Building**

**Figure 6-21: Example of RF Surge Protectors Installed at an RF Entry Port into a Multistory Building Away from the Equipment Room**

### 6.5.1 RF Surge Protection Device Types

Gas discharge tube technology and shorted stub (inductor) technology are commonly used in RF surge protection devices. RF SPDs containing non-linear technologies (like an MOV or SAD) should not be used since they could produce RF intermodulation.

Gas discharge tube technology is usually combined with a reactive band-shape network in an RF SPD. During normal operation, the tube is not energized and has very high impedance resulting in little RF insertion loss. During a lightning strike, the gas ionizes and provides a short to ground to dissipate the surge current. A gas discharge tube RF SPD is a broadband device and has the ability to absorb multiple lightning strikes, however, it may have to be replaced after a large lightning strike or after many smaller strikes.

Shorted stub (inductor) technology presents a “short” to earth of all DC and AC currents with frequencies outside the operating frequency of the SPD. At its operating frequency, a shorted stub has a very high impedance so it has little RF insertion loss. It also has the capability to handle multiple lightning strikes. The drawbacks of this technology are that it will pass “on-frequency” lightning energy. A shorted stub can also contribute to intermodulation and is often physically larger than a gas discharge tube device.

RF SPDs are selected based on their application as described in the following sections.

### 6.5.2 Transmit Coaxial Transmission Lines

RF SPDs for transmit coaxial transmission lines should have broadband capability for the frequency range needed and be rated for the amount of power that will be transmitted on the coaxial line. Only DC-blocked RF SPDs should be used.

### 6.5.3 Receive Coaxial Transmission Lines

RF SPDs for receive coaxial transmission lines should be DC-blocked unless there is a need for DC current to be passed on the coaxial cable to a tower top amplifier or active antenna. The frequency range is also a consideration.

For coaxial lines that must pass DC current, you should install an RF SPD designed for this purpose. The RF SPD should allow the injection and pick-off of a DC voltage providing integrated DC surge protection. Ensure the RF SPD has the proper operating voltage. Do not use shorted stub (inductor) devices in this application. When using a tower top amplifier, you should install an RF SPD in both the tower top amplifier and at the shelter RF entry port. A DC ground, shunt-fed antenna should be used as additional protection for tower top amplifiers, where possible. You should also keep antenna cables as short as possible.

### 6.5.4 Duplexed Transmit and Receive Coaxial Transmission Lines

When selecting an RF SPD for a duplex coaxial line, base the selection on the receiver’s requirements and a frequency range that will cover both the transmit and receive frequencies.

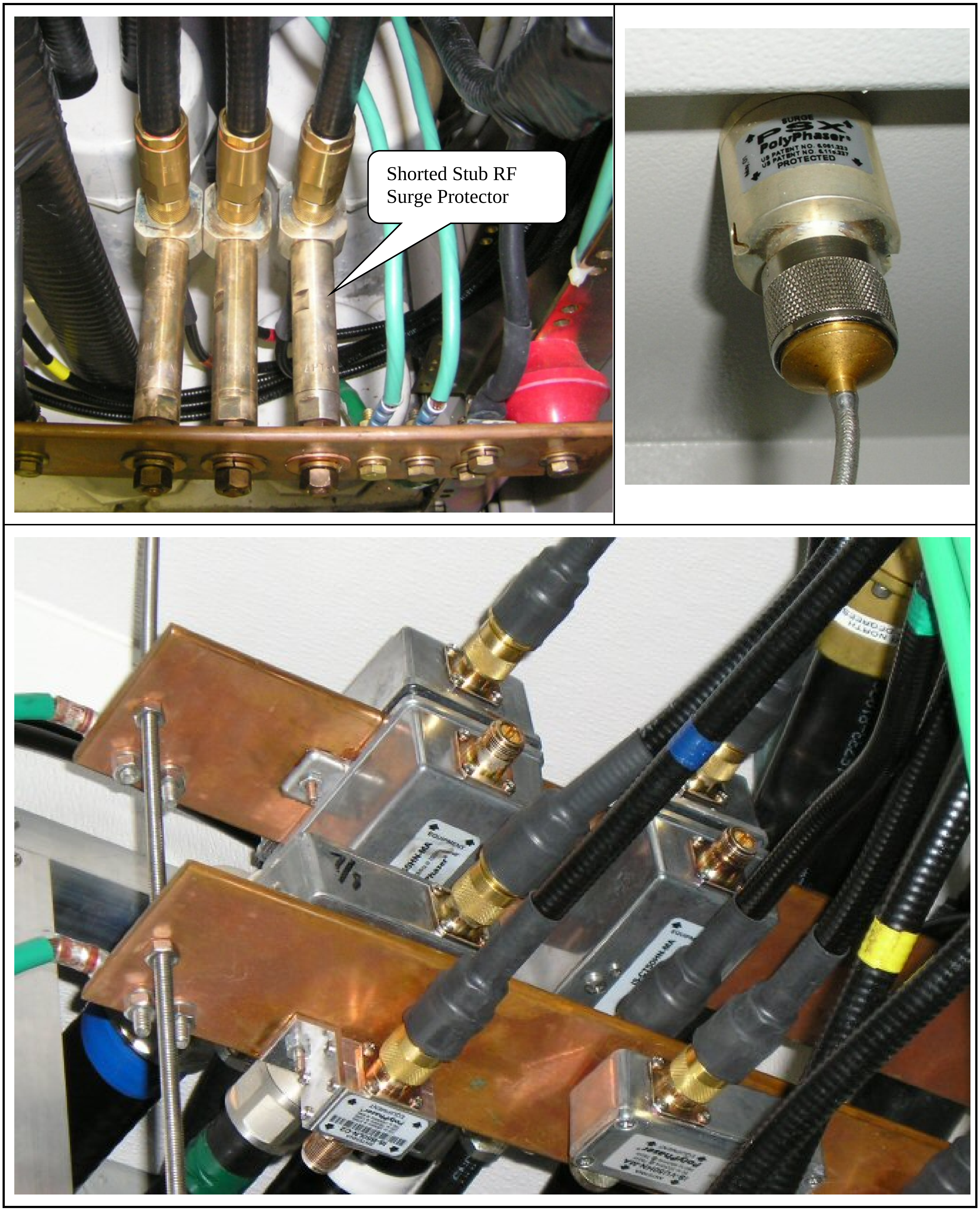



**Figure 6-22: Examples of Different Style RF Surge Suppressors**

### 6.5.5 GPS Receiver Coaxial Transmission Lines

Many GPS receivers use a GPS antenna amplifier. This requires installing an RF SPD that allows passing DC current. Be sure to select an RF SPD that meets the proper operating voltage and frequency requirements. If a GPS receiver does not use an antenna amplifier, you should install a DC-blocking RF SPD. Most GPS receiver manufacturers sell or specify GPS RF SPDs.

The GPS receiver's manufacturer's recommendations should be followed in selecting the GPS RF SPD since delays introduced by the RF SPD and the length of the coaxial transmission line may require adjustments in the GPS receiver setup.

### 6.5.6 Other Considerations in Choosing RF Surge Protection

After the RF SPD application is determined, several more parameters must be considered when selecting a device.

The type of RF entry port or bulkhead panel used or the physical space limitations at the cable entry point will determine the mounting style selected. Some bulkhead panels have an interior sub panel with integrated RF surge suppressor grounding and some RF SPDs can be bolted directly to this integrated grounding surface. Another consideration may be the RF SPD connector type and gender.

Table 6-4 lists the acceptable performance parameters of RF SPDs used in Harris facilities.

**Table 6-4: RF SPD Performance Parameters**

| Parameter | Performance Characteristics |
|---|---|
| Surge current capability: | ≥ 20kA |
| Turn-on voltage: | ≤ 1200 VDC* |
| Turn-on time: | ≤7 nsec |
| Insertion loss: | ≤ 0.1 dB over frequency range |
| VSWR: | ≤ 1.1 to 1 over frequency range |
| * This number should be chosen as low as possible for the RF power required. | |

## 6.6 TELECOMMUNICATIONS LINE SURGE SUPPRESSION

All copper telecommunications lines entering a facility should have surge protection devices installed and properly grounded. Copper telecommunications lines, like the incoming utility AC lines, present a significant source of external surges.

You should select SPD devices based on the type of line being protected and the type of line termination (punchblock, jack, or screw terminal). Typical telecommunications SPDs protect in both normal and common modes. All telecommunications SPDs used in Harris facilities should be UL-listed.

When possible, facilities requiring multiple telecommunications lines should use fiber optic links instead of copper.

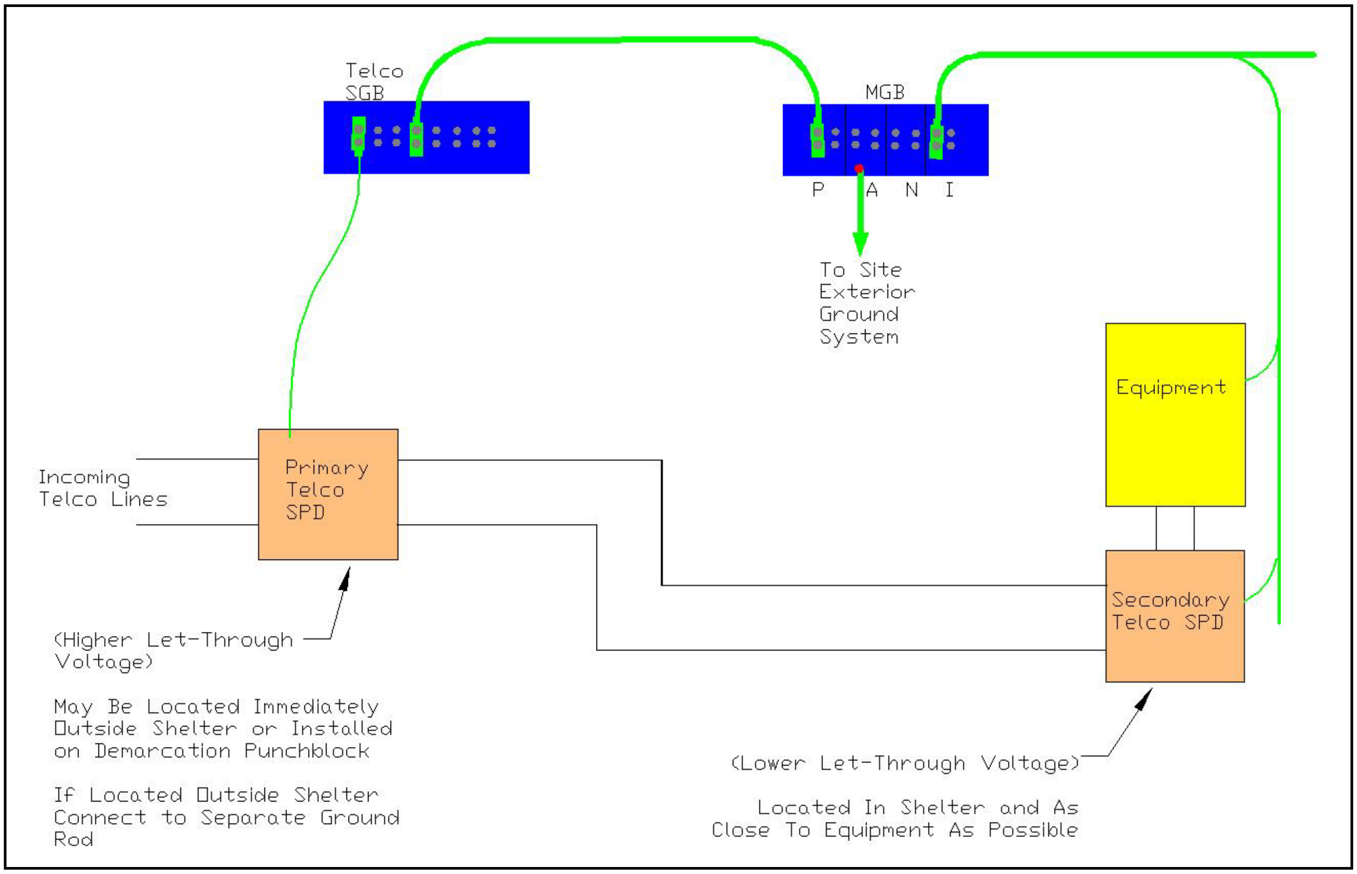



**Figure 6-23: Telecommunications Primary and Secondary Surge Protector Locations and Grounding**

### 6.6.1 Primary Telecommunications Line Surge Suppression

When using copper telecommunications lines, their primary SPDs and the cable's metallic sheath or shield should be grounded to the MGB. (See Section 5.7, Telecommunications Service Entrance.)

Primary telecommunications SPDs should comply with all applicable codes. Resettable devices are also available for this application. However, some NFPA 70 applications and local codes may require fused-type primary SPDs. In some cases, the telecommunications provider may install the primary telecommunications SPDs.

Often the incoming lines use a punchblock as a termination and demarcation point between the provider and the site equipment. When using a punchblock, install the primary SPDs on or within 2 feet of this punchblock.

Be sure the punchblock SPDs are designed for the type of punchblock used. Most punchblock SPD installations have an associated grounding strip that attaches to all of the SPDs on a single punchblock. This grounding strip provides a single ground point for all the SPDs on the entire punchblock. One #6 AWG conductor then grounds this punchblock grounding strip to either the MGB or a nearby SGB.

SPDs with screw terminals or RJ connectors (registered jacks) may also be used.

You must also ground any incoming telecommunication cable's unused pairs at the telecommunications service entrance. (See Section 5.7 Telecommunications Service Entrance for more detail.)

NOTE

Unused pairs in an incoming telecommunications cable must also be grounded to the Telecommunications SGB (see Figure 6-25). Contact the Telco provider to verify this will not disturb their equipment.

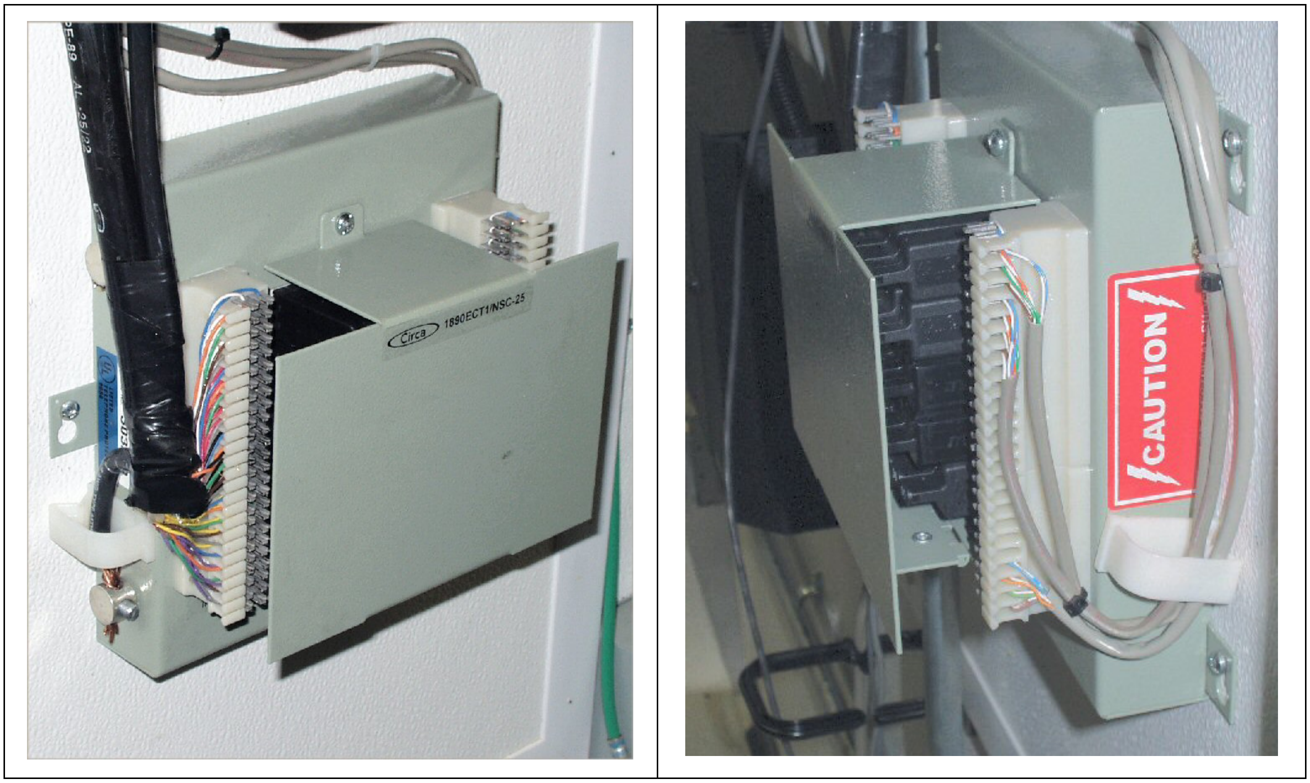



**Figure 6-24: Example of Primary Telecommunications Surge Protection Device (Building Entrance Terminal)**

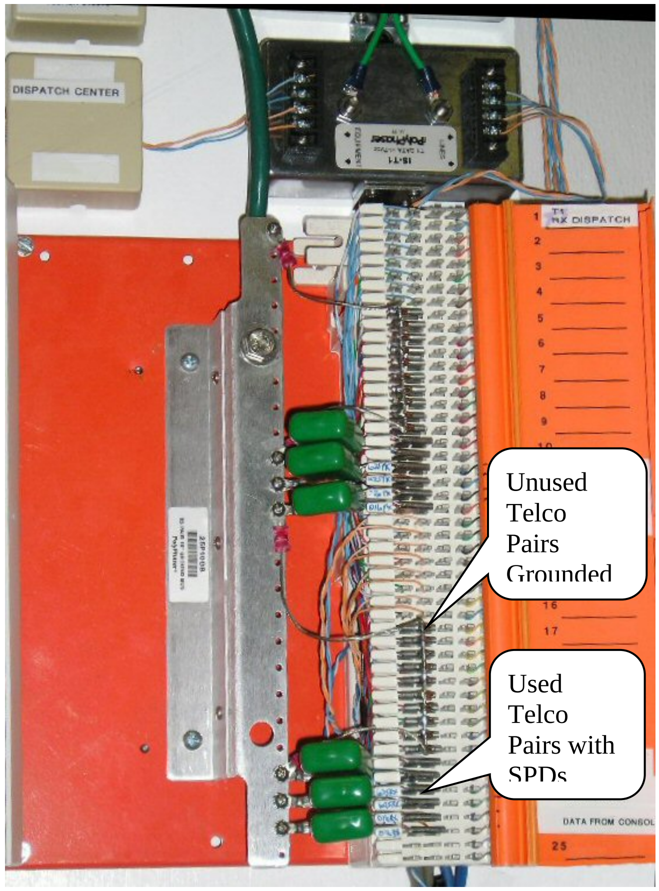


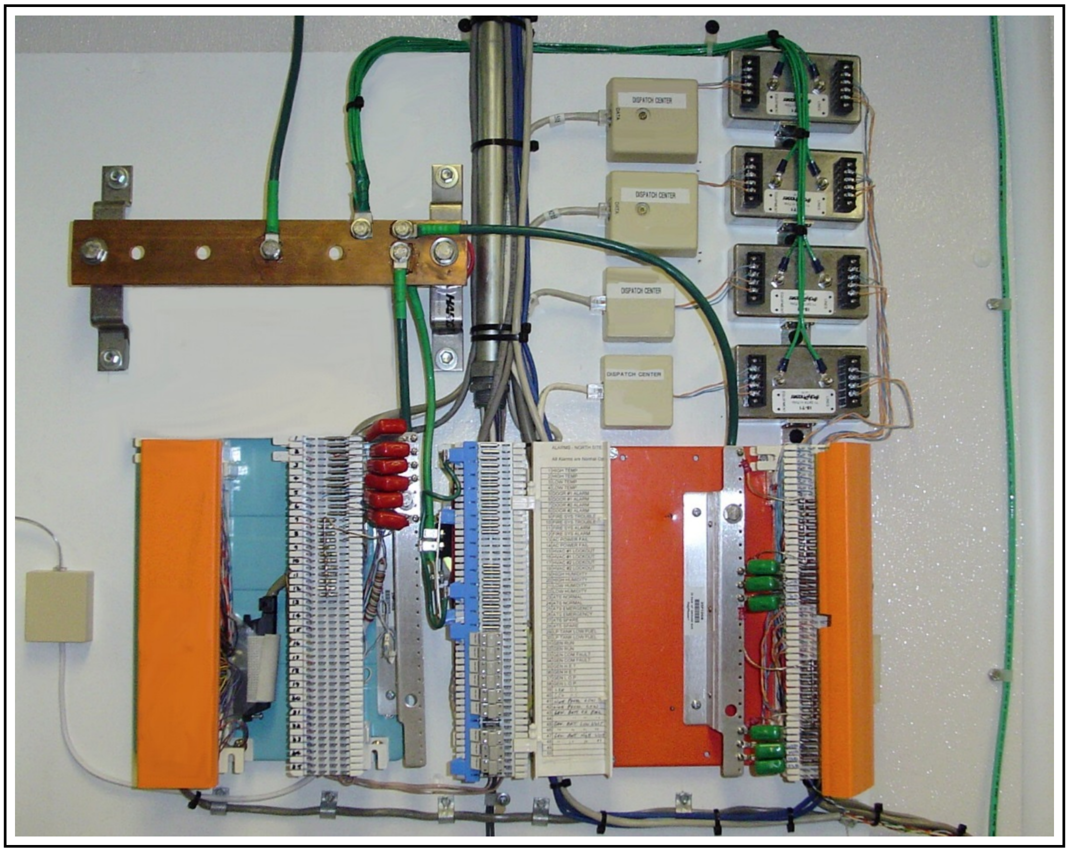

**Figure 6-25: Example of Grounding Unused Telco Pairs**

### 6.6.2 Secondary Telecommunications Line Surge Suppression

Installing secondary telecommunications line surge protection closer to the equipment is highly recommended. It may be used as additional external surge protection for the equipment and to protect against surges induced on the lines internal to the room.

Its parameters should be tighter than the primary protection and as close as possible to the needs of the specific piece of equipment being protected. Secondary SPDs should generally incorporate a SAD technology device.

For maximum effectiveness, secondary surge suppression devices should be located as close to the equipment input as possible.



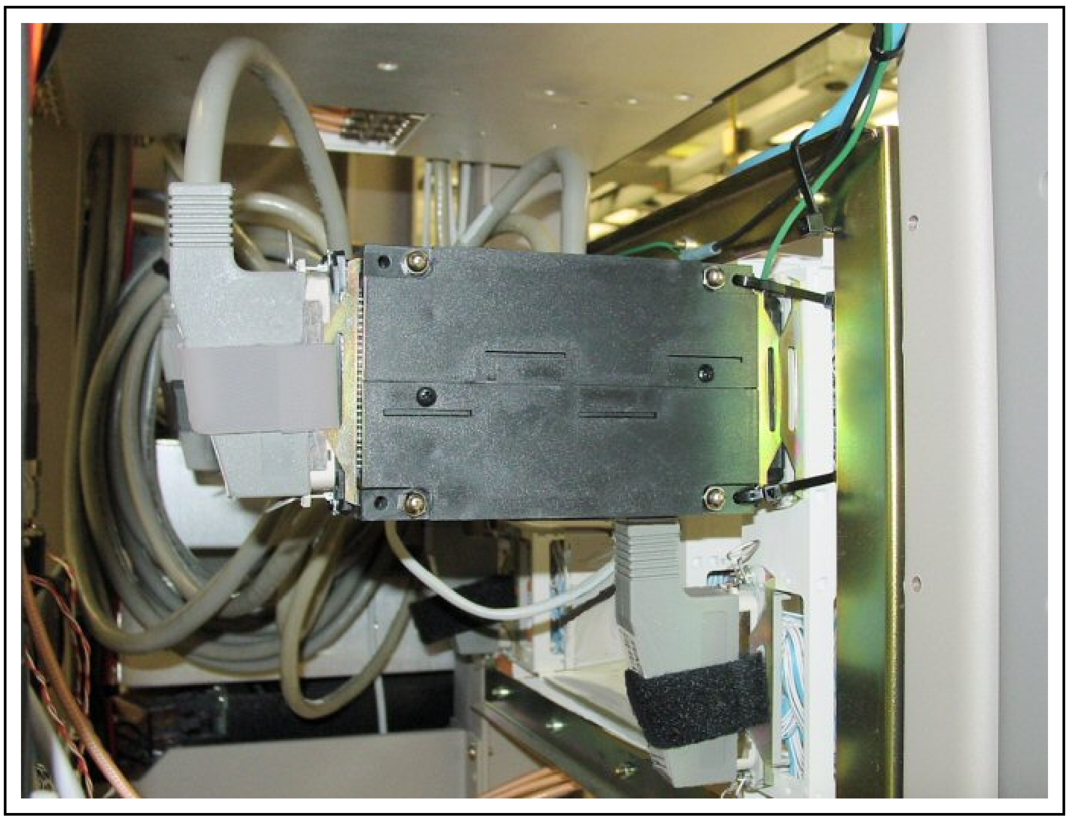


**Figure 6-26: Examples of Secondary Telecommunications Surge Protection Devices and Their Installation**

### 6.6.3 Selection of Telecommunications Line Surge Suppression Devices

#### 6.6.3.1 POTS 2-Wire Dial-up Telephone Lines

Ringing voltages up to 200 Volts may appear on 2-wire Plain Old Telephone Service (POTS) lines. You should select the SPDs with a nominal let-through voltage above this value, to allow for normal operation of the signal.

For a single phone line at a location, an individual equipment AC SPD that includes telephone and data circuit protection may be used, but it must then be UL 1459 and UL 497A Listed.

#### 6.6.3.2 Leased or Dedicated 4-Wire Lines and Extension Lines

Leased or dedicated 4-wire lines and extension lines do not have a ringing voltage like a POTS line. You should select SPDs with a lower nominal let-through voltage (typically 70 Volts). This still allows normal signal operation, but provides more protection.

#### 6.6.3.3 T1/E1 Lines

Only use SPDs designed for use on T1 or E1 lines because of their higher bandwidth. Typically, the let-through voltage should be no greater than 10 Volts.


**Figure 6-27: Three Different Styles of T1 Surge Protection**

# 6.7 DATA COMMUNICATIONS SURGE SUPPRESSION

Data communications links are more vulnerable to damage from induced surges than some other types of interfaces. This is because the link often terminates directly into equipment integrated circuits.

All data communications lines entering a facility should have proper surge protection installed.

When selecting data communications SPDs, be sure the device will not adversely affect the data link performance and that it offers the proper voltage protection for the specific protocol being protected.

## 6.7.1 Ethernet Surge Suppression

Ethernet surge suppression is required if an Ethernet cable goes outside a shelter or facility. If an Ethernet cable connects two devices that are not powered from the same AC service entrance, an Ethernet surge suppressor may also be needed.

Ethernet surge suppressors should be chosen for the correct connection speed (Cat5, 5e, 6, 6e, etc.). If the Ethernet connection passes power (Power over Ethernet) or POE, then the surge suppressor must also be chosen for the maximum power (W) being delivered.

Ethernet surge suppressors must be grounded to be effective.

## 6.7.2 Serial Data Communication Surge Suppression

All data communications lines (RS-232, RS-422, RS-485, etc.) entering a facility should have proper surge protection installed.

Data communications lines more than 35 feet long, routed between equipment cabinets located inside the facility, should also have SPDs installed at both ends. In lightning prone areas, we recommend installing data communications SPDs on cables more than 20 feet long. Using shielded cables also protects data links from induced surges. However, you should only ground the shield should at one end, the end closest to the MGB.

Data communications SPDs are available for installation on punchblocks, as screw-terminal units, and as connectorized in-line units. Screw-terminal and connectorized SPDs are available to protect either single or multiple communications links. Typical data communications SPDs protect in common mode.

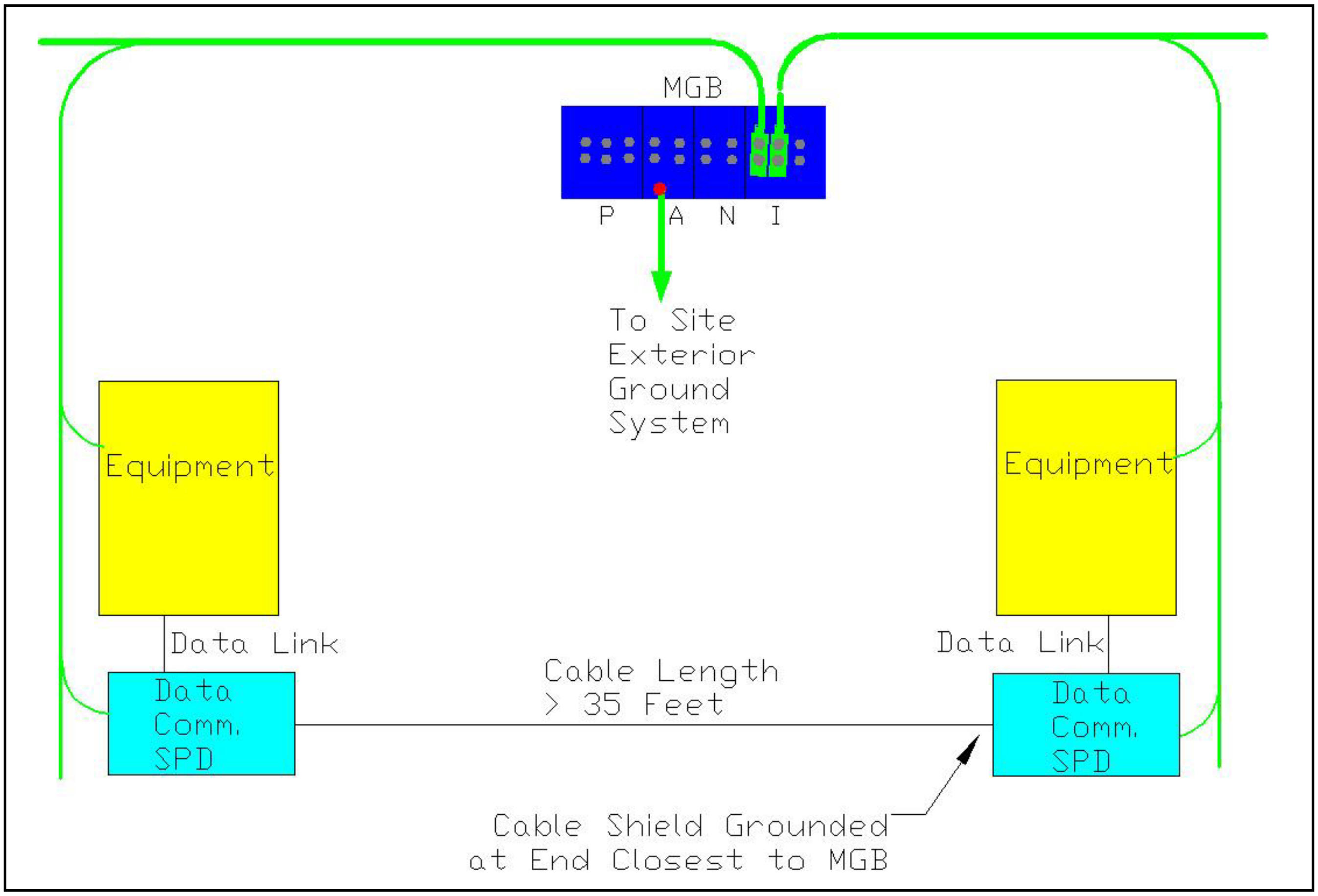



**Figure 6-28: Data Communications Surge Suppression Locations and Grounding**

Data communications links between pieces of equipment that are powered by different AC service entrances are especially susceptible to damage from induced surges since the ground pins from the two different sides are connected. For these data links, SPDs should be located at both ends of the cable as close as practical to the equipment being protected. In lightning prone areas, optically isolated transceivers may be used. These devices are only effective when they have an independent power source.

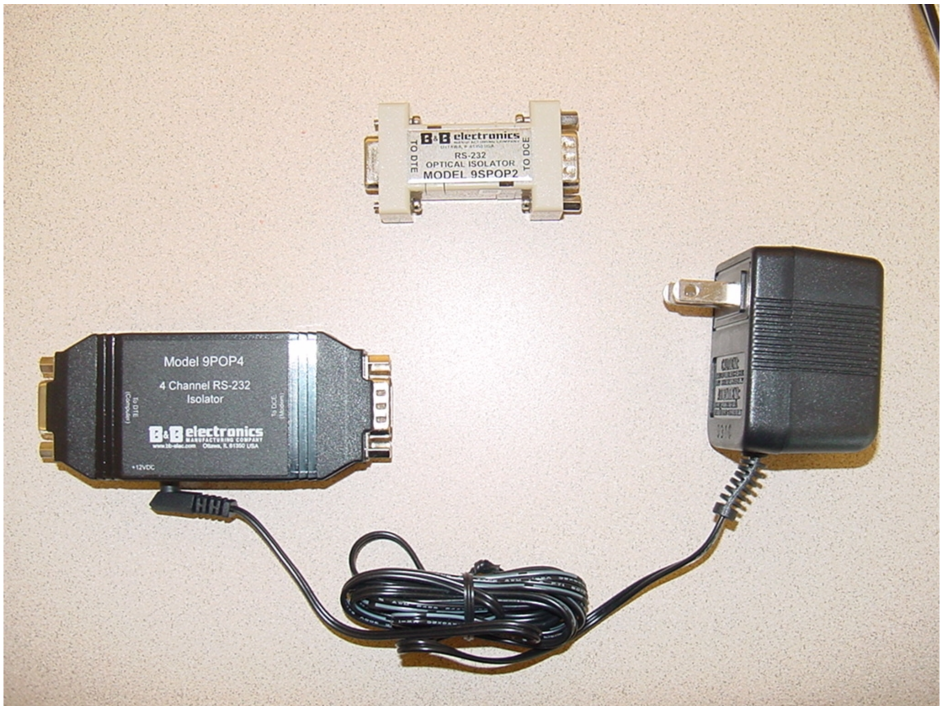



**Figure 6-29: Example of Optically Isolated Data Communications Surge Protectors**

For even more protection on longer data links, consider installing a back-to-back modem configuration, shown in Figure 6-30, between the two devices with appropriate phone line SPDs on both ends in addition to the data SPDs located at the equipment.

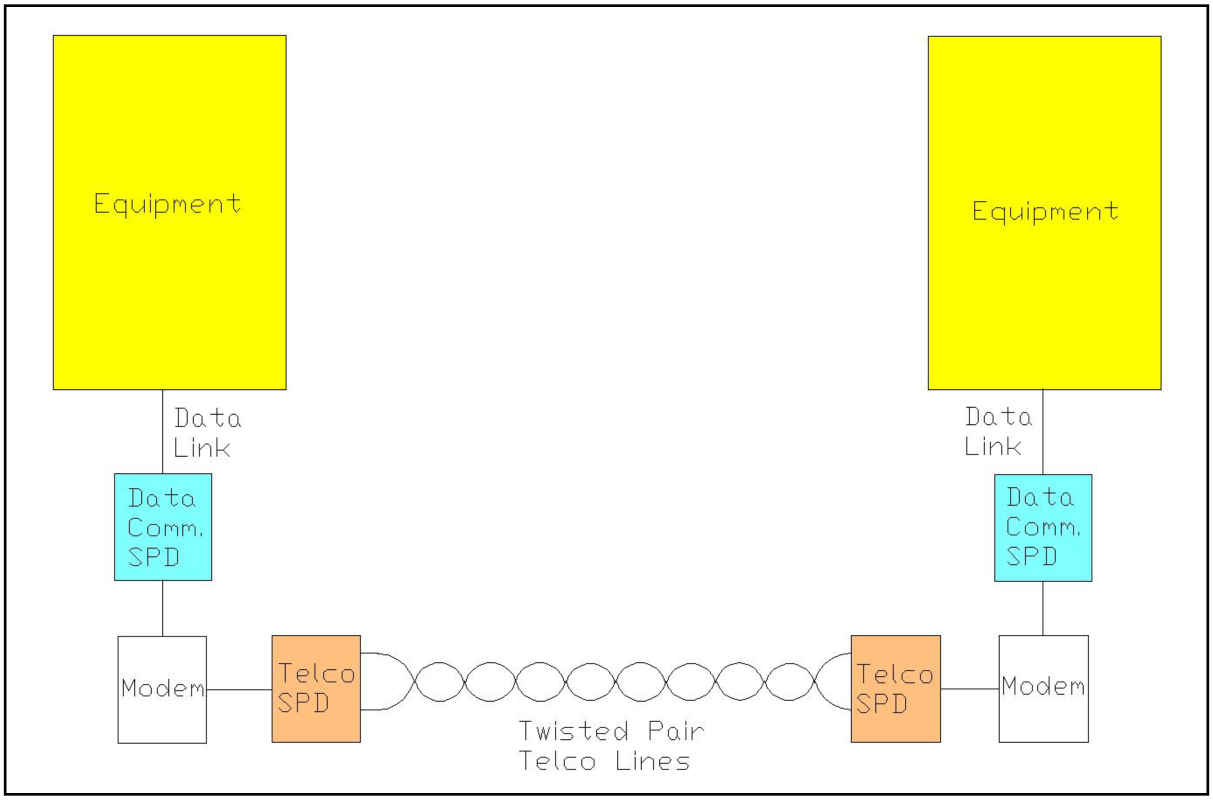



**Figure 6-30: Back-to-Back Modem Configuration for Protecting Longer Data Communications Links**

## 6.8 DC SURGE SUPPRESSION

You should install DC surge suppression devices if the power cables between the DC powered equipment and the DC power plant or batteries exceed 20 feet. At sites that are highly prone to lightning, we recommend installing DC SPDs at all electronic equipment loads regardless of distance.

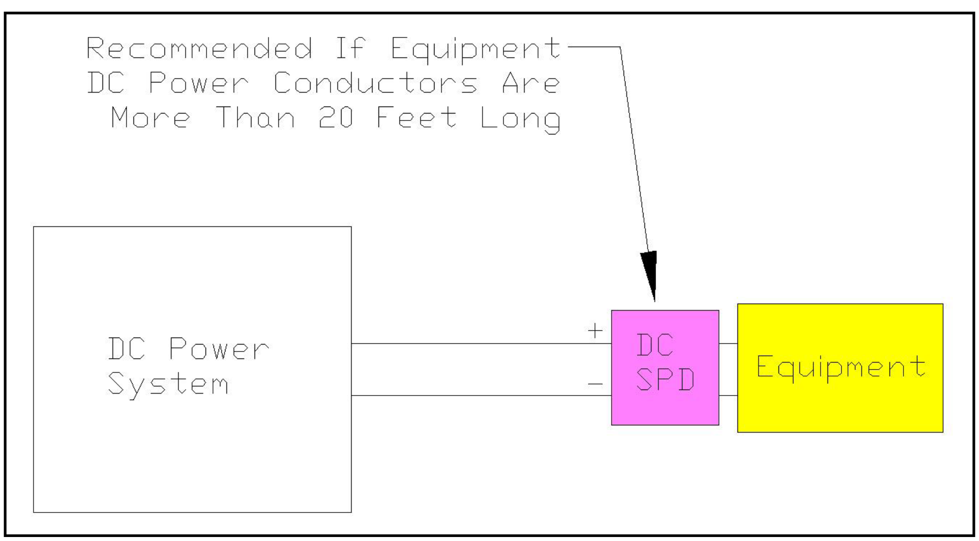



**Figure 6-31: DC Surge Suppression Protection Detail**

An equipment cabinet with an integrated DC breaker panel supplying DC power to the entire cabinet may use a single DC SPD installed at or on the DC power panel itself.

If a site has an external generator and its starter battery charger is located inside the shelter in the ATS, there is often alarm/measurement sensing circuitry connected to the DC leads going to the generator. Though the charger itself is not very sensitive to surges, this sensing circuitry may be. For this generator/ATS configuration, we recommend installing a DC SPD at the input to the sensing circuitry. This is more important if the generator is located more than 50 feet from the shelter in an area prone to lightning.

You should select DC SPDs based on the DC voltage and polarity of the DC power plant.

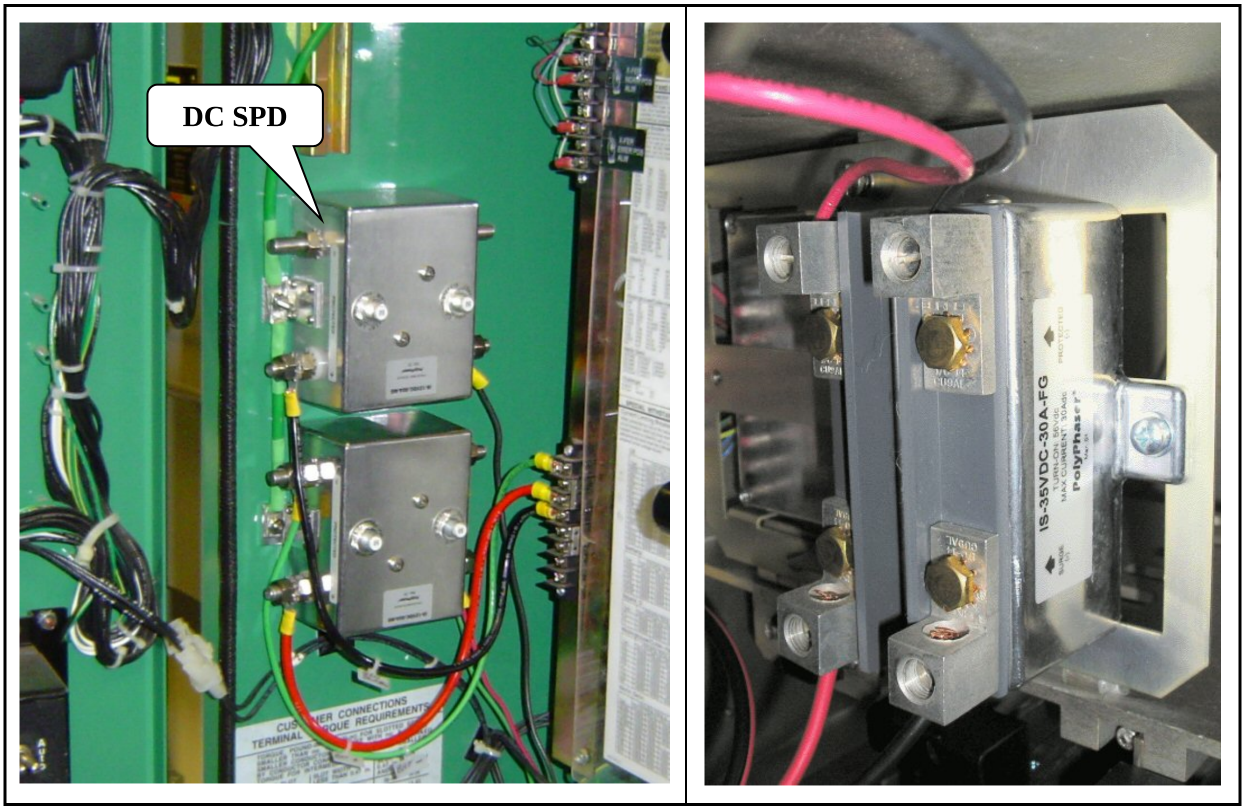



**Figure 6-32: Examples of DC Surge Protectors**

## 6.9 ALARM INPUT/CONTROL OUTPUT SURGE SUPPRESSION

All alarm inputs and control outputs entering or exiting a shelter or equipment room should have appropriate surge protection devices installed and grounded. These may include door and gate alarms or controls, generator alarms, etc. Common mode SPDs provide the most protection. They are available for installation on punchblocks and as stand-alone units.

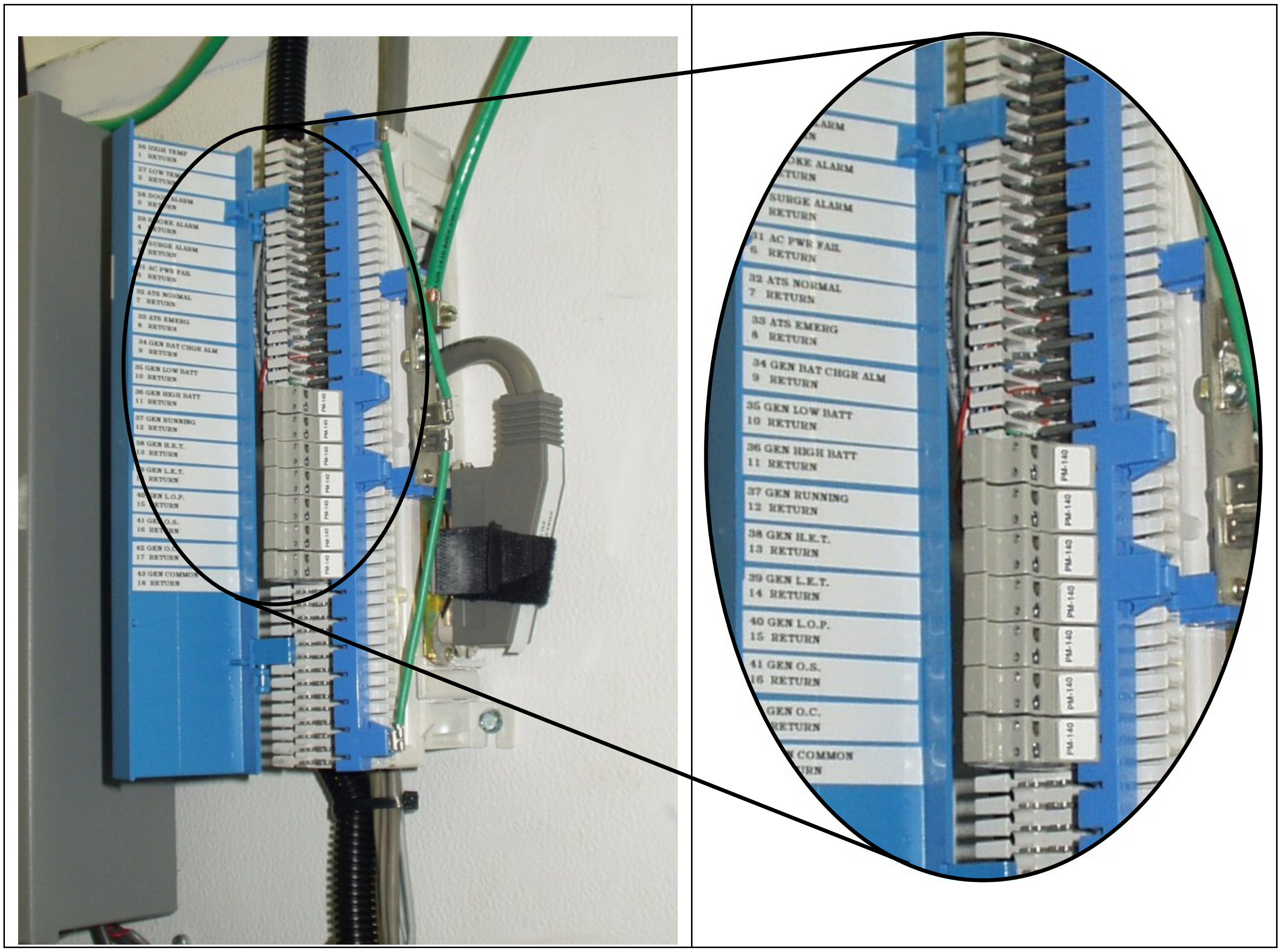



**Figure 6-33: Example of External Alarm Line Surge Protection**

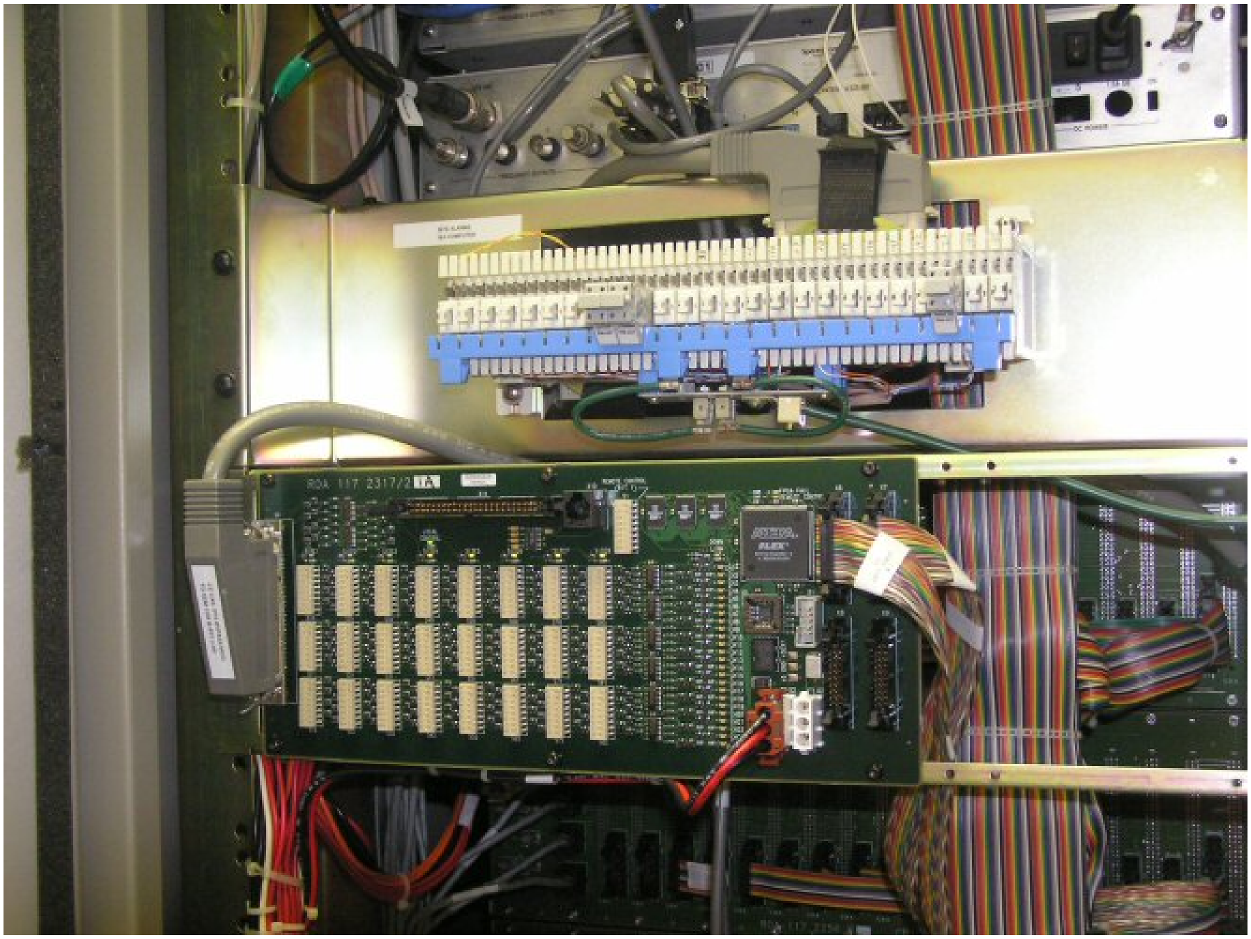


Figure 6-34: Alarm Line Surge Protection Located in Equipment Cabinet

## 6.10 TOWER LIGHTING SURGE SUPPRESSION

Tower lighting or strobe lights can provide paths for lightning surge currents to enter a shelter. Surge suppression devices installed within the tower lighting control unit usually protect only its circuitry.

When possible, the tower lighting controller should be located outside the shelter or building in a weatherproof enclosure either on its exterior wall, a pedestal beside the tower, or on a tower leg. When installed outside, the control panel housing should be bonded to the exterior ground ring.

All AC and alarm cables that enter the shelter from the tower lighting controller should have appropriate SPDs installed. (Strobe lighting systems may operate with voltages too large to allow the use of a SPD on its power conductors. We especially recommend installing strobe lighting controllers outside the shelter or building.)

When the tower lighting controller must be located inside the shelter or building, it should be located close to the RF entry port and AC service entrance. You should ground the control panel housing directly to the MGB. All AC power to the control unit, DC power to the lighting, control, and alarm conductors should have appropriate SPDs installed and properly grounded.

To reduce the possibility of RF interference from tower strobe lighting, it is highly recommended that cabling from the controller up to the light itself be routed as far away from the RF transmission lines (especially the receive line) as possible. We recommend at least 2 feet. If the receive antennas are located near the strobe light, we highly recommend installing any Radio Frequency Interference (RFI) shielding kits available from the strobe light manufacturer.

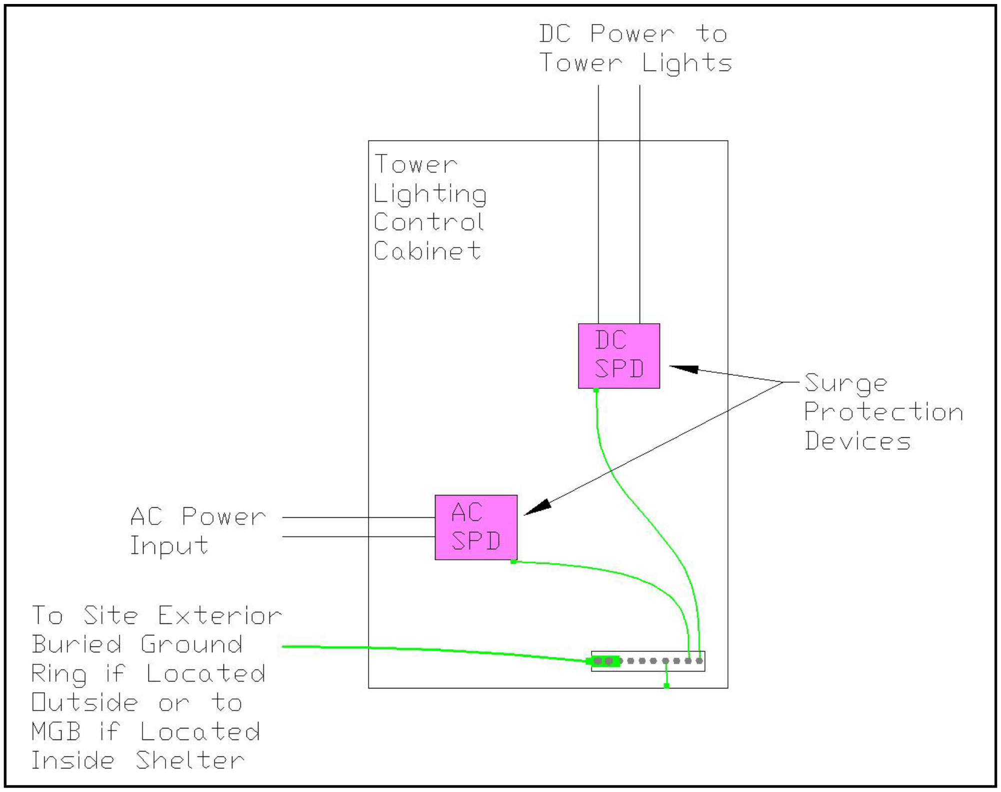



**Figure 6-35: Tower Lighting Controller Surge Suppression**

## 6.11 MISCELLANEOUS SURGE SUPPRESSION

Carefully examine the site for any possible paths for lightning surge currents to enter a shelter or equipment room. Miscellaneous equipment and cabling for Closed-Circuit TV cameras (CCTV), cable TV, security card readers, etc. should be identified and have proper surge protection installed.

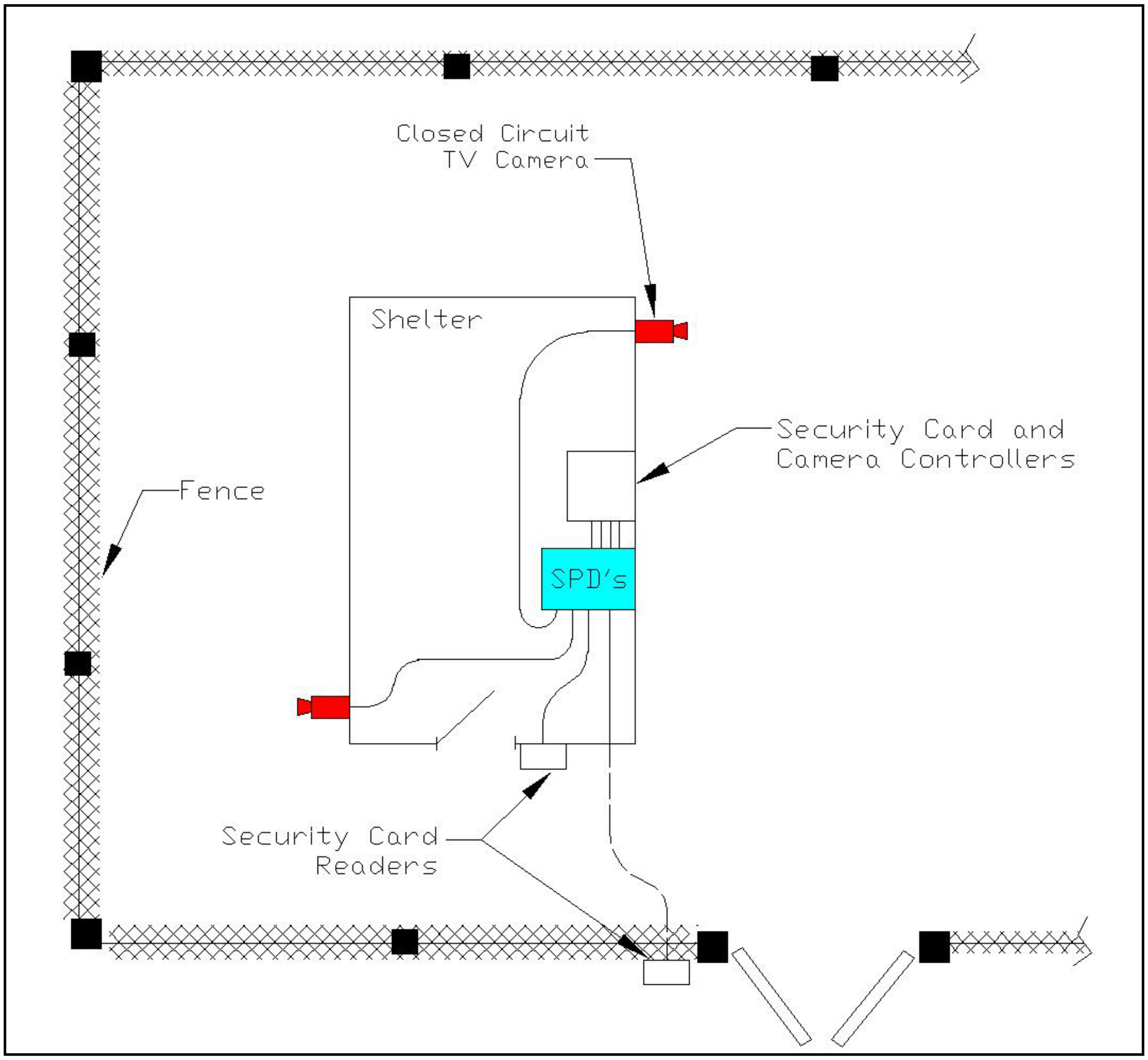



**Figure 6-36: Possible Additional Surge Protection Needs (CCTV and Security Card Reader Controls)**

## 6.12 SHIELDING CABLES FROM COUPLED/INDUCED SURGE ENERGY

Cables located at a tower site in a lightning prone area are susceptible to coupled or induced surges. This is especially true of long cable runs (runs greater than 25 feet), both inside and outside the shelter. There are several basic approaches to protect equipment from these induced surges.

1. Locate equipment to be connected together to minimize the length of cable needed between them. Attention to cable routing can also help minimize cable lengths.

2. Use shielded cable with the shield grounded at one end only. The shield should be grounded at the point closest to the MGB. The type of shield (foil, braid, etc.) used in the cable can influence how much shielding is provided at different frequencies.

3. Separate different types of cables (power, RF, data, etc.) in the cable ladder or tray by at least 2 inches. This practice also helps reduce noise that can be coupled into a cable from another cable.

4. Place cables in metallic conduit (ferrous metal for maximum protection) and ground one end of the conduit at the end closest to the MGB. This technique may also be applied outside the shelter, providing protection from both induced surges and physical damage.

5. Route cables inside enclosed metallic cable trays/ducts. Again, only the end closest to the MGB should be grounded and ferrous metal provides the maximum protection. Even cable ladders with raised sides provide some level of protection.

6. Install appropriate surge protection at both ends of the cable for data cables and at equipment end only for AC and DC power cables.

7. Use twisted pair cable and exercise care to maintain the twist ratio when building cables.

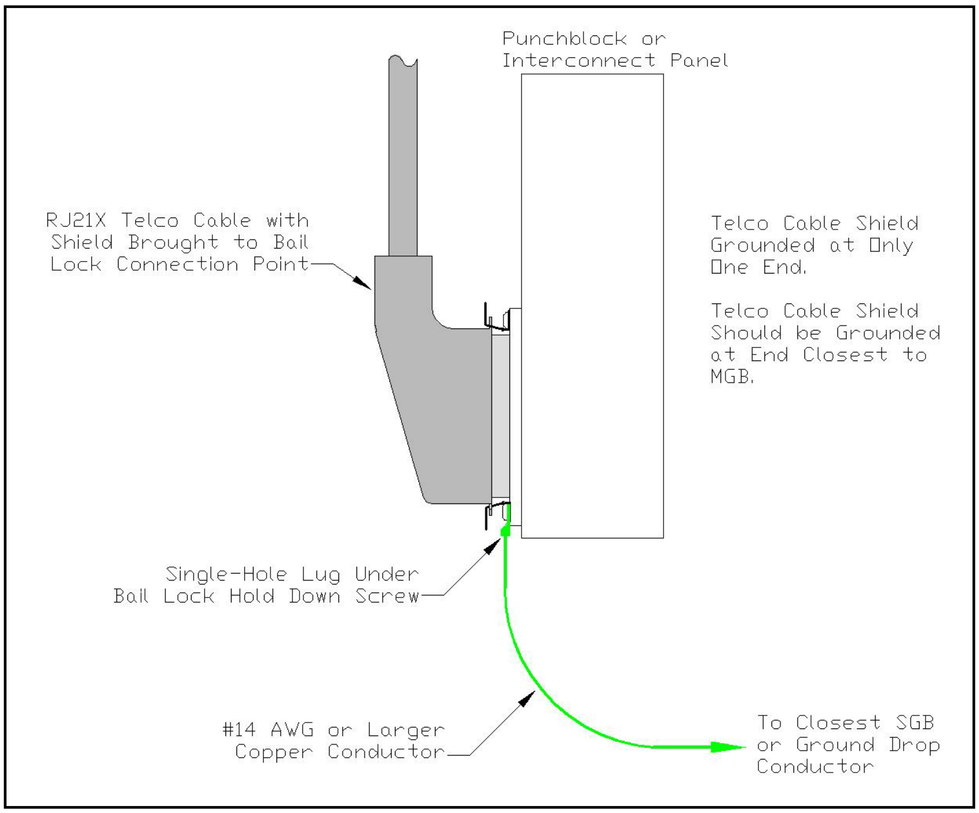



**Figure 6-37: Example of Grounding the Shield on a 50-Pair Cable**

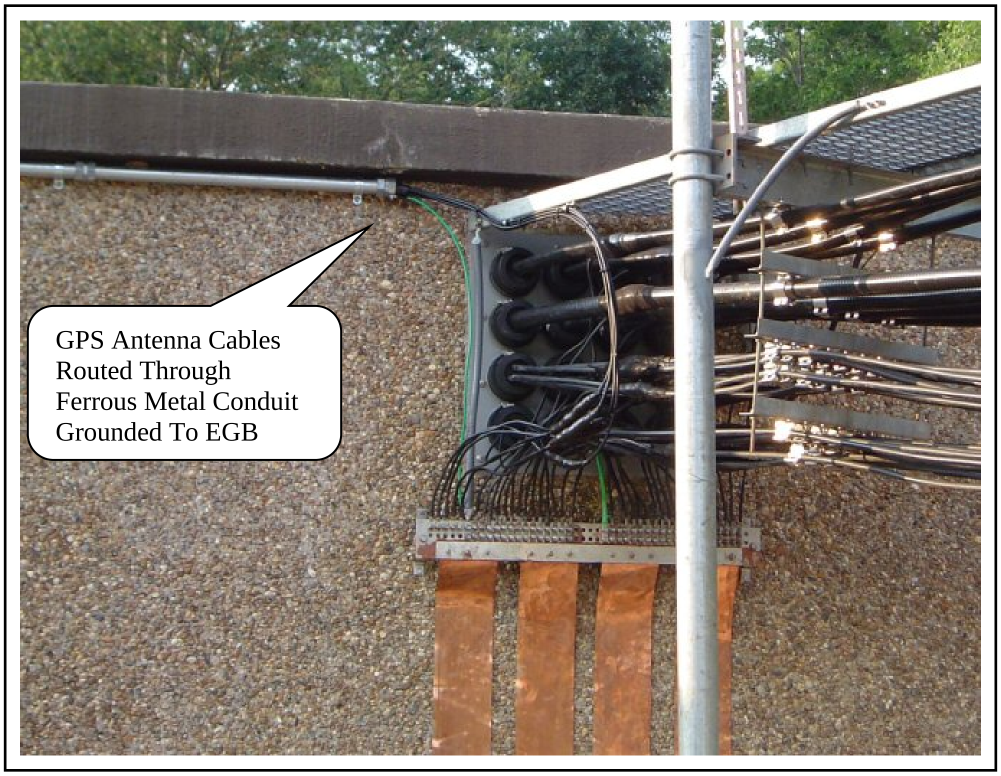



**Figure 6-38: Example of Shielding Cables in Metallic Conduit**

# 7. SPECIAL INSTALLATION SITUATIONS

The bulk of the information contained in the previous sections has dealt with new stand-alone shelter installations. Most of the concepts can be applied to other installation situations either directly or with some slight modifications. This chapter contains additional information for some common special installation situations. If you encounter conditions that present difficulties in grounding a site, contact Harris Systems Engineering or a grounding consultant for assistance.

## 7.1 ADDING NEW SHELTER TO AN EXISTING ANTENNA TOWER SITE

Adding a new equipment shelter to an existing antenna tower site requires accessing the quality of the grounding that is already present at the tower site. An accurate measurement of the existing grounding system is the first step. The next step is accessing the grounding of the existing tower. It is vitally important that the tower provides proper low impedance paths to ground to minimize the amount of surge current that reaches the equipment shelter. For personnel safety, it is important that other exterior metallic objects are properly grounded to reduce the possibility of side flashes.

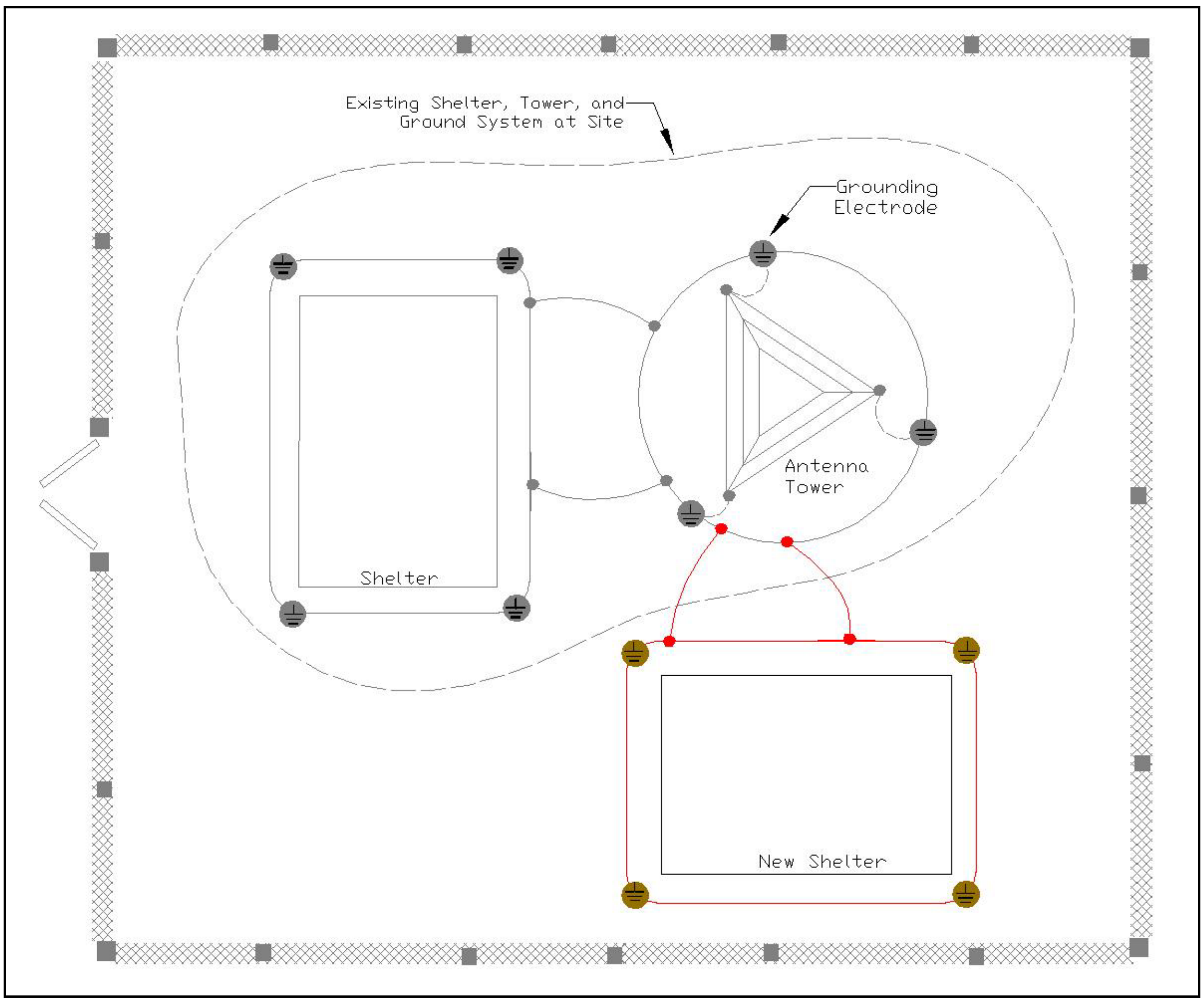



**Figure 7-1: New Shelter at Existing Tower Site Grounding**

Grounding electrodes and a ground ring should be installed around the new shelter as described in Section 4.1.1 Tower and Shelter Ground Rings. If the existing grounding system is found to be inadequate, then additional grounding electrodes may be installed to obtain an acceptable grounding system. **All additional grounding electrodes and the new shelter ground ring must be bonded to the existing grounding system per NEC code.** The shelter's interior grounding should be completed as described in Chapter 5.

## 7.2 EQUIPMENT ROOM IN EXISTING BUILDING

If the existing building grounding system is not acceptable, then an additional grounding electrode system should be installed. **This additional grounding electrode system must be bonded to the existing building grounding system per NEC code.**

The MGB for the equipment room should be connected to the building grounding system at the closest accessible point. This point may be at the building's main ground bar or a supplemental ground bar bonded back to the building's main ground; AC service entrance grounding electrode conductor; building steel; an electrically continuous metallic water pipe; or directly to the buried grounding system. All applicable NEC, NFPA, or local codes should be observed. The MGB should be connected to all available ground points that are accessible and close, for instance to the buried ground system and building steel.

If this MGB ground connection is less than 75 feet, you should use a #2 AWG, or larger, copper conductor. For a connection that is more than 75 feet, a #2/0 AWG, or larger, copper conductor should be used. This connection should be run in as straight a path as possible with a minimum bending radius of 8 inches and no angles less than 90 degrees. It should be fastened at least every 3 feet, and if it is run outside, it should be protected from physical damage for at least 6 feet above where it enters the ground.

You should install primary AC and telecommunications SPDs and ground them where they enter the building. RF transmission cables should have their last grounding kit grounded installed just outside their entrance into the building. RF SPDs should be located at the entrance to the building just inside the RF entry port. They should be grounded to either the RF entry port or to an RF SGB that is grounded to the closest accessible point.

Secondary AC and telecommunications SPDs should be installed in the equipment room and grounded to the equipment room's MGB.

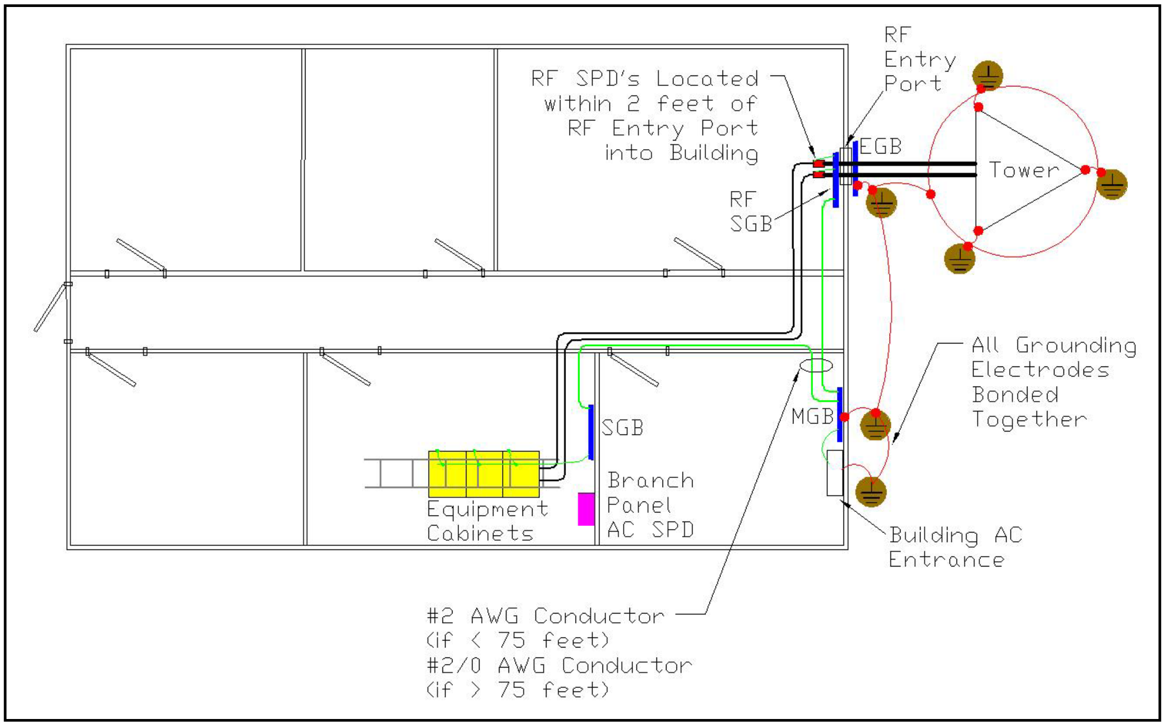



**Figure 7-2: Equipment Installed in Room in Existing Building**

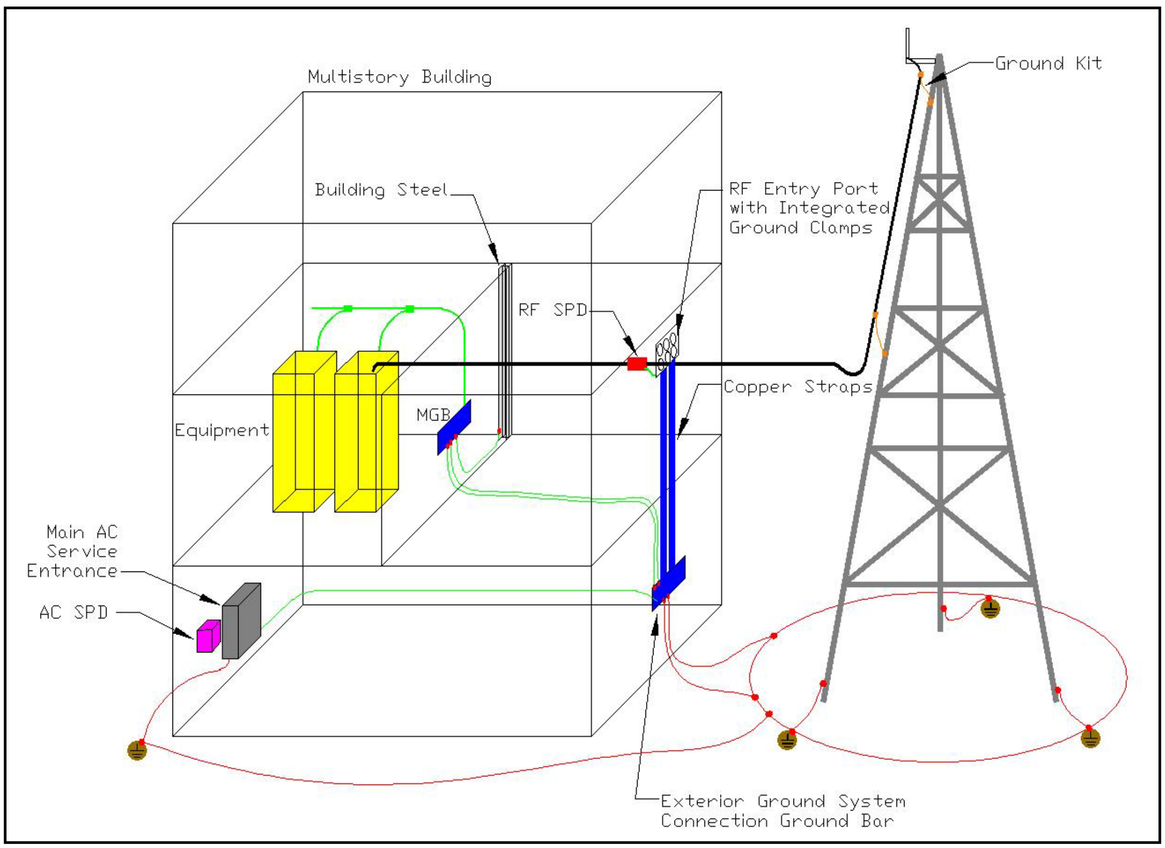



**Figure 7-3: Equipment Installed in Multistory Building**

Figure 7-4: Example of Exterior Collection Ground Bar on Multistory Building

Figure 7-5: Example of RF Entry Port in Side of Multistory Building

**Figure 7-6: Close-up of RF Entry Port Example on Side of Multistory Building**

**Figure 7-7: Example of RF Surge Protectors Grounded at RF Entry Port inside Multistory Building**

## 7.3 EQUIPMENT ROOM IN TALL BUILDING OR ON ROOF TOP

The information in Section 7.2 applies here also. But equipment rooms installed in tall buildings and on roof tops may have some additional special considerations. First, a 5-ohm ground is desirable, but it may not be achievable.

Newer multistory buildings may have more than one ground bar installed on each floor. These ground bars, though ultimately bonded to the building's main ground bar, may be bonded through different paths and be designated for different purposes. Often one ground bar is designated for grounding AC and large inductive loads like air conditioners and elevators. This ground bar may have a noisy ground. The other ground bar may be designated for telecommunications and computer networking equipment. This ground bar has a less noisy ground.

When using this building grounding scheme, the equipment room MGB should be tied to the technical ground bar for the floor. If the equipment room has a large dedicated UPS system to supply AC power, the ground for the UPS should be tied to the floor AC ground bar.

See Section 4.2.4 Antenna Support Structures on Building Rooftops for additional details.

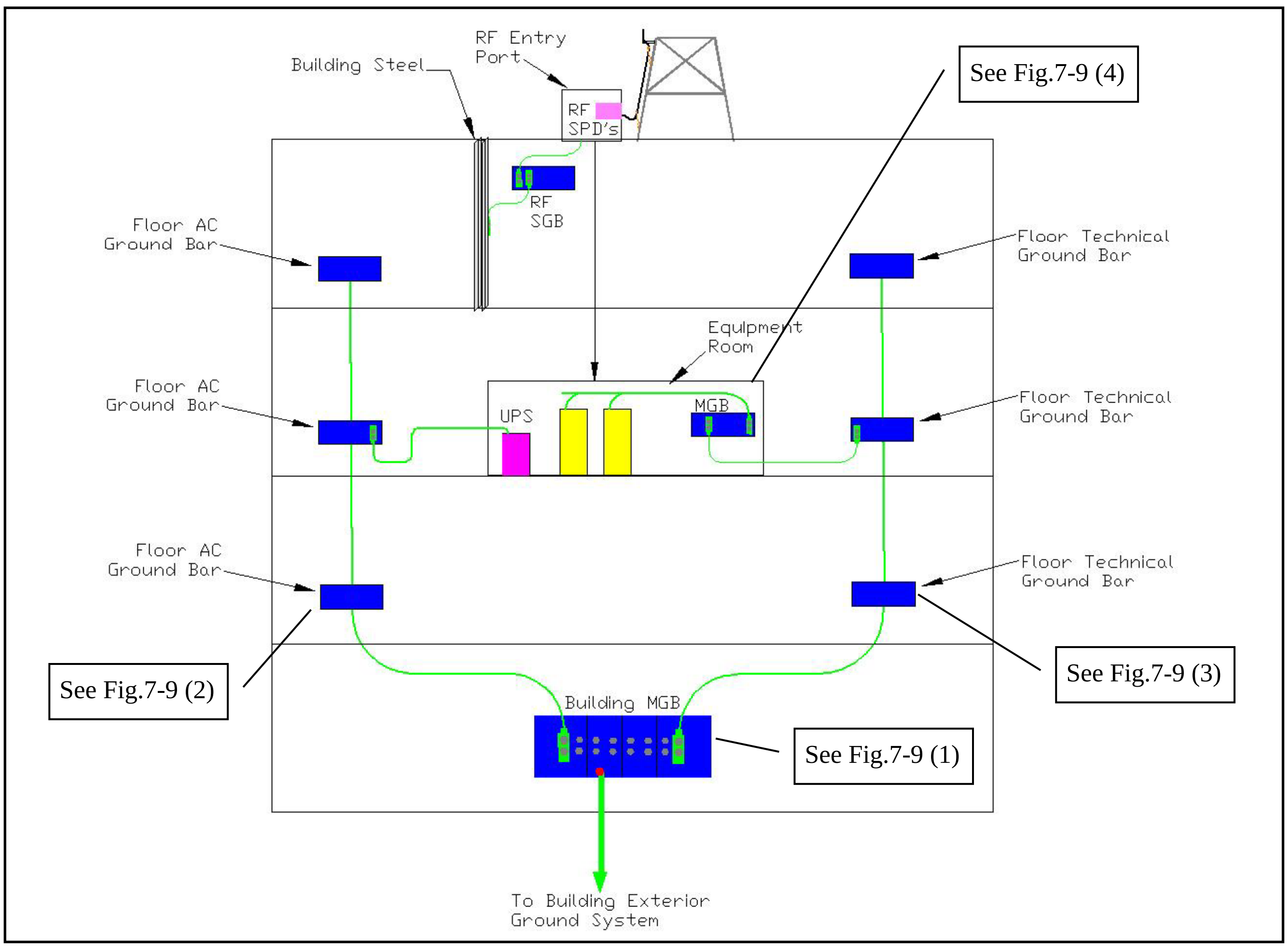



**Figure 7-8: Equipment Room in Tall Building with Building Ground Bar System**

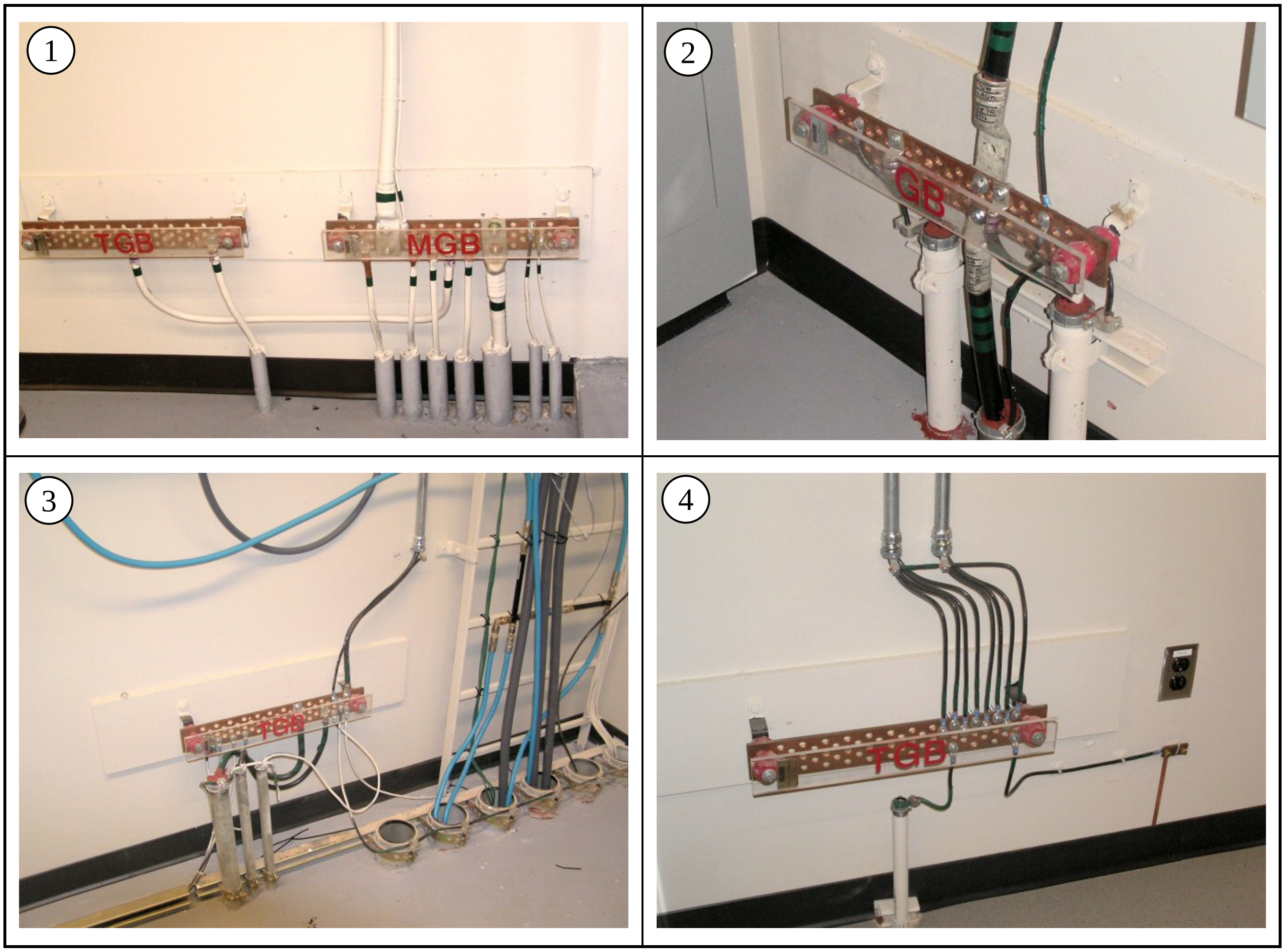



**Figure 7-9: Example of Ground Bars Composing Ground Bar System in Tall Building**

**Figure 7-10: Example of Antenna Structure on Tall Building and RF Transmission Line Ground Kit Bonding**

**Figure 7-11: Example of RF Entry Structure on Tall Building and RF Surge Protection Located Inside**

## 7.4 GROUND CONNECTIONS TO BUILDING STEEL

When the only available ground path for an equipment room Master Ground Bar (MGB) is a connection to building steel, the connection should be made to provide the lowest inductance connection possible. The MGB is bonded to the building steel using a dedicated #2 AWG, or larger, copper conductor. If the MGB is located more than 75 feet from the bonding point, then a #2/0 AWG, or larger, copper conductor should be used.

There are several methods that may be used to bond to building steel. If an exothermic weld or high-compression crimp style connection is allowed, this provides the lowest inductance bond possible. A large two-hole lug connection with anti-oxidant compound applied provides the next lowest inductance connection. If these types of connections are not allowed, then a UL-listed clamp should be used similar to the one shown in Figure 7-12.

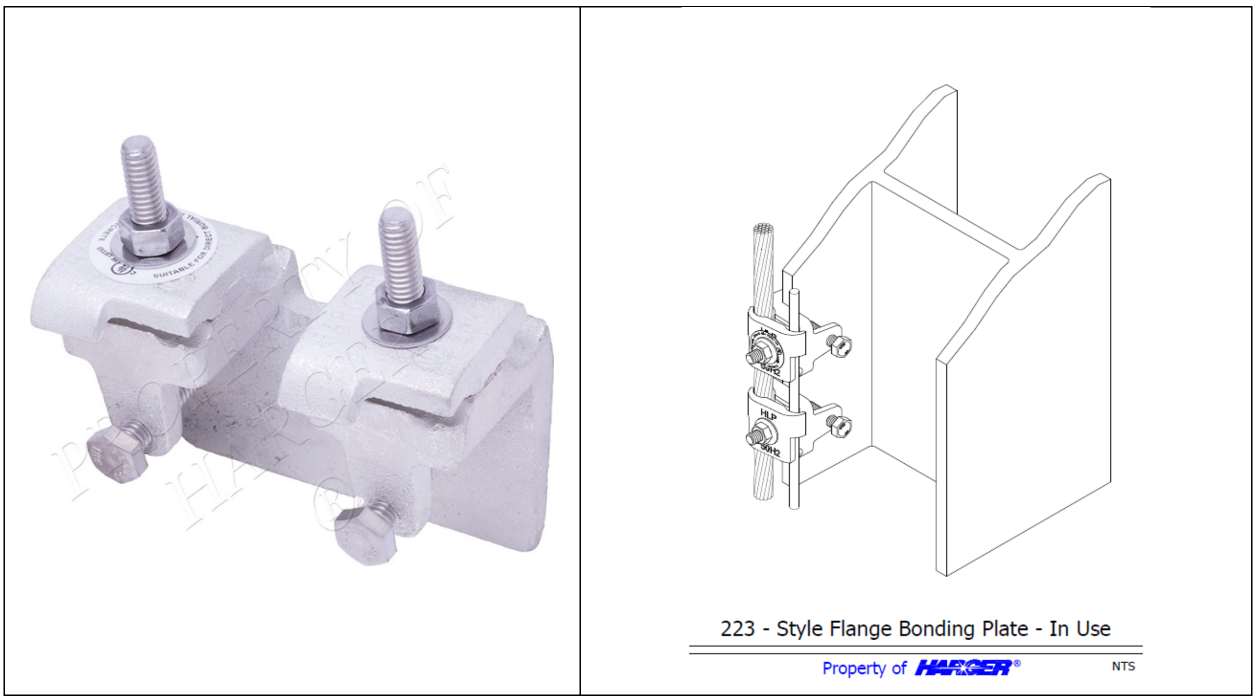



**Figure 7-12: Harger 223 Style Cable To Flat Metal Connector**
(Courtesy of Harger Lightning & Grounding)

CAUTION

A connection method that weakens the building steel should never be used.

For smaller installations such as a radio control station, a smaller UL-Listed clamp may be used similar to the one shown in Figure 7-13.

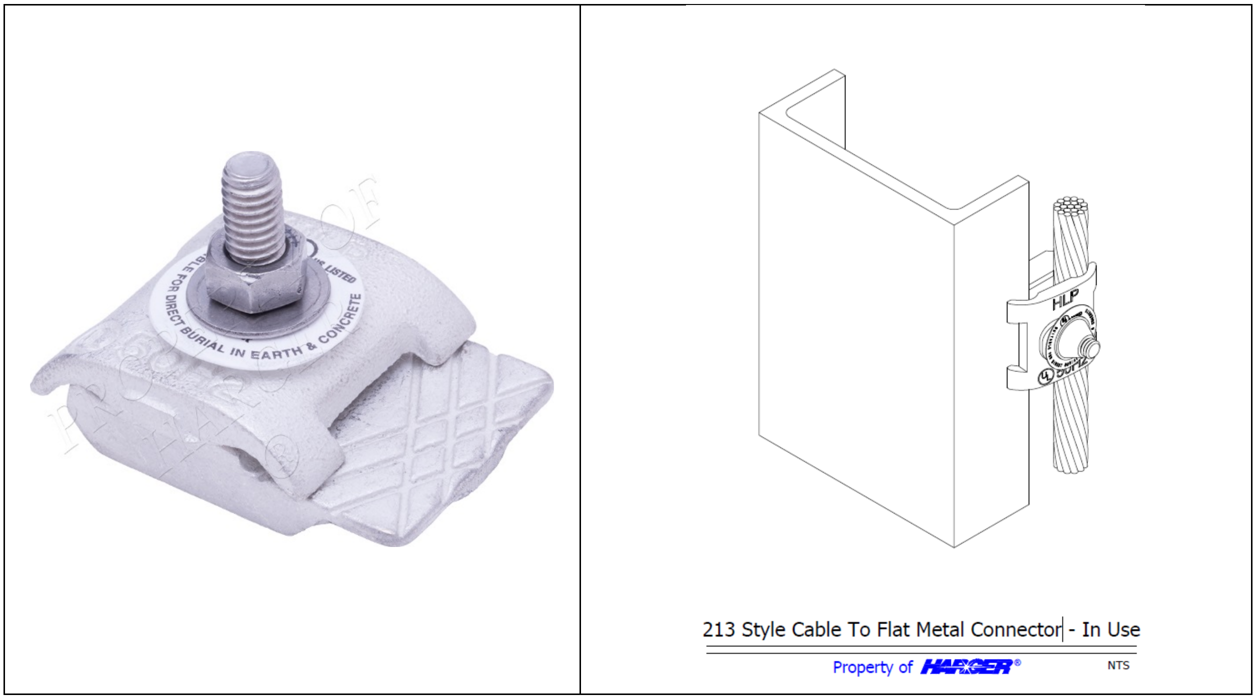



**Figure 7-13: Harger 213 Style Flange Bonding Plate**
(Courtesy of Harger Lightning & Grounding)

## 7.5 TOWER-MOUNTED/PAD-MOUNTED REPEATER EQUIPMENT

Tower-mounted or pad-mounted repeater equipment requires proper grounding and surge protection. A 5-ohm ground is not required for these installations, but we recommend installing a grounding system with a target of less than 25 ohms resistance for critical sites especially in a lightning prone area.

For a single equipment enclosure at a site, the enclosure's internal ground bar or sometimes the chassis serves as the MGB and should be bonded to the site grounding system using a #2 AWG, or larger, copper conductor. If multiple equipment enclosures are interconnected at the site, a main ground bar should be centrally located and be the only point bonded to the site grounding system. The connection from the main ground bar to the site grounding system should be as short and direct as possible with routing and all bends being in the direction of the grounding system. No bends should have a radius of less than 8 inches or angles less than 90 degrees.

The antenna tower should be grounded as detailed in Section 4.2. For tower-mounted equipment, the cabinet's MGB should be connected, using #2 AWG or larger copper conductor, to the tower grounding system. For pad-mounted equipment located more than 20 feet away from the tower, an additional grounding electrode should be installed near the equipment MGB and be bonded to the site grounding system. **If other equipment cabinets or shelters are present, then all buried grounding systems should be bonded together per NEC code.**

The RF transmission lines should have grounding kits installed as detailed in Section 4.4 RF Transmission Lines Grounding. For a tower-mounted equipment enclosure, the last coaxial grounding kit, before the drip loop near the enclosure, should be bonded to the tower or the tower ground bar if it is located nearby. For pad-mounted equipment enclosures, the last coaxial grounding kit near the enclosure should be bonded to an external ground bar connected directly to the buried ground system just outside the enclosure.

RF surge protection should be installed on all RF transmission lines. These RF SPDs should be bonded to the equipment enclosure's MGB. Any data or telecommunications lines should also have proper SPDs installed and bonded back to the enclosure's main ground point. If the enclosure is DC powered, DC power surge protection should be installed and bonded to the MGB. If the enclosure is AC powered, AC surge suppression should be installed, as detailed in Section 6.4.4.1.

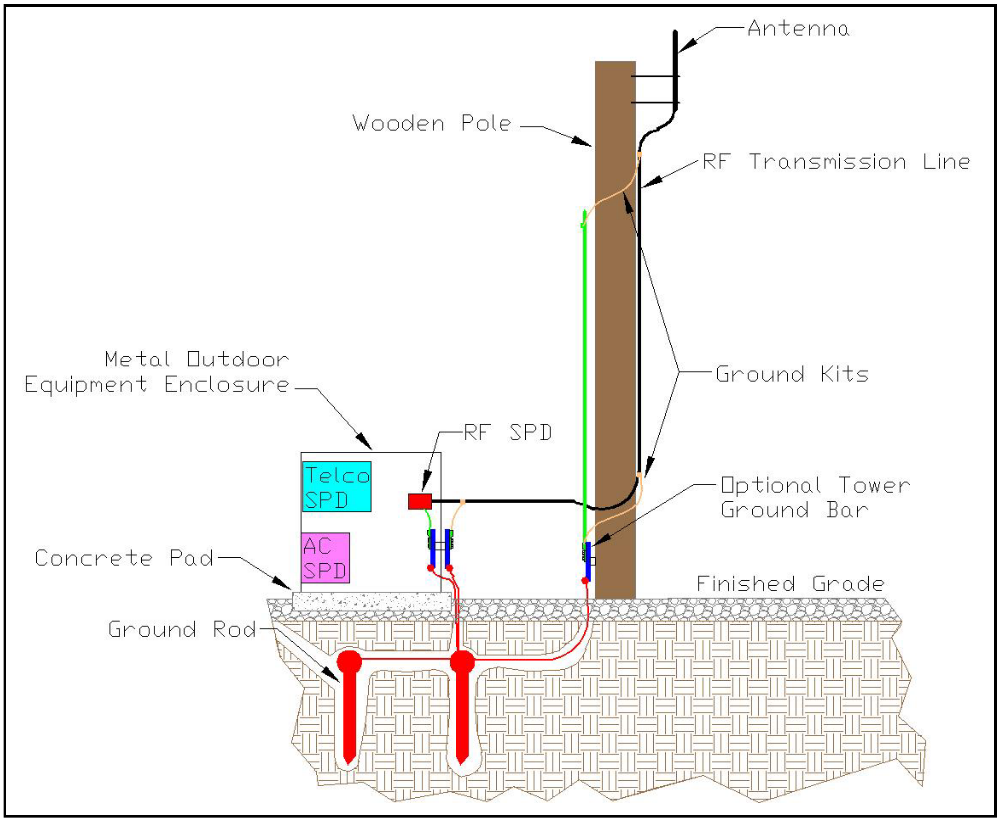



**Figure 7-14: Pad-Mounted Equipment Grounding Detail**

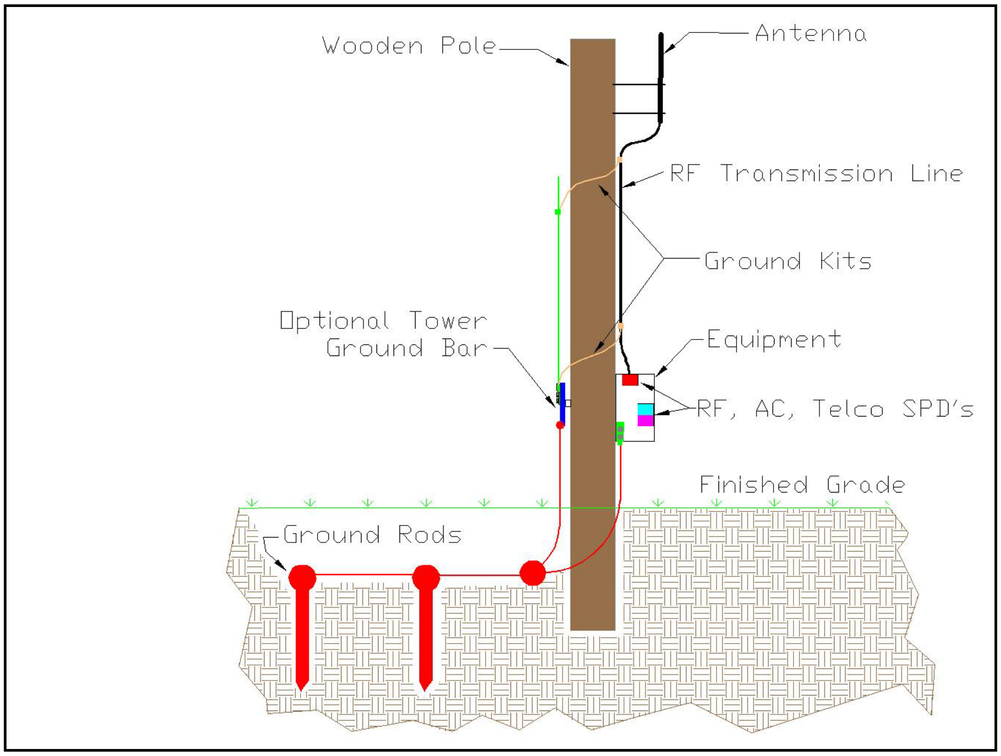



**Figure 7-15: Tower-Mounted Equipment Grounding Detail**

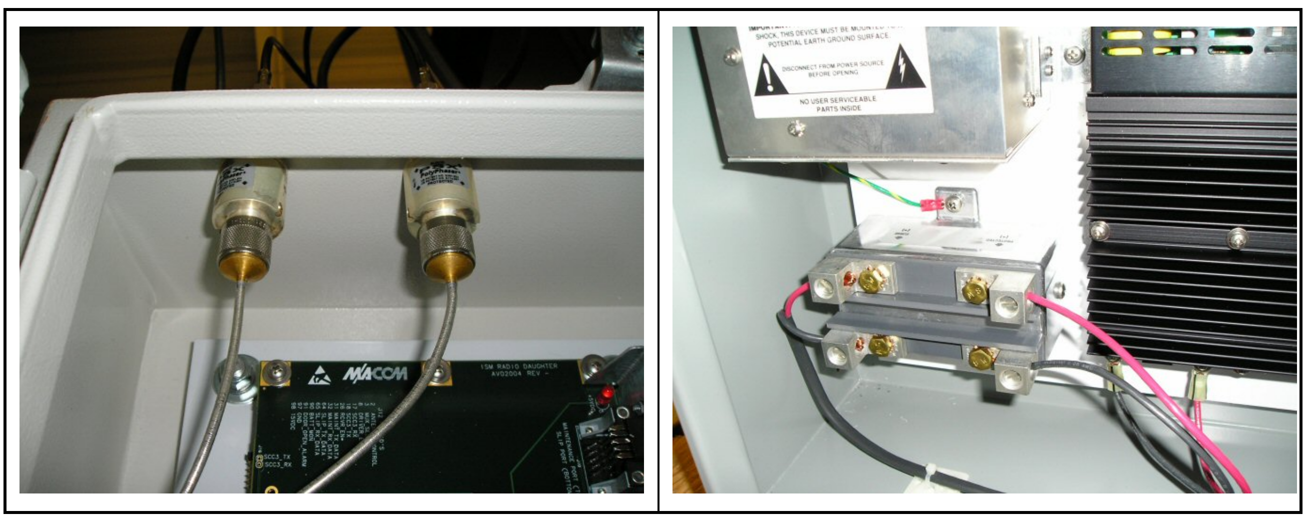


**Figure 7-16: Examples of Tower-Mounted Equipment SPDs inside Enclosure**

## 7.6 RADIO CONTROL STATION

Radio control stations are often installed in public safety buildings without dedicated equipment rooms or grounding. Antenna mounting location, routing of the RF transmission line, and surge protection on the RF, AC power, and any phone or data lines are the primary considerations. A 5-ohm ground is not required for a radio control station installation.

If multiple RF lines are coming into the facility, you should install a multi-port RF bulkhead panel to allow for waterproof cable entrances. For a single RF transmission line, single RF entry ports are available.

Ground kits should be installed on all RF transmission lines. (See section 4.4 RF Transmission Line Grounding for details.) An EGB may be installed for multiple RF ground kit bonding or a dedicated ground conductor to the buried ground system may be used for a single RF transmission line. This ground bar or conductor should be bonded with a #2 AWG, or larger, copper conductor to a grounding electrode installed underneath the RF entry location. **This grounding electrode must be bonded to the grounding system for the building per NEC code.**

The most important consideration for a remote radio control station location is proper surge protection. Each RF transmission line must have an RF SPD at the entrance into the building.

RF SPDs installed inside the RF bulkhead panel should be grounded to the outside EGB down conductor. This connection should be made below the EGB connection to the down conductor.

The radio control station, and any equipment connected to the station, like a modem, should be connected to an individual equipment AC SPD as described in Section 6.4.3.4.

Any audio lines, phone lines, or data connections coming to the location should also have proper SPDs installed if they go outside the building or go to equipment on a different AC service. (See Sections 6.4.4.2, 6.6, 6.7, and 6.7.1 for details.)

In lightning prone areas special care should be used if direct-connected remote controllers are located away from their radio control station. This includes being located in a different building or being located in an area on a different AC service. In these situations running fiber between the remote controller and the radio control station is recommended with a fiber converter between the data connection and the fiber on both ends.

The furniture in or on which the radio control station is installed should also be properly grounded. This includes any metallic surfaces or furniture framing.

The SPD grounds and the furniture grounds should be connected to the MGB or the radio room SGB.

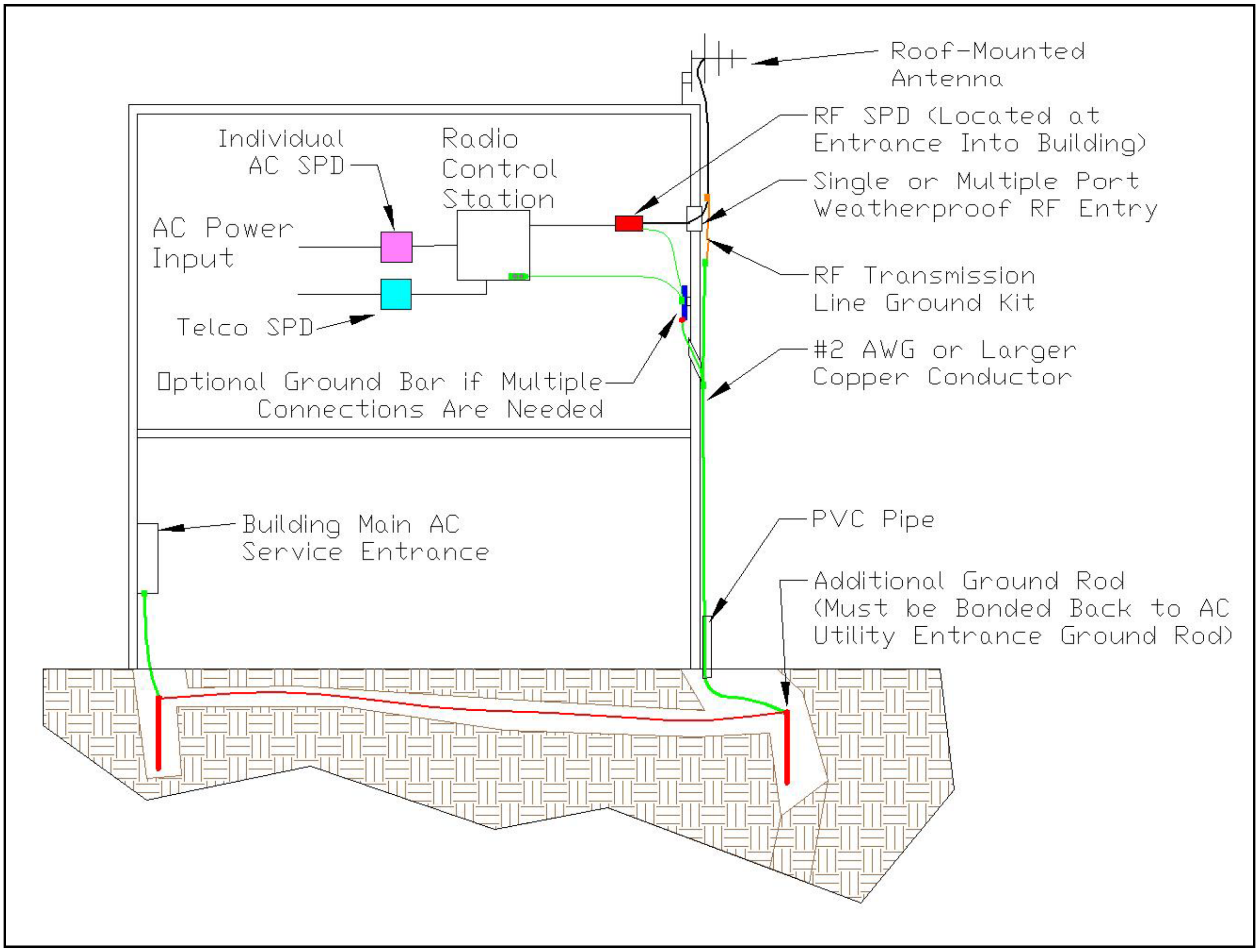



**Figure 7-17: Radio Control Station Grounding Detail**

## 7.7 REMOTE CONSOLE OR REMOTE SYSTEMS MANAGEMENT COMPUTER

The most important consideration for a remote console or remote systems management computer location is proper surge protection. A 5-ohm ground is not required for a remote console or remote systems management computer location.

The computer, monitor, and any equipment connected to the system, like audio enclosures or modems, should be connected to an individual equipment AC SPD as described in Section 6.4.4.2. Ideally, the remote console or remote systems management computer should obtain its power from either a dedicated UPS or whole building UPS.

Any data or phone line connections coming to the location from outside the building should also have proper SPDs installed. (See Sections 6.6, 6.7, and and 6.7.1 for details.)

The furniture in or on which the console or remote systems management computer is installed should be properly grounded. This includes any metallic surfaces or furniture framing.

The SPD grounds and the furniture grounds should be connected to the MGB or SGB for the location.

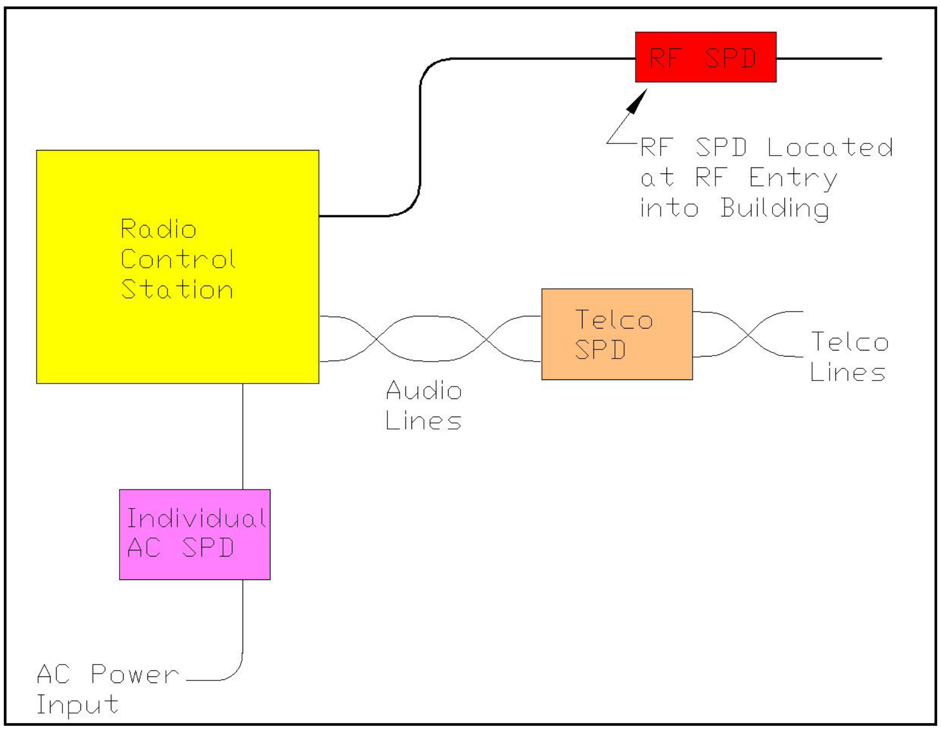



**Figure 7-18: Radio Control Station Surge Suppression Needs**

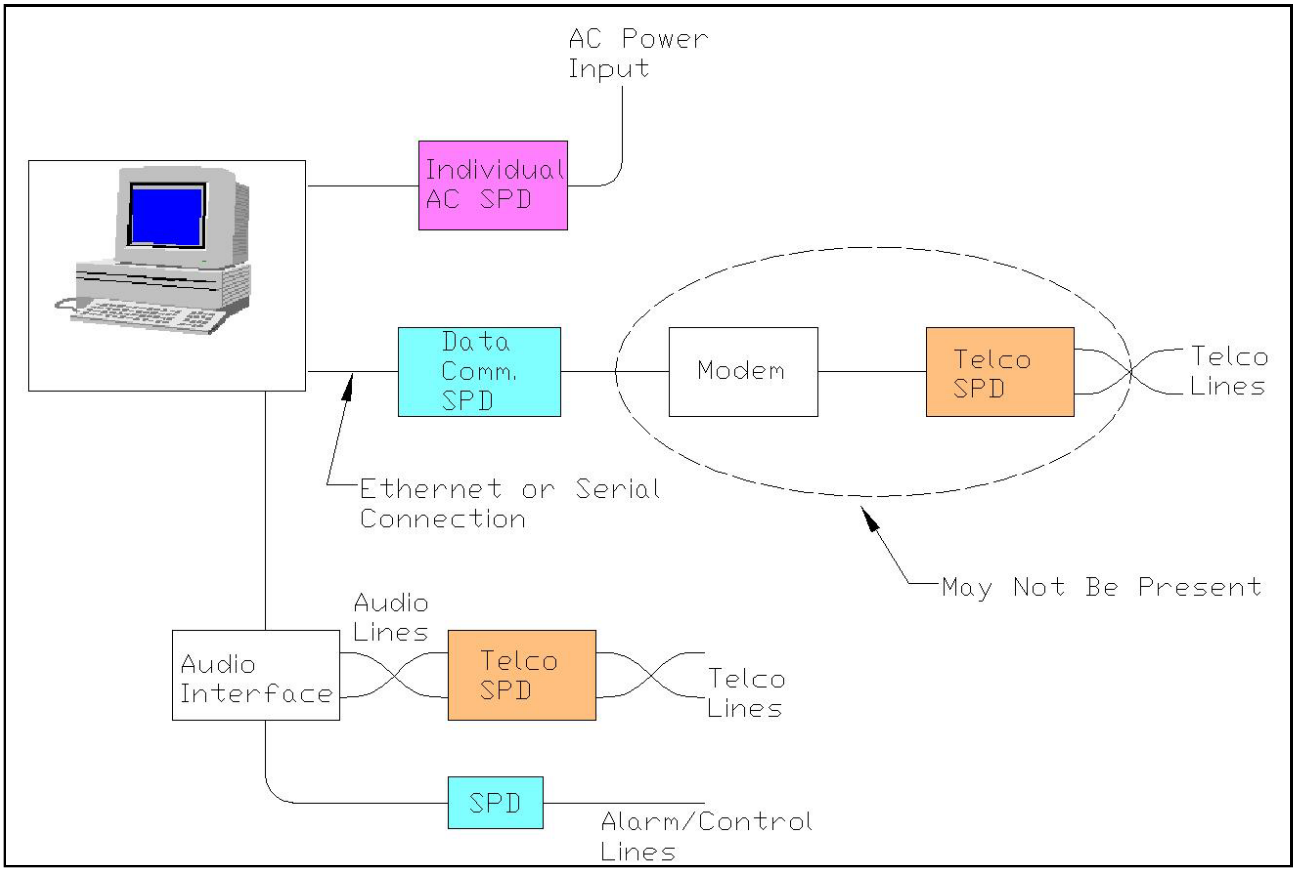



**Figure 7-19: Remote Dispatch Console Surge Suppression Needs**

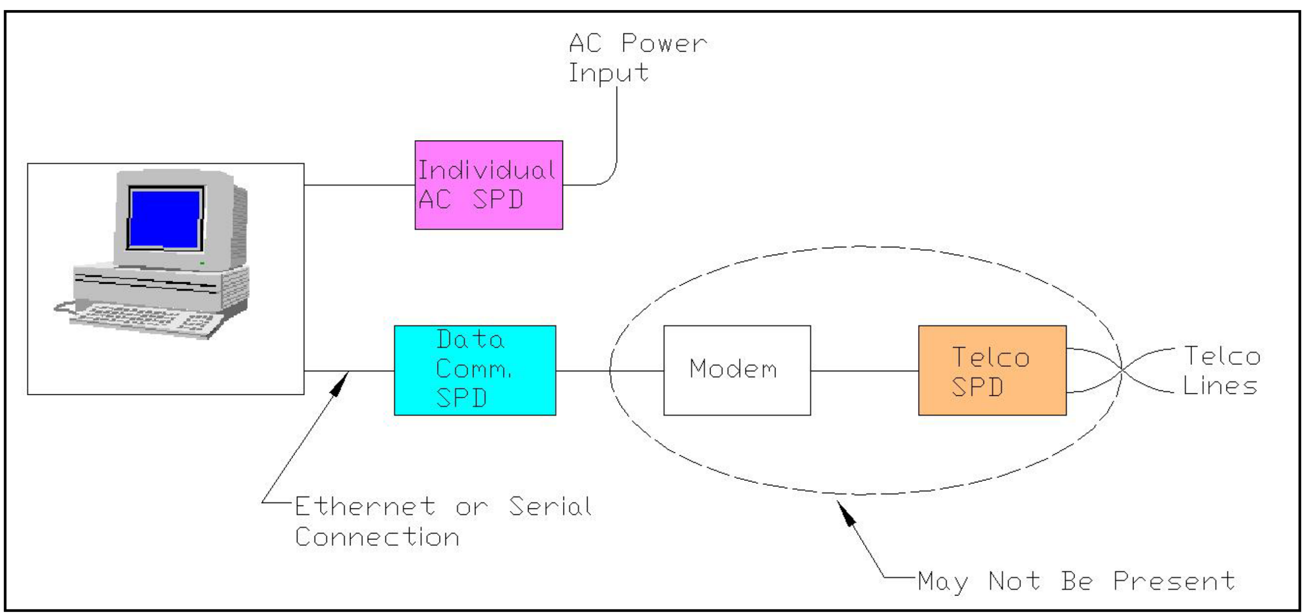



**Figure 7-20: Remote Systems Management Device Surge Suppression Needs**

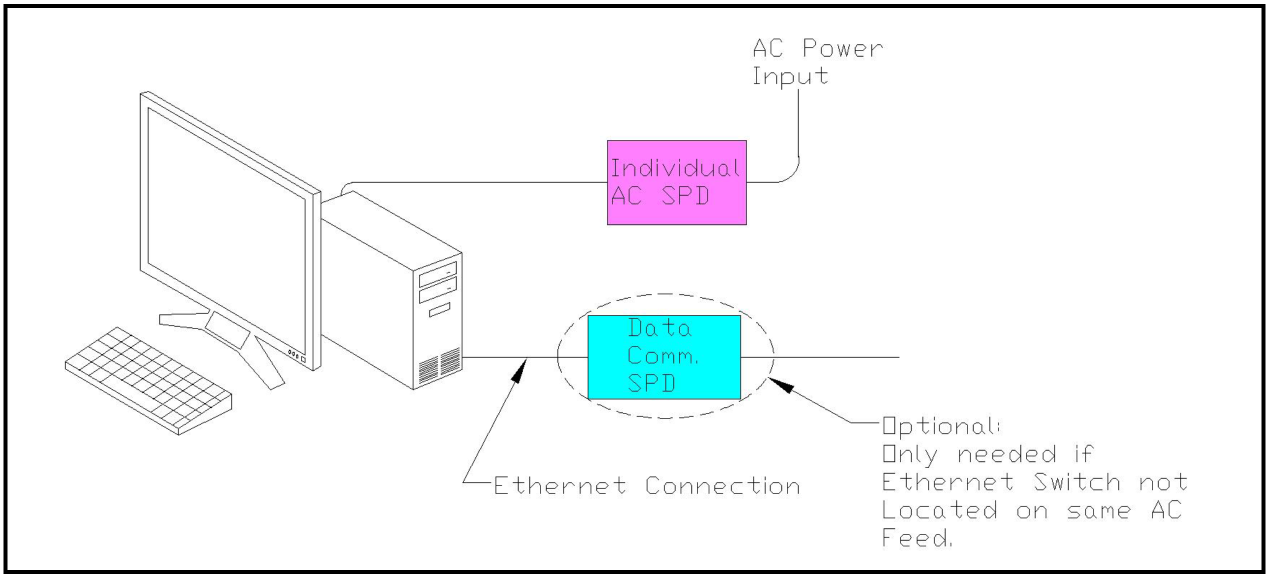



**Figure 7-21: Systems Management Terminal Ethernet Connection**

# 7.8 DISPATCH CENTERS

## 7.8.1 Dispatch Console Equipment Grounding

All console equipment, mounting enclosures, and furniture at a dispatch center should be bonded to an SGB that is located in that room. This SGB should be connected to the building MGB grounding system.

Each dispatch position should have a separate #2 AWG, or larger, ground bus conductor connected to the SGB or to a ground bus "home run" connected to the SGB. All console equipment grounding connection points, mounting rails, furniture, and any SPDs associated with and located at that position should be connected to this ground bus conductor using a #14 AWG, or larger, conductor. Do not daisy chain grounding connections.

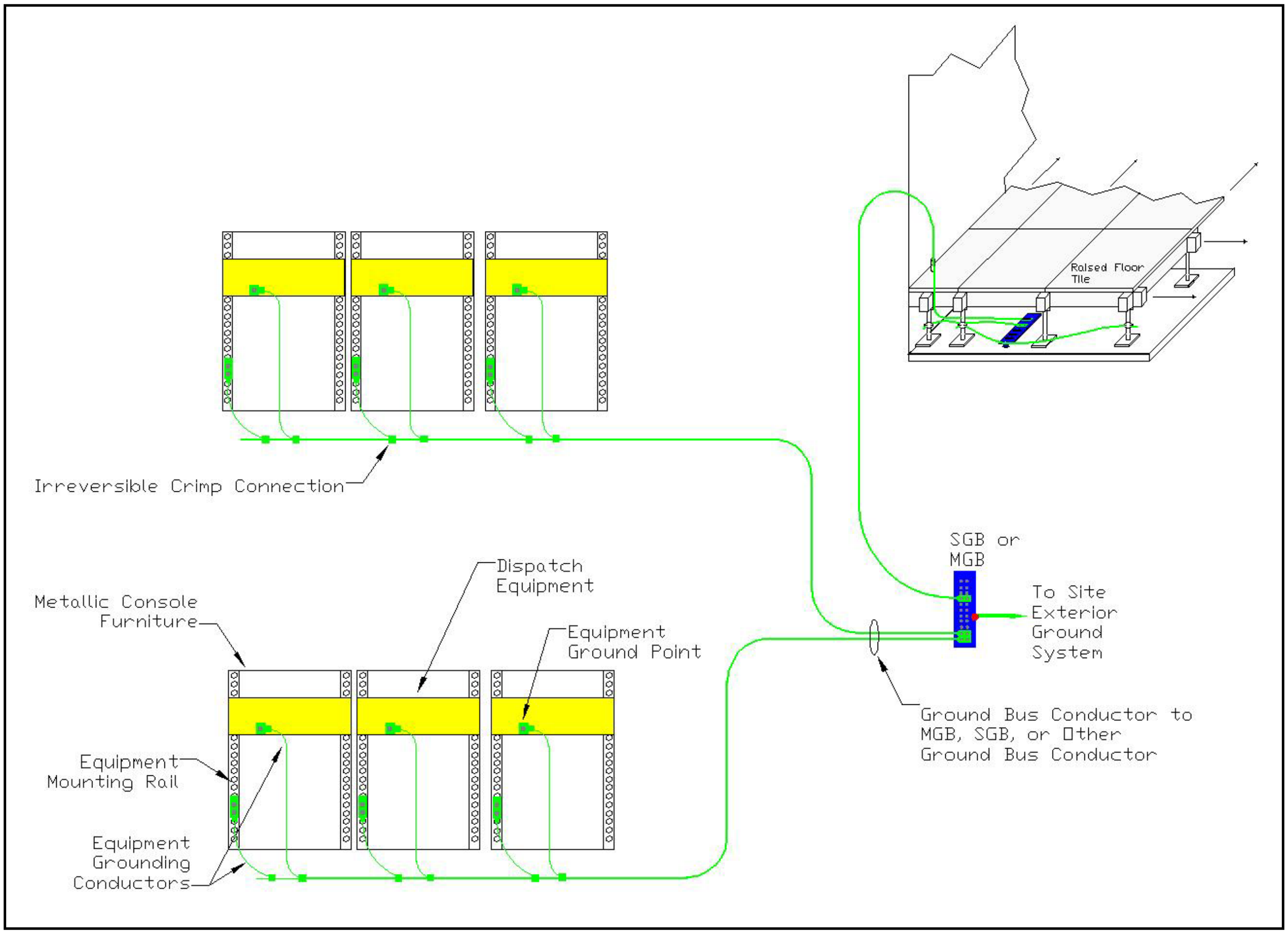



**Figure 7-22: Dispatch Console Equipment and Room Grounding Detail**

Primary AC and telecommunication line SPDs should be located at their entrance into the facility. These SPDs should be bonded to the building MGB. Individual equipment AC SPDs and secondary data or telecommunication line SPDs should be located at each dispatch position. (See Section 6.4.4.2, 6.6, and 6.7 for details.)

Ideally, the dispatch positions should obtain their power from either a dedicated UPS or a whole building UPS.

## 7.8.2 Co-located Dispatch Center Equipment

Dispatch consoles that are co-located with the console switch equipment should be grounded to an SGB that is bonded to the switch equipment room MGB. See section 5.2.2, Supplemental Ground Bus Bars for details on sizing the conductor.

Surge protection should be installed on both ends of the data communications links if they are more than 50 feet long to protect against induced surges. This is especially important if there is a tower located near the building.

The dispatch console equipment itself should be grounded and have surge protection as detailed in Section 7.8.1.

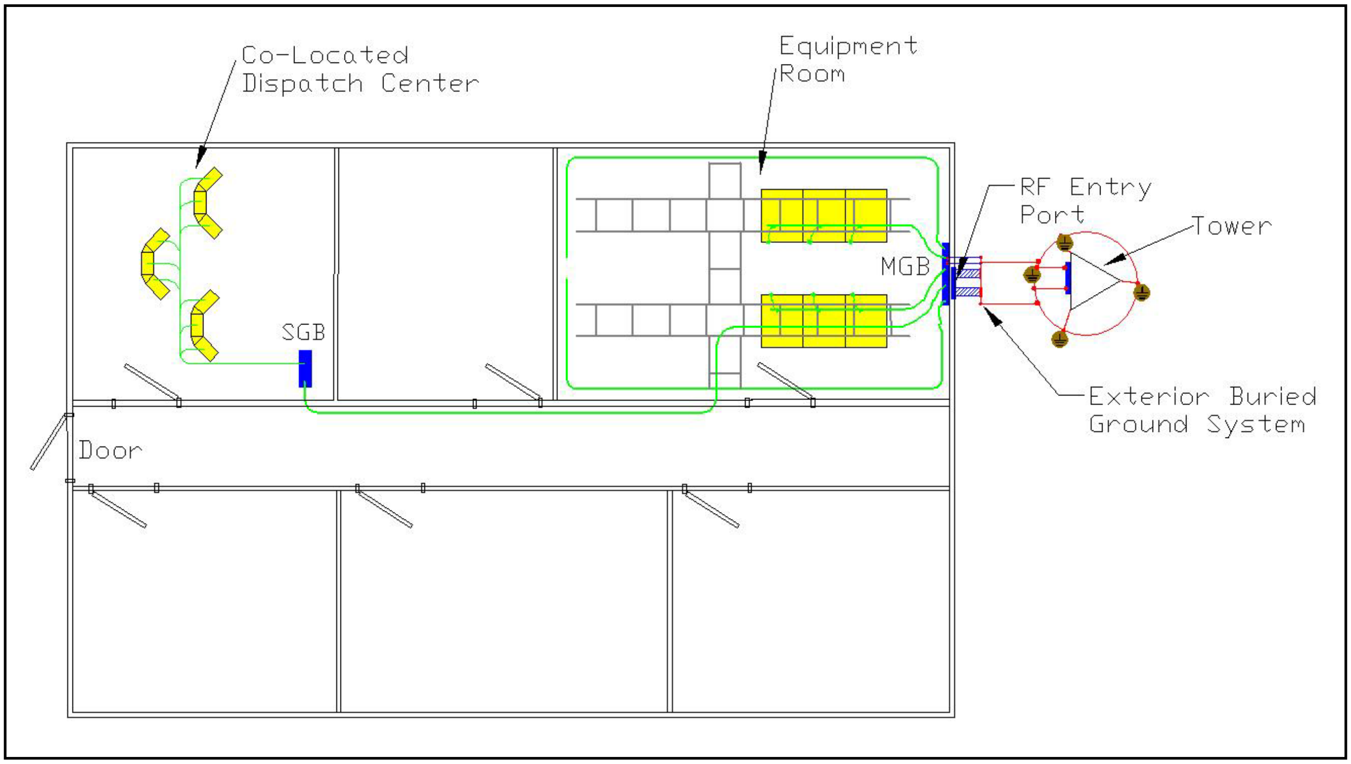



**Figure 7-23: Co-Located Dispatch Center Grounding**

### 7.8.3 Remote Dispatch Center Equipment

Remote dispatch center equipment should be grounded to the building MGB or to an SGB that is bonded to the MGB. See section 5.2.2, Supplemental Ground Bus Bars for details on sizing the conductor.

We highly recommend using fiber optic links between the dispatch console switch site and the remote dispatch center. This applies to remote sites located close to the console switch or far away. Fiber optic links reduce the number of surge paths coming into the location.

If copper telecommunications or data lines must be used, you must install primary surge protection at the building entrance that is grounded to the building MGB. Lower let-through voltage secondary surge protection should also be installed as close to the dispatch console equipment as possible. (See section 6.7 for more details.) This same principle applies to any telephone lines that are brought into the dispatch center or console positions for call director or E911 purposes.

The dispatch console equipment itself should be grounded and have surge protection as detailed in Section 7.8.1.

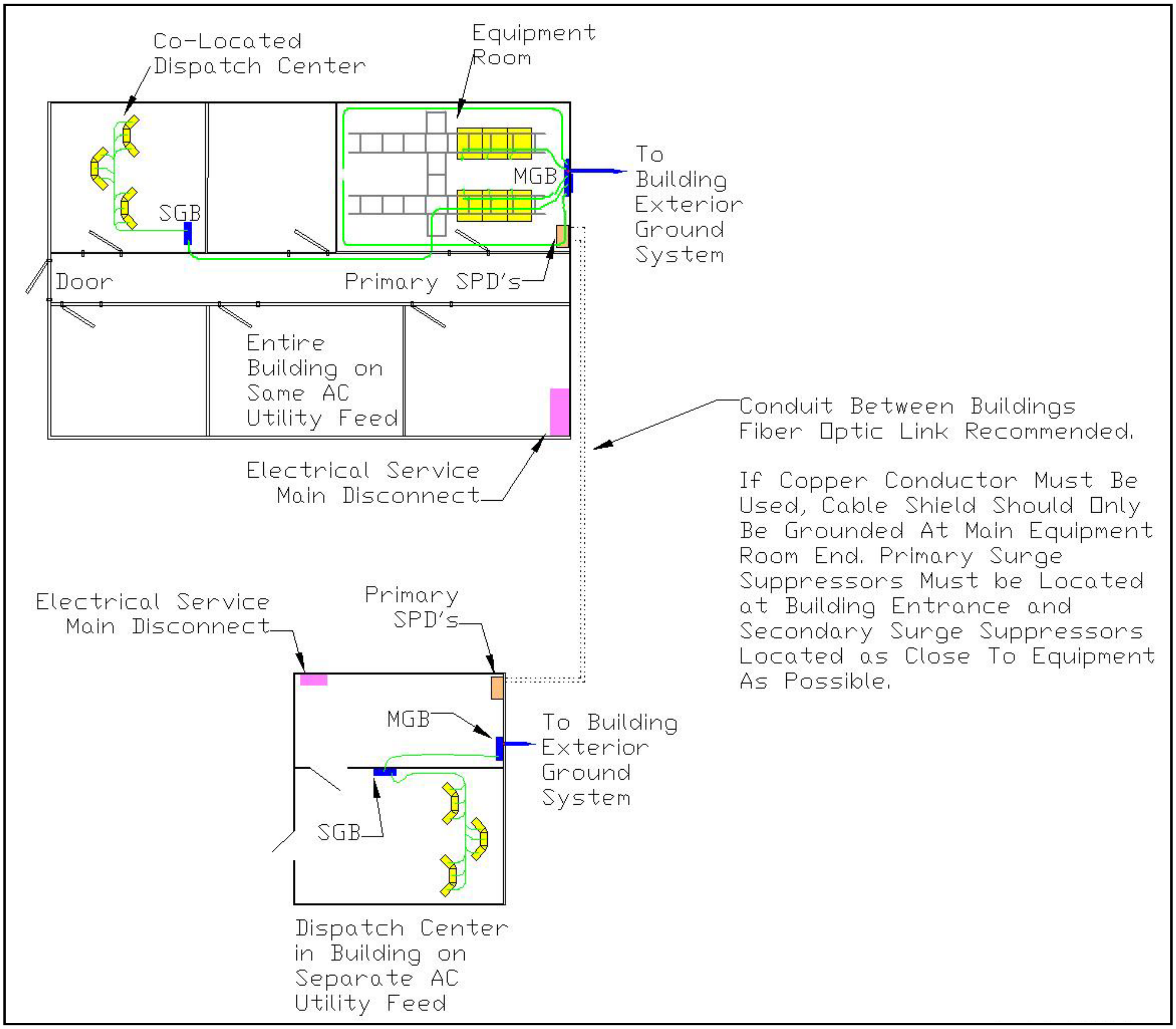



**Figure 7-24: Remote Dispatch Center Grounding**

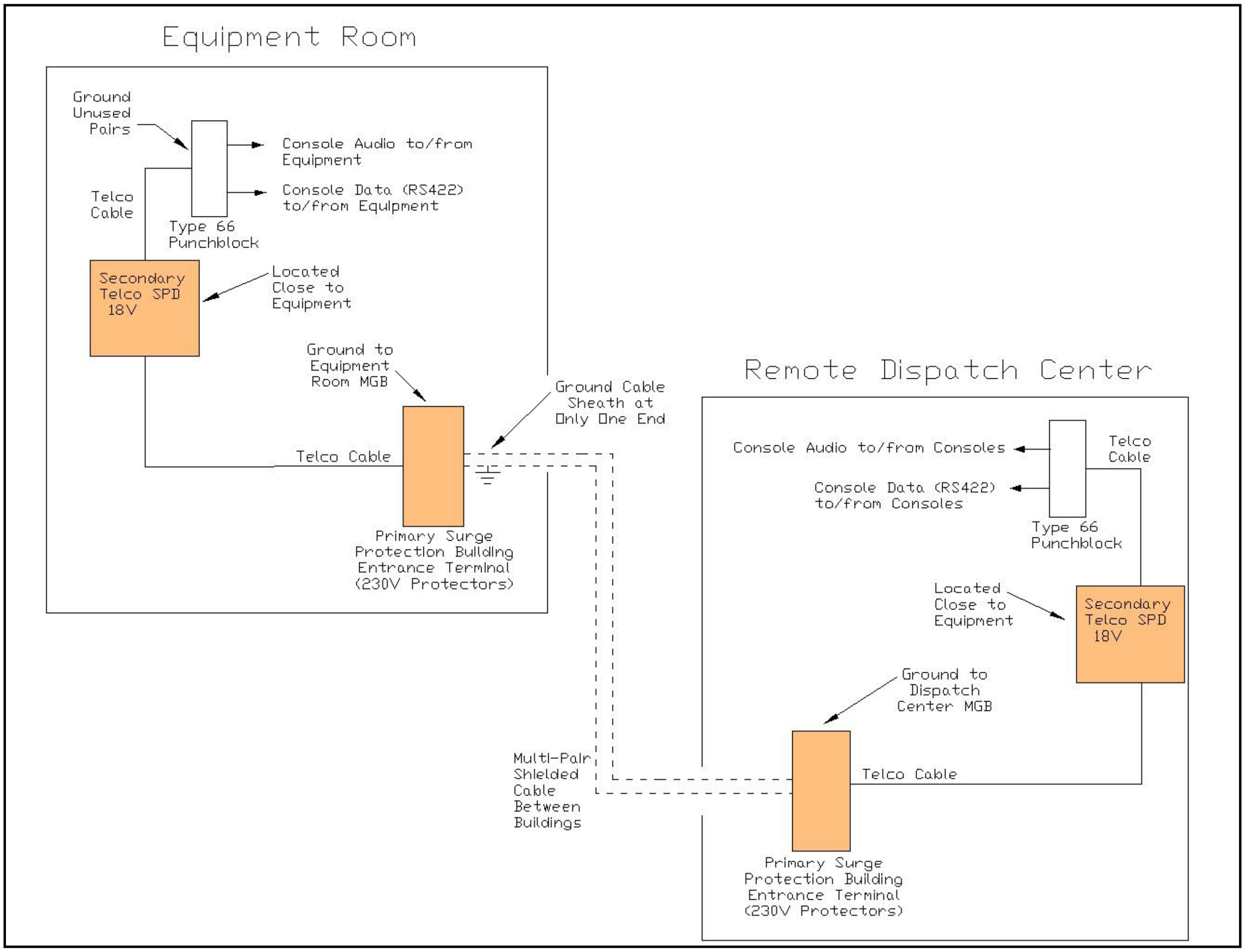



**Figure 7-25: Example of Telecommunications Surge Protection for Remote Dispatch Center**

## 7.9 GENERATOR LOCATED MORE THAN 75 FEET FROM SHELTER

Ideally, the site backup generator should be located as close to the ATS as possible. This minimizes the length of cables on which lightning energy may be coupled. If the generator is located more than 75 feet from the ATS, ensure all incoming conductors from the generator are surge protected and properly grounded to reduce the possibility of damage.

See Section 4.8 Exterior Generators Grounding for details on grounding the generator and its fuel tank.

Install appropriate surge protection devices at the ATS on all alarm and control lines between the generator and the ATS.

If a data link to the generator is used, use optically isolated data line protectors, that have a separate power source. These should be located at both the generator and the ATS to protect the circuitry. See Section 6.7 for more detail.

Some generators have the starter battery charger located inside the ATS. Often there is alarm or measurement sensing circuitry connected to the DC leads going outside to the generator. Though the charger itself is not very sensitive to surges, the alarm or sensing circuitry may be. For this generator/ATS configuration, we recommend installing a DC SPD on these lines at the ATS. The particular DC SPD depends on the DC voltage and polarity of the DC power plant.

For high exposure sites, where the generator is located far from the shelter, a panel-type AC SPD may be installed at the generator AC input to the ATS to protect the ATS control circuitry. An AC SPD similar to the one described in Section 6.4.3.2 should be chosen for this location.

NOTE

Low voltage wiring should be run in a separate conduit from the AC power conductors. If metallic conduit is used, it should only be bonded to the ground system on one end. Always follow the generator and ATS manufacturer's installation recommendations.

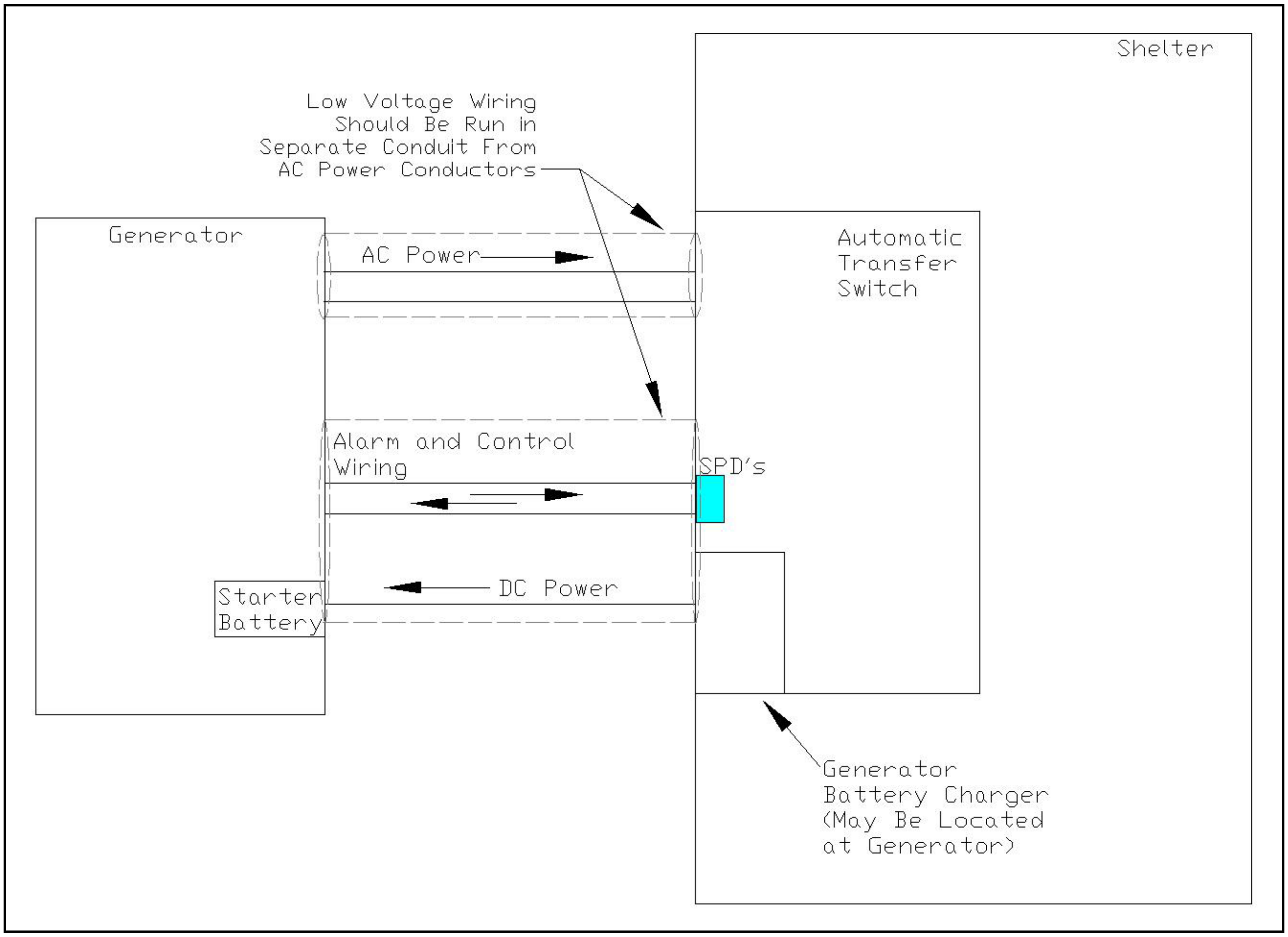



**Figure 7-26: ATS Surge Protection Required When Generator Located Close to Shelter**

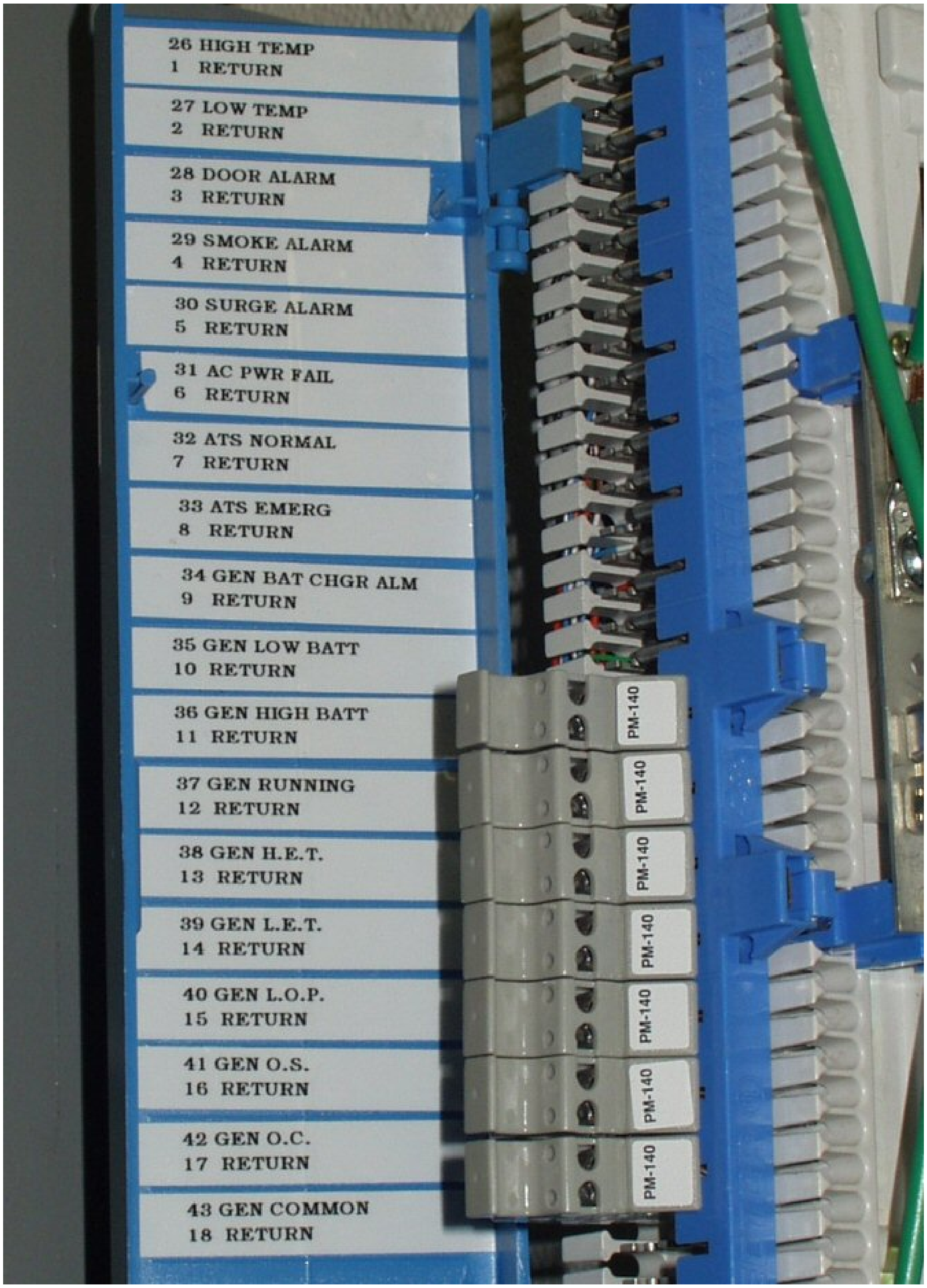



**Figure 7-27: Example of Generator Alarm Line Surge Protection**

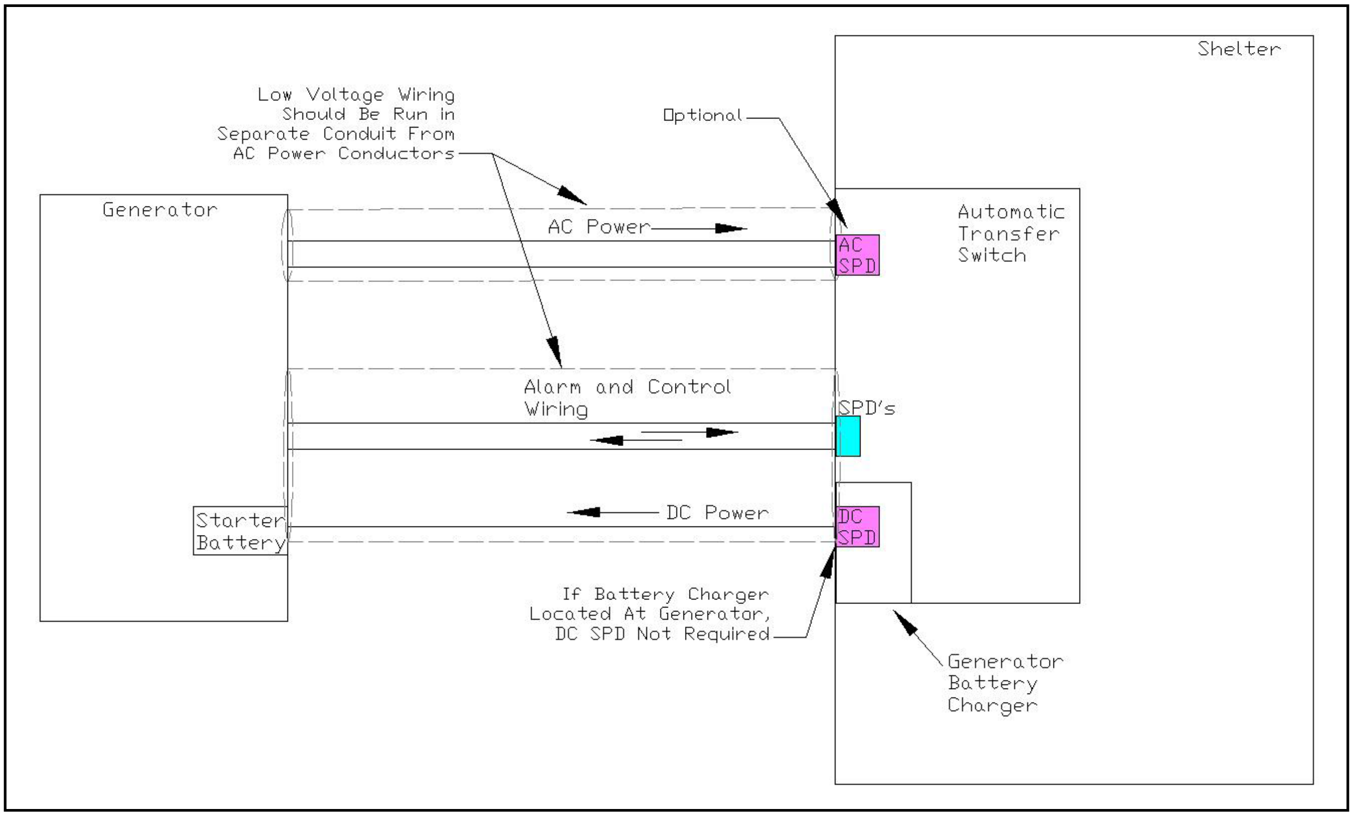



**Figure 7-28: ATS Surge Protection Required When Generator Located More than 75 Feet from Shelter**

**Figure 7-29: Example of DC SPDs Installed in ATS when Generator Located Far from Shelter**

## 7.10 RF TRANSMISSION LINE UNDERGROUND ROUTING TO SHELTER

Routing the RF transmission lines underground between the tower and the equipment shelter greatly reduces the amount of possible lightning surge current that may reach the shelter. Routing the RF transmission lines underground may also be done for aesthetic or zoning reasons. Cable routing over an outer walkway at a multiuse building may also be reason for routing the RF transmission lines underground.

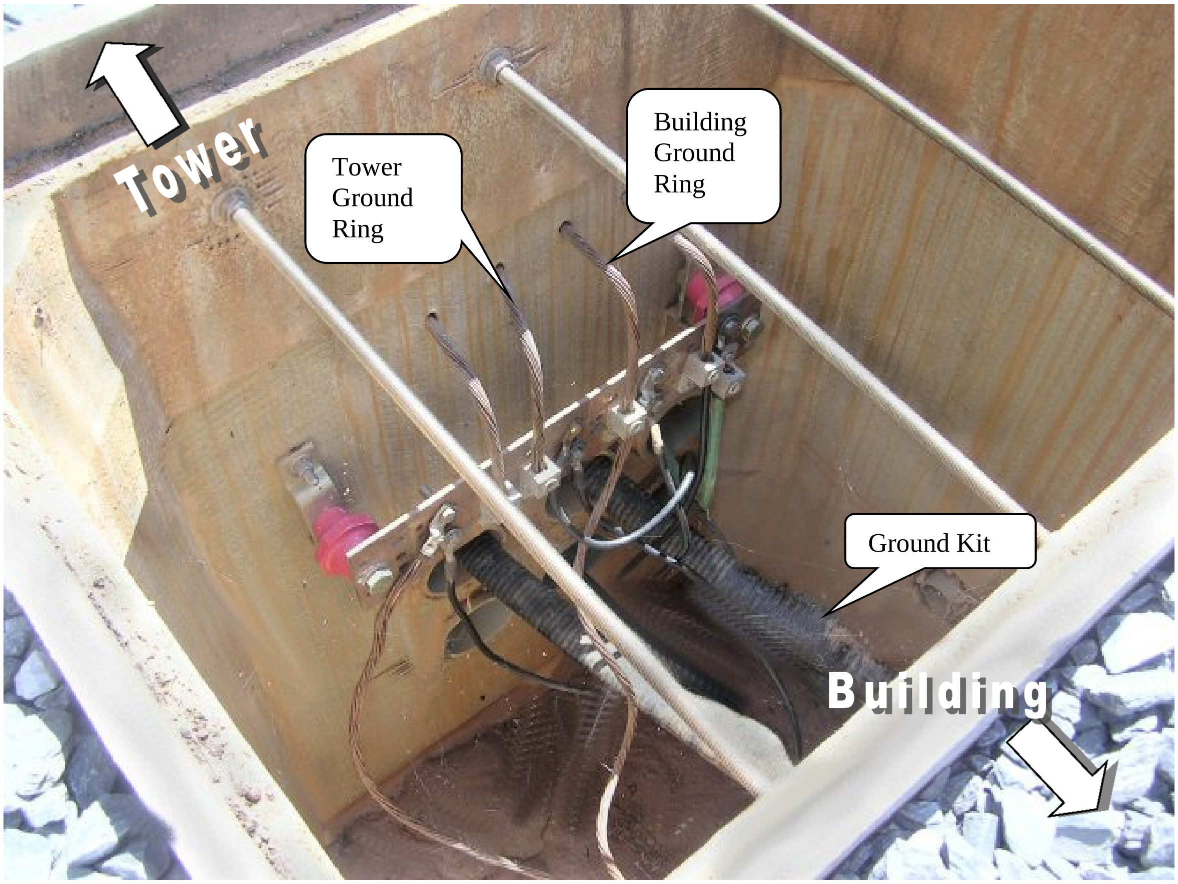
RF transmission lines can be routed underground either in a duct system with covers accessible along the path or in underground conduit runs that may have access wells along the path.

When RF transmission lines are run underground, the line’s bottom ground kit should be installed and grounded to a tower ground bar. The ground bar should be placed as close to the ground as possible and adjacent to the location where the cables enter the ground. Another ground kit is installed on the line at the shelter entry point either immediately outside the shelter or at the first point of entry into the room, if the entry into the equipment room is also underground.

Additional ground kits may be installed on the RF transmission lines along the underground path but are not required. If these ground kits are used, ground them to additional ground bars that are directly bonded to the buried ground system.

RF surge protection should be located just inside the shelter or equipment room and within 2 feet of the RF transmission cable entry point.

**Figure 7-30: Example of Underground Antenna Cable Routing in Ground-Level Cable Trough/Duct**




Ground access well for underground RF transmission line routing

Cable entry to underground conduit


Conduit to building

**Figure 7-31: Example of Underground Antenna Cable Routing in Conduit to Underground Building RF Entry**

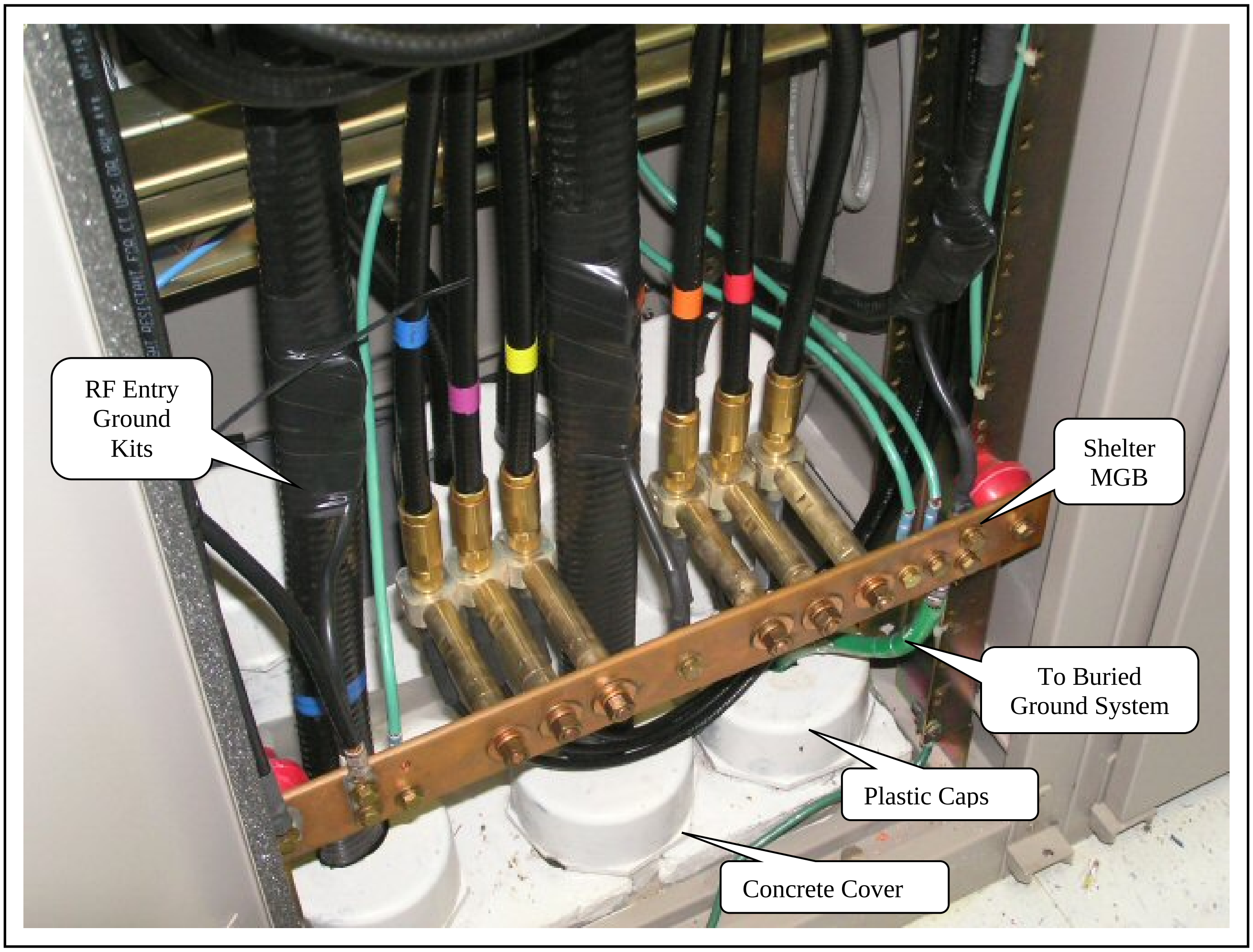



**Figure 7-32: Example of Underground RF Entry into Building**


**Figure 7-33: Different Method of Leaving Tower to Route RF Transmission Lines Underground**

## 7.11 WATER TOWER SITES

Locating an RF site at a water tower requires some special considerations. There are many different water tower designs and installation situations. This section provides some basic guidelines for grounding a site located at a water tower.

Equipment room grounding and surge protection practices detailed in Sections 5 and 6 should be followed.

RF transmission lines should have ground kits installed according to the instructions in Section 4.4, RF Transmission Line Grounding. These ground kits should be bonded to the water tower steel structure or grounding points provided.

NOTE

Antenna mounting and RF transmission line routing/grounding options vary by water tower type. Welding or even bolting to water towers can present unique challenges and restrictions. A thorough site installation plan should be reviewed by Harris Systems Engineering prior to installation.

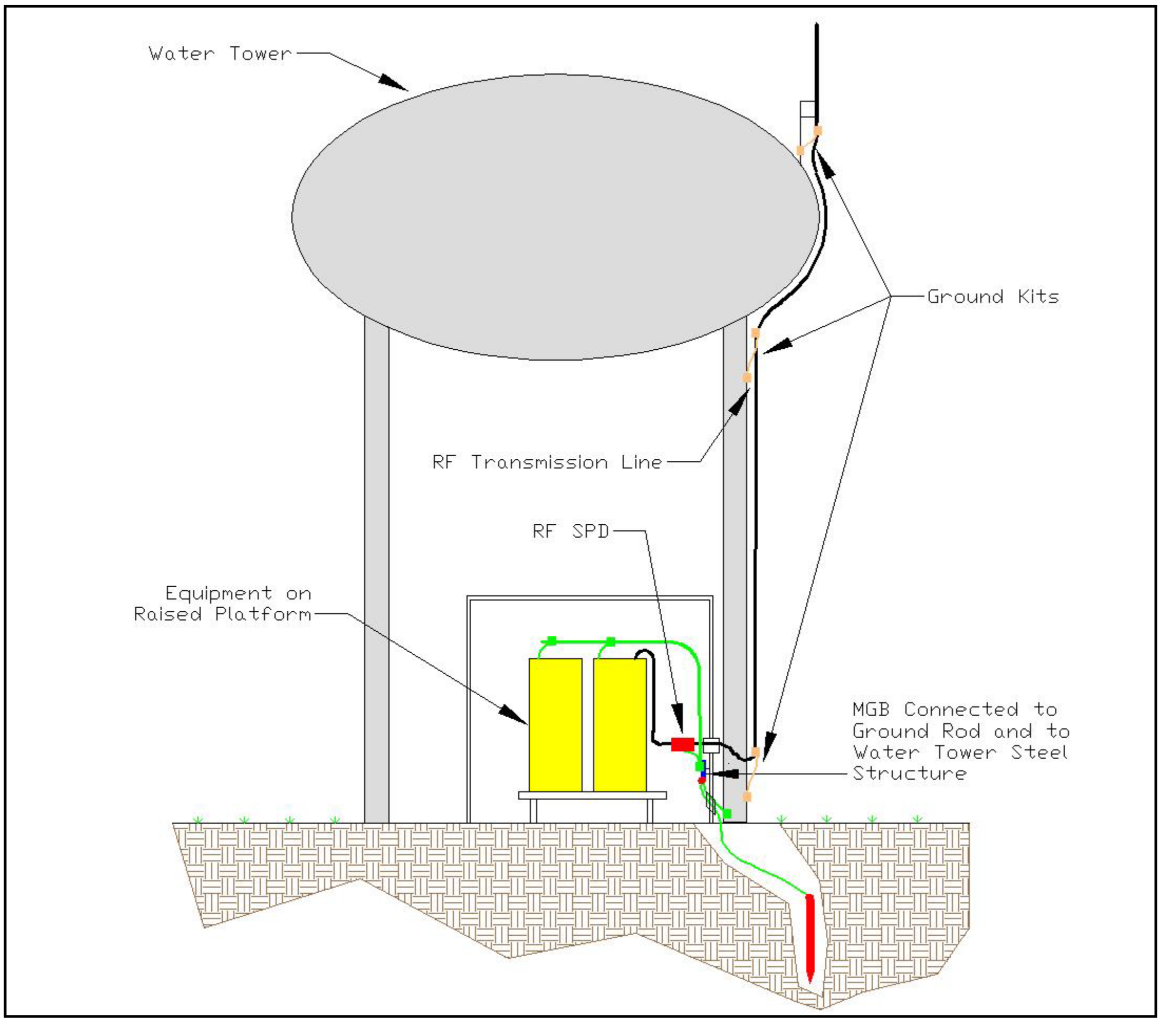



**Figure 7-34: Example of Site Grounding at a Water Tower Site**

The RF transmission lines should leave the water tower structure at as low a point as possible. If the equipment shelter or enclosure is located outside the water tower structure, we recommend routing the RF transmission lines underground to the shelter. The shelter should have a ground ring installed (see Section 4.1.1) and bonded to the water tower structure. The shelter MGB and EGB should be bonded to this buried ground ring.

If the equipment is located inside or underneath the water tower structure, it should be located in a waterproof shelter or enclosure. The equipment should also be installed on a raised platform. Special attention to humidity control is required.

Although a water tower should provide an exceptional ground system, non-conductive couplings/bushings and corrosion may reduce its effectiveness. You should bond the MGB to the water tower steel structure. In addition, at least one ground rod should be installed outside the water tower structure and be bonded back to the site MGB. This additional ground rod must also be bonded to the AC entrance ground rod.

**Figure 7-35: Example of Water Tower Antenna Cable Routing and Grounding**

Figure 7-36: Examples of Antenna Cable Routing at a Different Style Water Tower

**Figure 7-37: Example of Equipment Room Ground Connection at Another Style Water Tower**

## 7.12 MOBILE DEPLOYABLE TOWER SITE GROUNDING

Mobile deployable tower sites require grounding similar to a permanent tower site for both personnel safety and RF performance. These mobile sites are also known as Cell on Wheels (CoW), System on Wheels (SoW), mobile trailer sites, or Rapid Deployable Units (RDU).

The mobile site should have a designated trailer ground bus bar where a temporary ground system connection can be made. For ease of discussion, this trailer ground bus bar will be called a Deployable Ground Bus (DGB). The DGB is the collection point for all of the connections that would normally go directly to the site’s buried ground rings at a permanent site. The equipment Master Ground Bar (MGB), if present, should be bonded to the DGB using #2 AWG, or larger, stranded copper wire. The trailer frame itself and the deployable tower structure should also be bonded to the DGB using #2 AWG, or larger, stranded copper wire.

The recommended ground system for a mobile deployable tower site should consist of at least three equally spaced driven ground rods bonded together to form the deployable site ground ring.

The driven ground rods should have a *minimum diameter of 5/8 inch and a minimum length of 8 feet.* The distance between the ground rods should be twice the length of the ground rod (where space permits) or between six (6) feet (minimum) and twice the ground rod’s length (maximum). These rods should be located either around the deployable tower base itself or as close to it as possible. The top of the ground rods may be left at ground level, or buried just below grade to avoid tire puncture.

The ground rods should be bonded together with #2 AWG, or larger, stranded copper wire using at least a UL-listed mechanical acorn clamp connection to each ground rod. The conductor may be buried or left at grade, and it should form a ring around the deployable tower. If the deployable tower is located more than 10 feet from the equipment container or trailer, then an additional driven ground rod is recommended near the DGB. This additional ground rod would be bonded to the ground ring formed by the other rods.

It is recommended that the tower grounding consist of at least two equally spaced grounding conductors of #2 AWG, or larger, stranded copper wire connected from the bottom of the deployable tower to the newly formed ground ring. The DGB should also be bonded to the ground ring using #2 AWG, or larger, stranded copper wire. All connections to the ground ring should go toward the closest ground rod and be at least clamped to the ground ring using UL-listed mechanical clamps. Connections to the ground ring should be short and direct, with no bends with a radius less than 8 inches or angle less than 90 degrees.

Depending on the distance from the deployable tower to the DGB the bottom tower RF transmission line ground kits may be bonded to the DGB or to a Tower Ground Bar (TGB) on the deployable tower. If a TGB is used, then it should bond directly to the ground ring like the tower using #2 AWG, or larger, stranded copper wire.

Due to the nature of deployable towers, additional ground kits may not be practical higher up the tower.

If the mobile deployable tower site is powered from an existing AC utility feed, the DGB should be bonded to the AC utility ground rod. If the no external AC utility power is present and the deployable site is powered by a generator, then the generator should be treated as a separately derived AC system (See Section 5.9).

The equipment located on or inside the trailer, enclosure, container, etc. should use single point grounding to the MGB. Surge suppression should be present on all incoming AC, RF, and data/telco communications lines. This surge suppression should be grounded to the MGB.

The deployable mobile site ground kit conductors and mechanical clamps may be reused with only the driven ground rods needing to be replaced in the kit. The conductor and mechanical clamp connection points should be cleaned with steel wool to remove any oxidation when the ground kit is deployed each time. Use of antioxidant compound is recommended, but not required. (Abandoned ground rods should be cutoff or driven below grade.)

If it is not possible to use driven ground rods due to location on cement or asphalt, then a connection to some ground point such as an AC utility power pole or light pole ground, etc. should be made to the DGB at a minimum. In this situation, the tower and TGB, if present, should be bonded to the DGB.

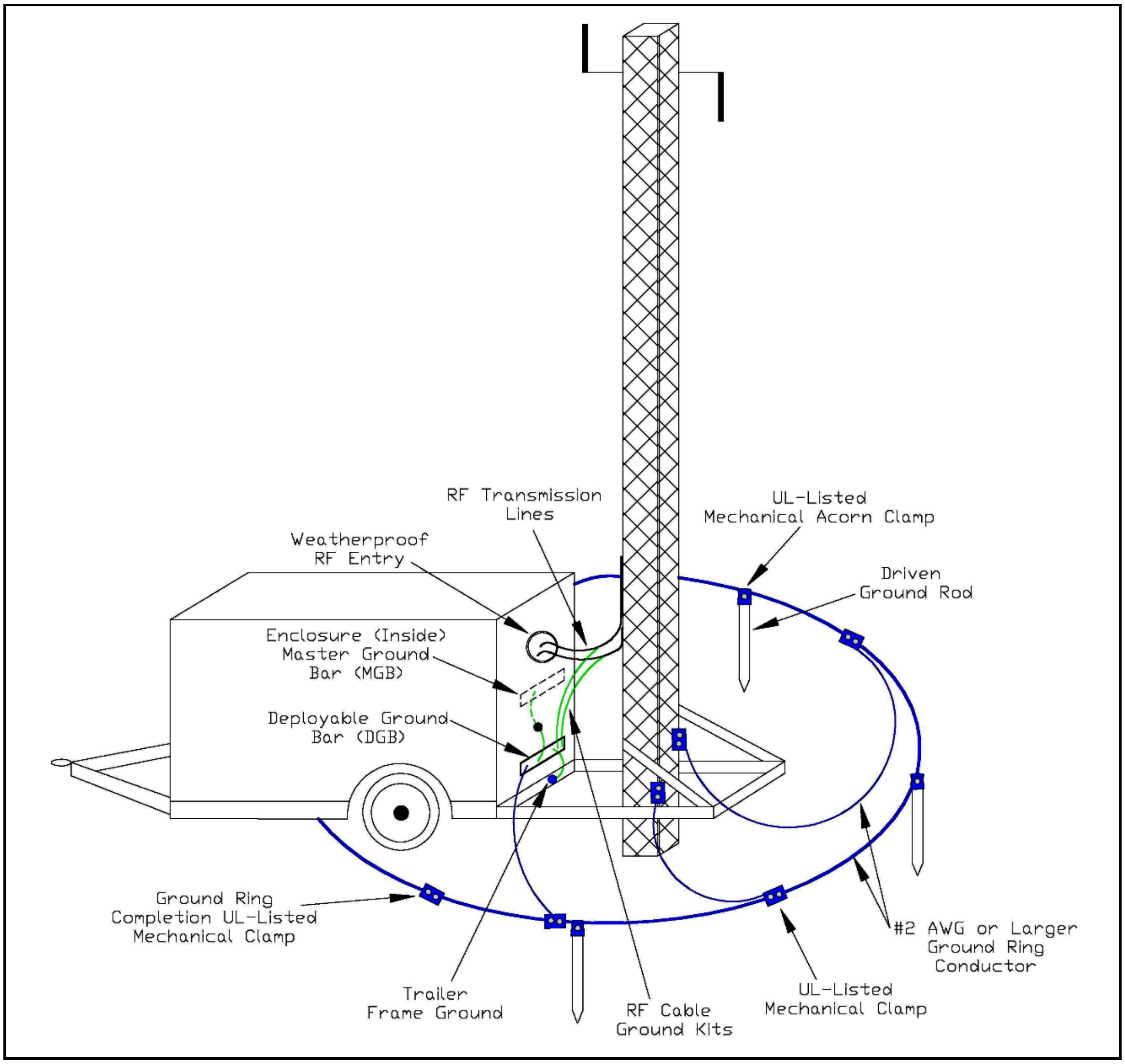



**Figure 7-38: Recommended Mobile Deployable Tower Site Grounding**

## 7.13 DIFFICULT GROUND SYSTEM INSTALLATION LOCATIONS

If difficult site conditions such as limited space, stone mountain tops, sand, coral, limestone environments, or high resistivity soil exist, special care and attention to the grounding system design should be taken.

Appendix E details some of the techniques that may be used to overcome some of these difficult ground system installation situations. Contact Harris Systems Engineering with any ground system design or installation questions. A consulting grounding engineering firm may also be contacted in these cases.

# APPENDIX A SOIL RESISTIVITY MEASUREMENTS

## A.1 REASONS FOR MEASURING SOIL RESISTIVITY

Soil resistivity measurements are needed for two purposes. First, the soil resistivity directly affects the design of a grounding system. Soil resistivity is the key factor that determines the resistance of a grounding electrode, and to what depth it must be driven to obtain low ground resistance. Measuring the soil resistivity at a site facilitates designing a grounding system that meets the performance objectives, thus saving time and money on site development.

Soil conditions can vary greatly even within small geographic areas. Soil resistivity measurements can help identify difficult grounding conditions early before work at a site begins. This is especially important for small sites with limited space for installing grounding electrodes. Soil resistivity measurements can identify the average soil resistivity for different depths under the surface. Knowing the average soil resistivity at different depths can identify when using deeper grounding electrodes will achieve a desired ground system resistance more efficiently than many more shallow grounding electrodes. It can also help identify when special grounding techniques may be required. For a large site, measuring the soil resistivity may help identify the area of lowest soil resistivity at the site to achieve the most economical grounding system.

Additionally, the soil resistivity has a direct impact on the degree of corrosion activity the buried grounding system components are exposed to. A lower soil resistivity corresponds to an increase in corrosion activity. If the soil resistivity is measured to be less than 2000 ohm-cm for the depths at which the grounding system will be installed, preventive measures are recommended to increase the effective longevity of the grounding system and prevent galvanic corrosion of the tower or guy anchors if present. (See Section 2.2.1.1, Ground Rods and Section 2.2.2, Exterior Bonding Conductors.)

## A.2 FACTORS AFFECTING SOIL RESISTIVITY

Soil resistivity is determined largely by its content of electrolytes, which consist of moisture, minerals and dissolved salts. Soil resistivity changes seasonally due to differences in the amount of moisture in the soil and the soil's temperature. These changes should be considered when designing a grounding system for a particular region especially if the area experiences either moisture or temperature extremes, such as a desert or extended periods of deep ground freezing. Table A-1 shows the typical resistivity ranges of different types of soil.

**Table A-1: Soil Resistivity By Soil Type**

| Soil | Resistivity (Ohm-cm) [Typical Range] |
|---|---|
| Sea Water (reference) | 100 - 200 |
| Surface soils, loam, etc. | 100 - 5,000 |
| Clay | 200 - 10,000 |
| Sand and gravel | 5,000 - 100,000 |
| Surface limestone | 10,000 - 1,000,000 |
| Limestones | 500 - 400,000 |
| Shales | 500 - 10,000 |
| Sandstone | 2,000 - 200,000 |
| Granites, basalts, etc. | 100,000 |
| Decomposed gneisses | 5,000 - 50,000 |
| Slates, etc | 1,000 - 10,000 |

By comparison:

**Table A-2: Resistivity of Some Backfill Materials Used in Ground System Enhancement**

| Backfill Material | Resistivity (Ohm-cm) [Typical Range] |
|---|---|
| Specially Processed Bentonite Clay | ~60 |
| Naturally Occuring Bentonite Clay | ~300 |
| Carbon-based Materials* (Includes Conductive Concrete) | 25-500 |
| Normal Concrete (buried) | ~30,000 |

* Using carbon-based ground enhancement materials, including conductive concrete that has carbon-based material added, may accelerate the corrosion of the copper ground system due to dissimilar metals contact.

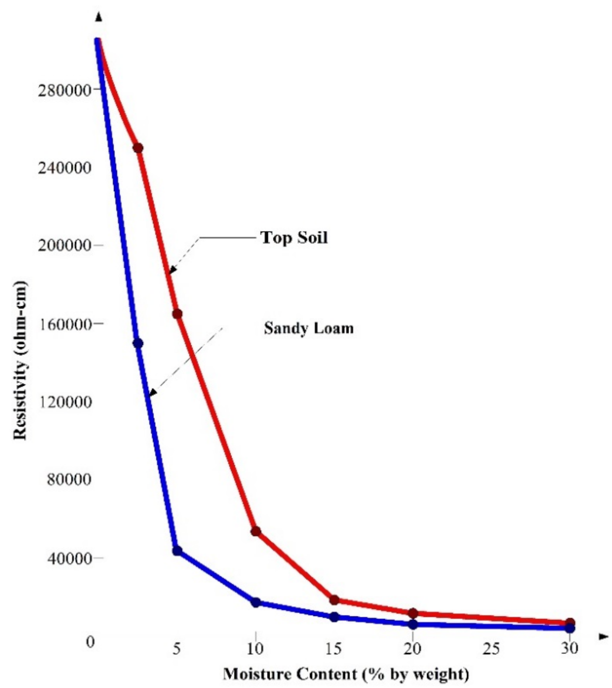
Care must be used in choosing a ground enhancement material. Bentonite clay backfill specially processed for grounding applications provides a lower resistivity than unprocessed naturally occuring bentonite clay. All clay backfill materials must be hydrated to be effective.

### A.2.1 Soil Moisture

The resistivity of a soil sample changes quite rapidly until approximately 20 percent or greater moisture content is reached. Table A-3 shows how the resistivity of two different soil types varies based on their moisture content as a percentage of weight. A dry soil has high resistivity if it contains no soluble salts. Two samples of soil, when thoroughly dried, may in fact become very good insulators having a resistivity in excess of $10^9$ohm-cm.

**Table A-3: Moisture Content Influence on Soil Resistivity**

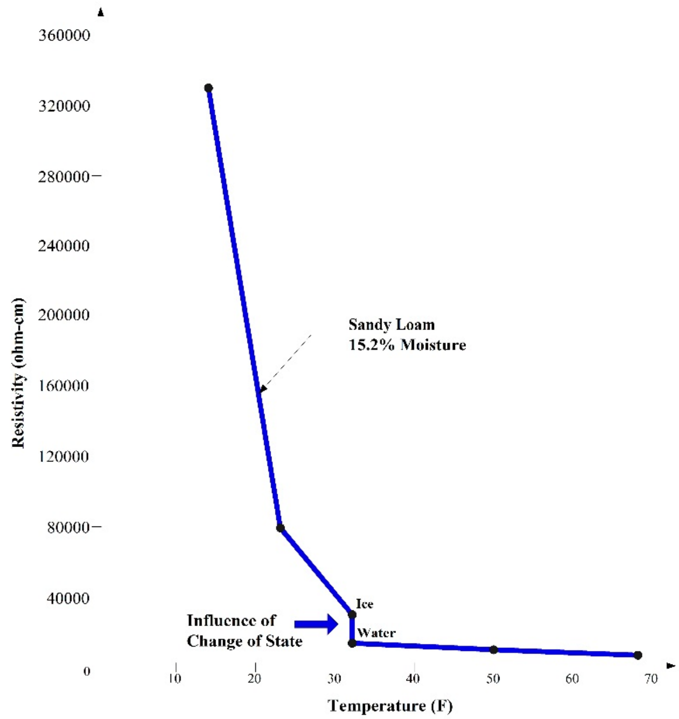
| Moisture Content (% by weight) | Resistivity (Ohm-cm) | | |
|---|---|---|---|
| | Top Soil | Sandy Loam | |
| 0 | > $10^9$ | > $10^9$ | |
| 2.5 | 250,000 | 150,000 | |
| 5 | 165,000 | 43,000 | |
| 10 | 53,000 | 18,500 | |
| 15 | 19,000 | 10,500 | |
| 20 | 12,000 | 6,300 | |
| 30 | 6,400 | 4,200 | |




### A.2.2 Soil Temperature

The resistivity of the soil is also influenced by its temperature. Table A-4 shows the variation of the resistivity of sandy loam, containing 15.2% moisture, as the temperature changes from +20° to -15°C. In this temperature range the resistivity varies from 7,200 to 330,000 ohm-cm.

**Table A-4: Temperature Influence on Soil Resistivity**

| Temperature | | Resistivity (Ohm-cm) | |
|---|---|---|---|
| °C | °F | |  |
| 20 | 68 | 7,200 | |
| 10 | 50 | 9,900 | |
| 0 (water) | 32 (water) | 13,800 | |
| 0 (ice) | 32 (ice) | 30,000 | |
| -5 | 23 | 79,000 | |
| -15 | 14 | 330,000 | |



## A.2.3 Seasonal Variations and Grounding Electrode Depth

Soil resistivity is directly related to moisture content and temperature. Therefore it is reasonable to assume that the resistance of any grounding system will vary throughout the different seasons of the year. Such variations are shown in Figure A-1.

Both temperature and moisture content become more stable at greater distances below the surface of the earth. Ground rods should be driven a considerable distance below the surface of the earth for the grounding system to be most effective at all times. Best results are obtained if the ground rods reach the water table.

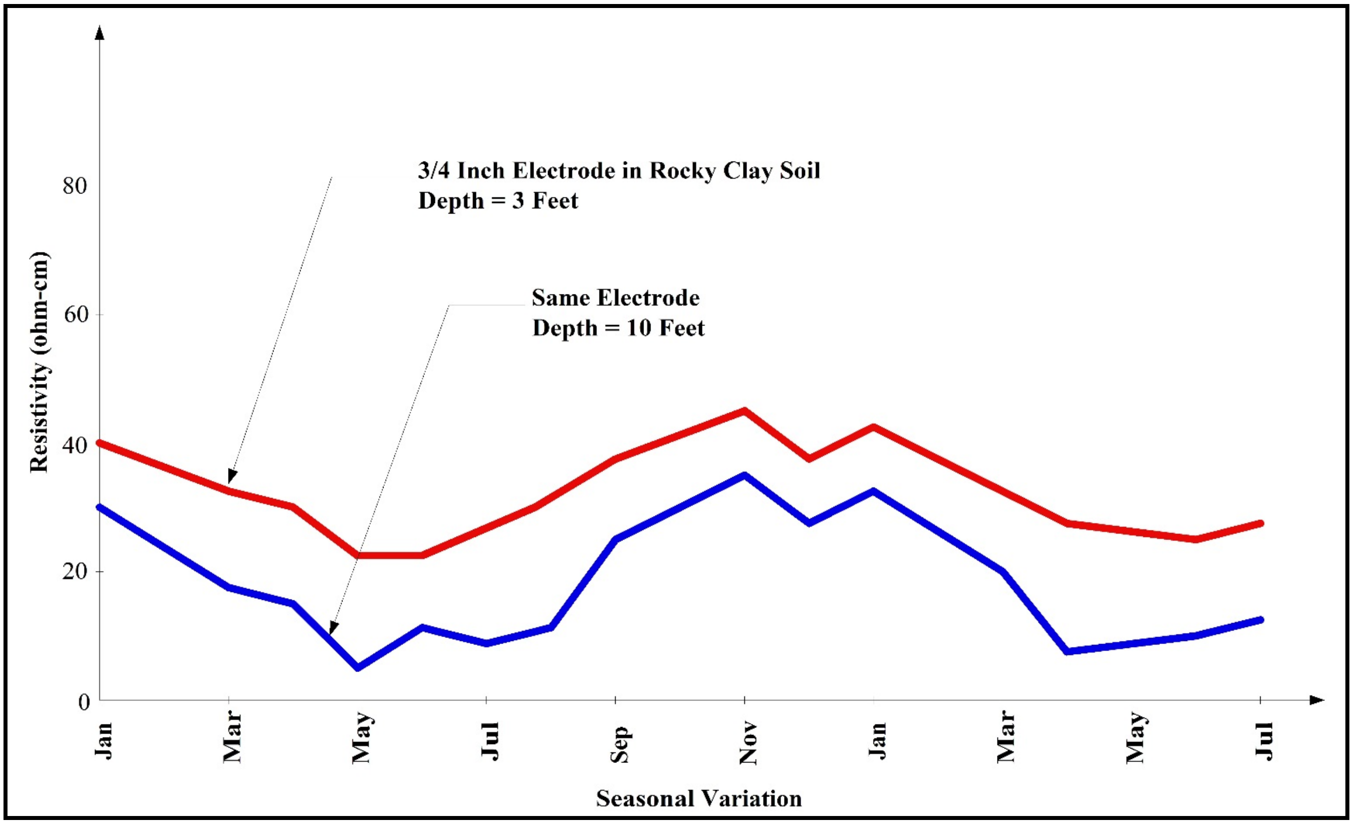



**Figure A-1: Soil Resistivity by Seasonal Variation**

## A.3 MAKING SOIL RESISTIVITY MEASUREMENTS

Soil resistivity may be measured in two different ways. The preferred method is to make a 4-point Wenner test at the site location. With this method the average soil resistivity over different depths may be measured. If a 4-point test cannot be performed, then soil samples may be taken and sent to a grounding consulting firm for testing.

### A.3.1 4-Point Wenner Method

A 4-point test uses a test meter to pass a constant current through the earth and measures the voltage drop between two points.

#### A.3.1.1 Theory

Four probes are inserted into the soil in a test area. The probes are installed in a straight line and equally spaced. The spacing of the test probes determines the depth to which the average soil resistivity is measured from the surface.

During the 4-point test, the two outer probes are used to pass the constant current through the earth. The two inner probes are used to measure the voltage drop through the earth between them. Knowing the constant current being injected and the measured voltage drop between the two inner probes, the test meter calculates resistance displayed in ohms.

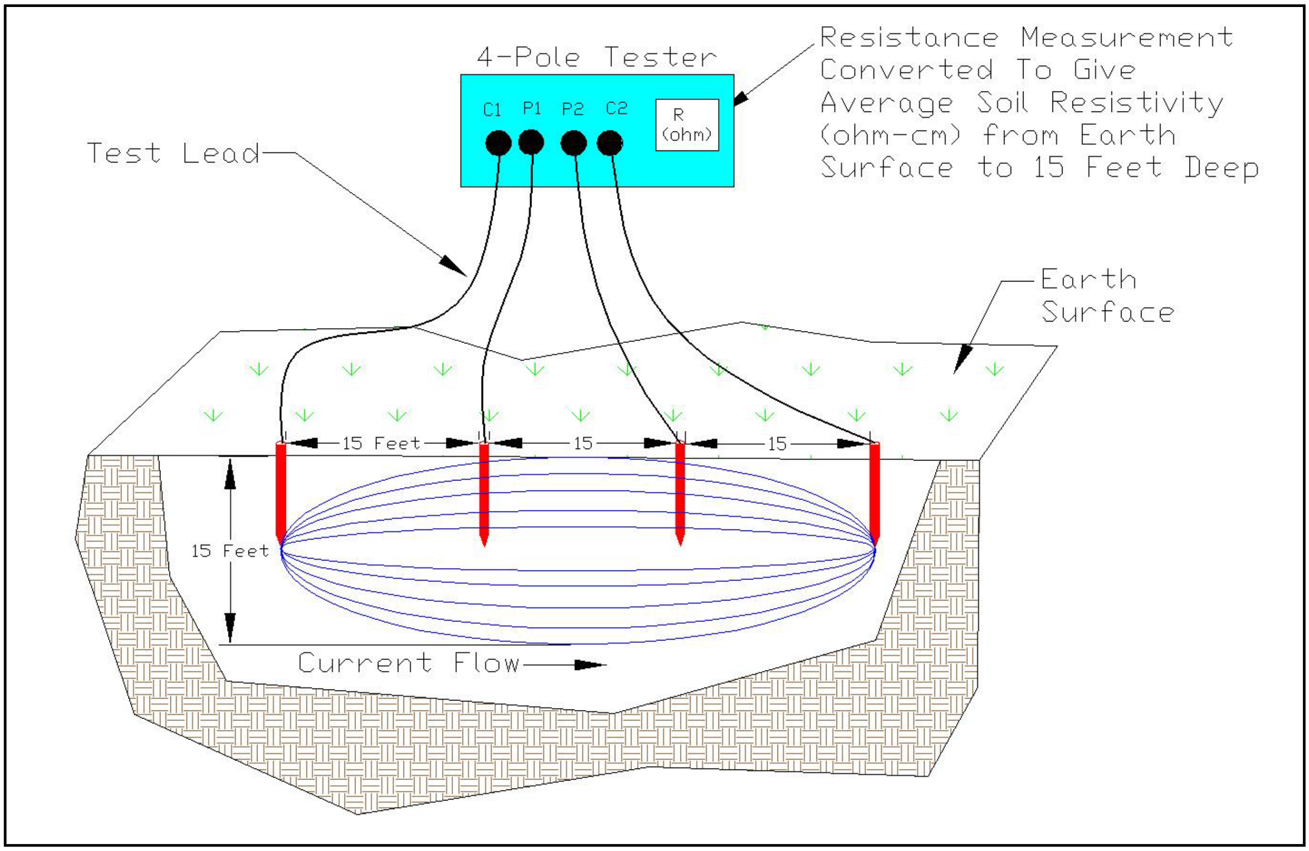



**Figure A-2: 4-Point Wenner Test Theory**

The meter's displayed resistance value in ohms must be converted to soil resistivity which is expressed in ohm-m or ohm-cm. Ohm-m is the resistance of a volume of earth measuring one meter by one meter by one meter. Ohm-cm is the resistance of a volume of earth measuring one centimeter by one centimeter by one centimeter. This converted resistance value is the average soil resistivity between the soil surface and a depth equal to the probe spacing. (See Section A.3.1.5, Converting 4-Pole Test Meter Displayed Value to Soil Resistivity Value for details.)

### A.3.1.2 Equipment Required

- A 4-pole digital ground resistance meter with an up-to-date calibration and an operation manual. (Contact Harris Systems Engineering for specific testing product information.)
- Four metallic test probes at least18 inches long (In sandy or frozen soil, longer test probes, three (3) to six (6) feet, may be required to obtain a measurement.)
- Four lengths of insulated conductor with clips for connecting the 4-pole meter to the test probes.
- Tape measure at least 100 feet long
- Hammer for driving test probes
- Safety glasses and rubber gloves

- Copy of site plat with future location of shelter and tower shown
- Test sheet for recording measurements and converted values

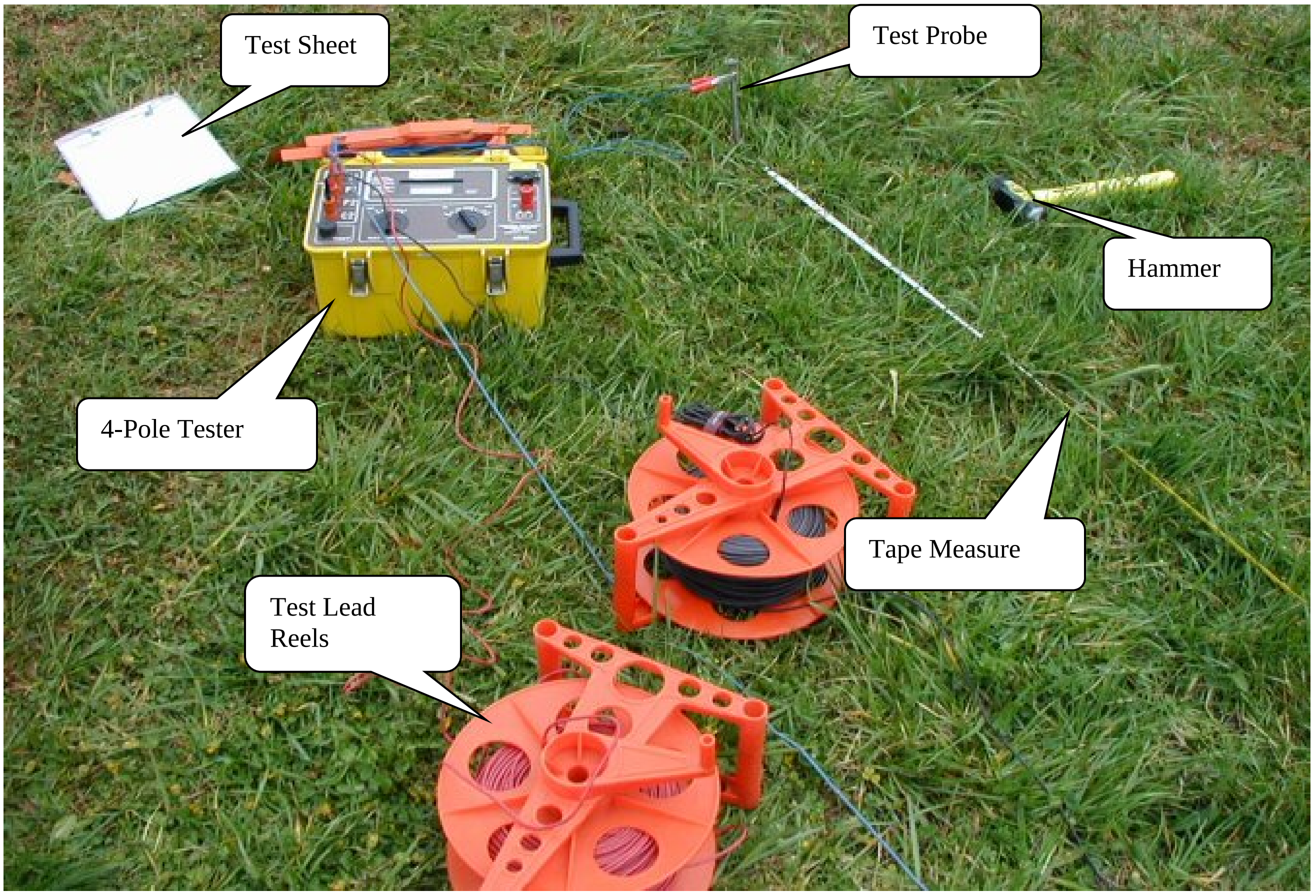



**Figure A-3: Example of Some Equipment Needed to Make 4-Point Wenner Test**

**Figure A-4: Example of Two Different Styles of 4-Pole Wenner Test Meters**

### A.3.1.3 Soil Resistivity Testing Methodology

Several readings at different probe spacings and at different areas of the site should be made. Readings are usually taken at probe spacings of 5, 10, 15, 20, 30, and 40 feet. If the calculated soil resistivity exceeds 30,000 ohm-cm, then probe spacings up to 100 feet are recommended. If the readings will be used for a ground system design by an outside firm, then 100 feet measurements are also recommended.

Remember that the probe spacing determines the depth from the surface at which the average soil resistivity is being measured. For example, a probe spacing of 15 feet will provide the average soil resistivity between the surface and a depth of 15 feet.

Preference should be given to areas containing moist loam as opposed to dry, sandy areas, but measurements should not be made in standing water. Measurements made in wet soil without standing water are valid since surface moisture rarely reaches more than 18 inches under the surface.

Underground metallic objects that run parallel to a test measurement may distort test readings. For this reason, measurements should be taken first in one direction and then in a direction perpendicular to the first. Taking a third set of measurements at a 45-degree angle to the first is highly recommended especially if underground metallic objects are present.

NOTE

Making measurements directly underneath overhead power lines should be avoided.

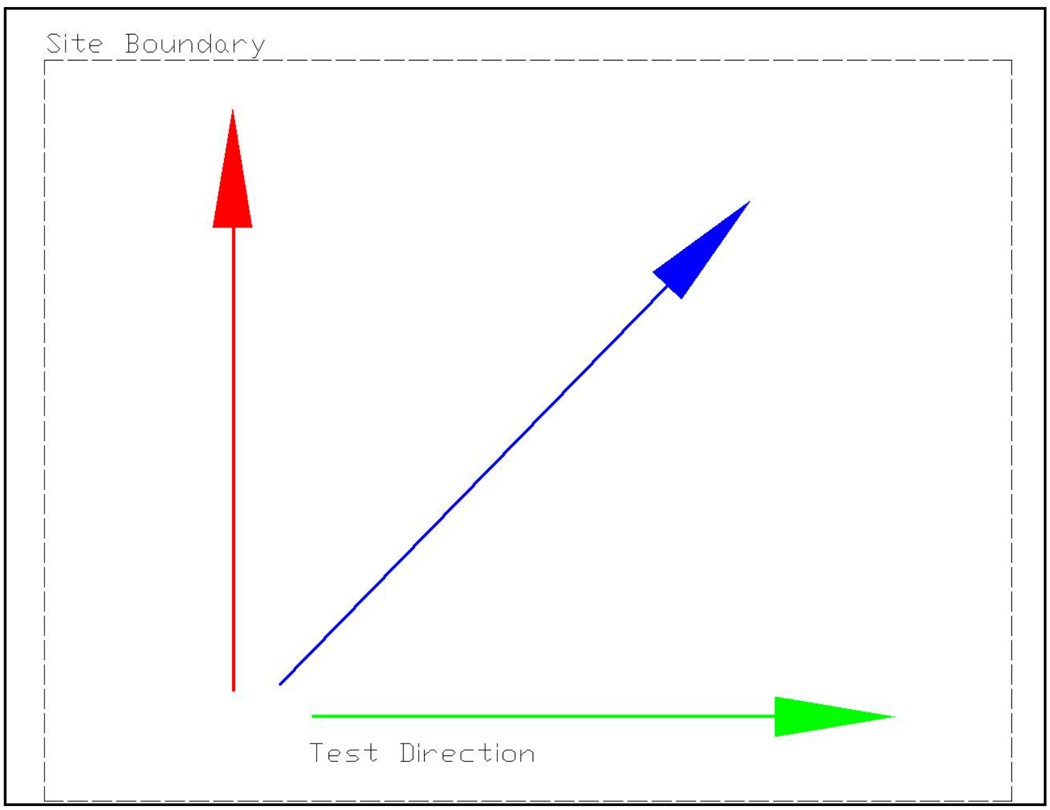



**Figure A-5: Recommended 4-Point Test Directions Layout**

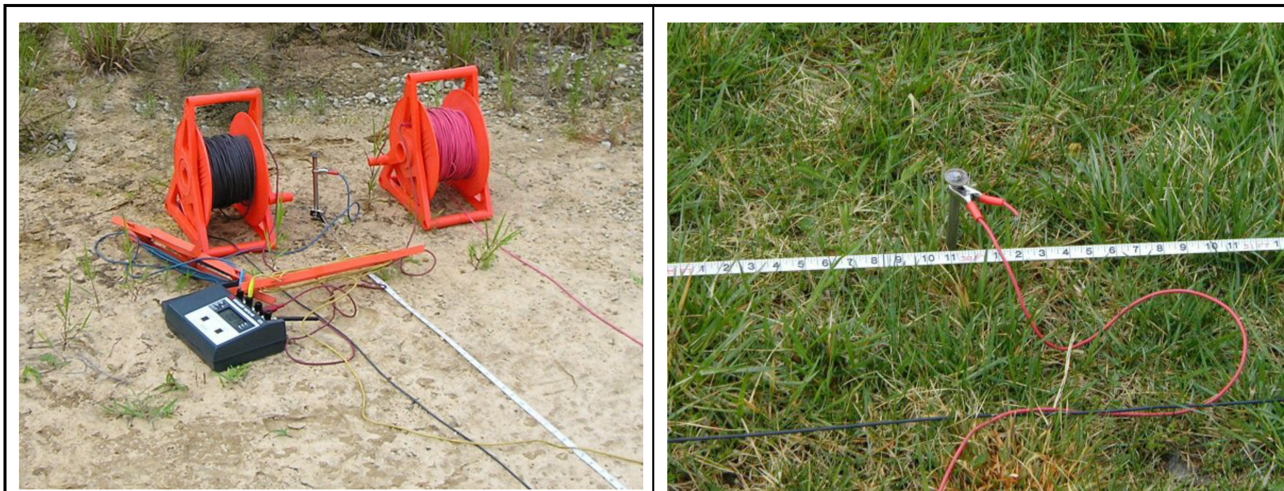


**Figure A-6: 4-Point Wenner Ground Resistance Test with C1 Probe and P2 Probe for 15 Feet Probe Spacing Test**

### A.3.1.4 4-Point Test Procedure

Before soil resistivity tests are performed at a site, the soil at the site should already be graded to the level at which the foundation will be placed and compacted.

The following test procedure is to be used as a guideline. The user's manual for the particular test meter being used should be referred to for detailed operating instructions.

1. Identify the locations and directions of the various measurements to be made on the site plat. Move to the first measurement location.

2. Verify that there is no connection between the first current terminal and the first voltage terminal on the test meter. This connection is used to convert some 4-pole test meters to a 3-pole test meter for making other types of measurements.

3. Place the four test probes in the ground equally spaced in a straight line using the tape measure as a guide as shown in Figure A-7. Each of the four test probes should be inserted into the ground to the same depth. This depth should be at least 12 inches.

4. Connect the insulated conductors between the test probes and the test meter terminals. Note that connecting the test meter terminals to the wrong test probes will result in inaccurate readings.

5. Set the 4-pole test meter to the lowest test current setting and the highest resistance range.

6. Press the test button and read the test meter's digital display. Adjust the resistance range to the lowest setting that still provides a stable reading without error indications. Increase the test current to the highest setting that still provides a stable reading without error indications.

**The meter's test current poses a shock hazard if the test probes or terminals are touched while the meter's test button is pushed.**

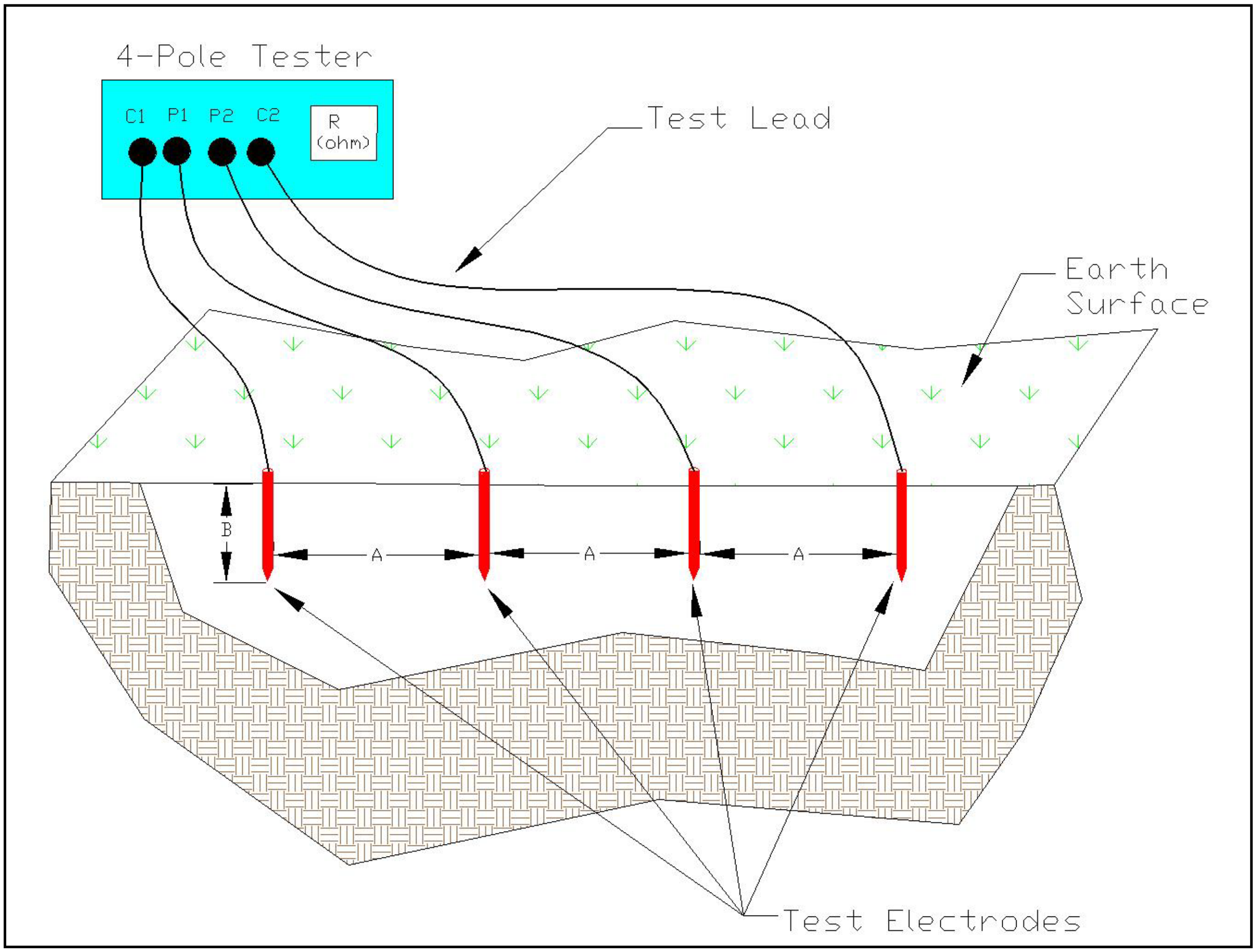



**Figure A-7: 4-Point Test Probe-to-Test Meter Connection Order**

If the reading is unstable or displays an error indication, check the connections and ensure that the resistance range is at the highest setting. The resistance range and test current settings may be adjusted until a combination is found that provides a stable reading without error indications.

In very high resistivity soil, water may be poured around the test probes to achieve a better electrical connection without influencing the test results. If adding water does not help, longer test probes may have to be used. Again, they should be driven to equal depths.

7. Record test location, test probe spacing, and the test meter reading on the test sheet available in Section C.3.

8. Repeat steps 3 through 7 for the different probe spacings.

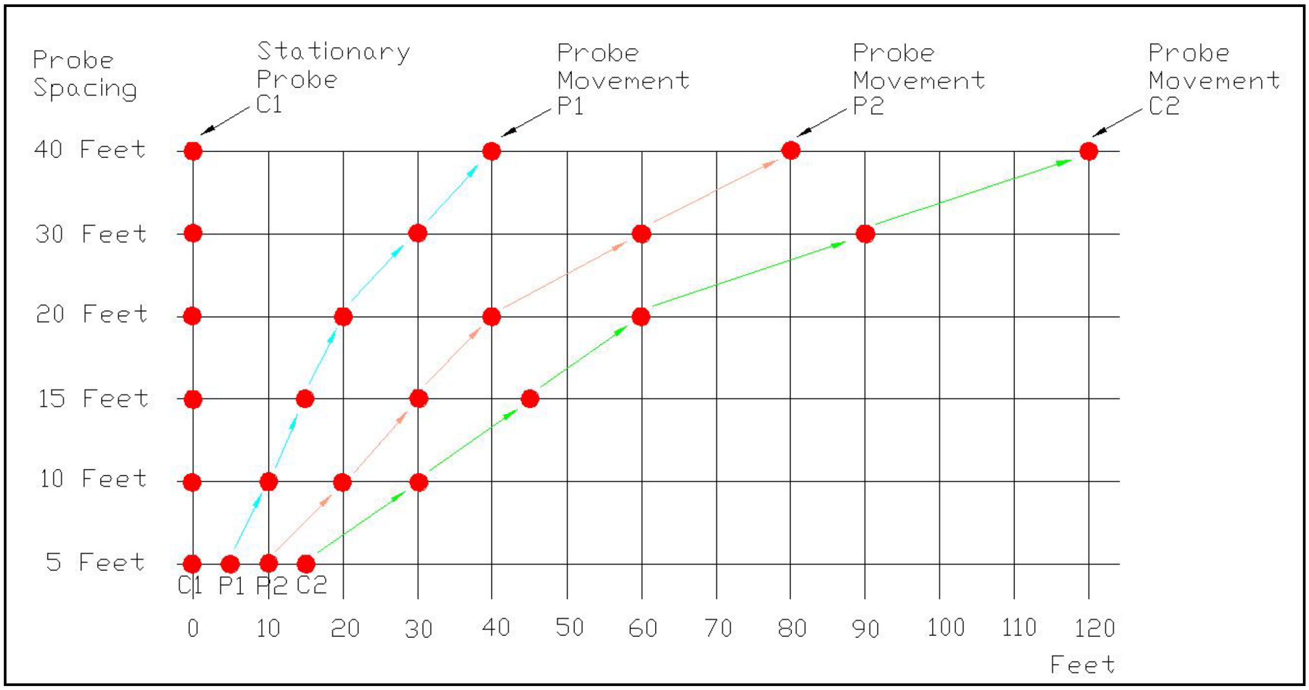



**Figure A-8: 4-Point Test Probe Movement for Different Probe Spacings (Done for Each Test Direction)**

9. Repeat steps 3 through 8 for each test location and direction.

10. Calculate the actual soil resistivity measurements (ohm-cm) for each test location and probe spacing based on the recorded test meter displayed measurements (ohm). See Section A.3.1.5 Converting 4-Pole Test Meter Displayed Value to Soil Resistivity Value.

### A.3.1.5 Converting 4-Pole Test Meter Displayed Value to Soil Resistivity Value

An automated conversion spreadsheet is available from Harris Systems Engineering for converting the test meter's displayed resistance in ohms to a soil resistivity value in either ohm-cm or ohm-m. The theory behind these calculations is discussed below.

The Wenner formula is used to convert the test meter's displayed resistance in ohms to ohm-cm or ohm-m. The difficulty of converting the value in ohms to a soil resistivity value in ohm-cm depends on the depth that the electrodes were inserted into the soil in relation to the electrode spacing.

The complete Wenner formula is:

$$\rho \text{ (ohm-cm)} = \frac{4\pi AR}{1 + \dfrac{2A}{\sqrt{(A^2 + 4B^2)}} - \dfrac{2A}{\sqrt{(4A^2 + 4B^2)}}}$$

where:

$\rho$ = Soil resistivity in ohm-cm

A = Distance between electrodes in centimeters

B = Depth of electrodes in centimeters

R = Test meter displayed resistance value in ohms

If A > 20 B, then the Wenner formula simplifies to:

$\rho$ (ohm-cm) = $2\pi AR$ where: $\rho$ = Soil resistivity in ohm-cm

A = Distance between electrodes in cm

R = Test meter displayed resistance value in ohms

B = Depth of electrodes in cm (A > 20 B)

For practicality, the test probe spacing is usually measured in feet when a test is conducted.

The simplified Wenner formula (A > 20 B) with a conversion for a probe spacing in feet is:

$\rho$ (ohm-cm) = 191.5 AR where: $\rho$ = Soil resistivity in ohm-cm

A = Distance between electrodes in feet

R = Test meter displayed resistance value in ohms

191.5 is a constant

B = Depth of electrodes in ft (A > 20 B)

To convert the soil resistivity value from ohm-cm to ohm-m, the value is divided by 100:

$$\rho \text{ (ohm-m)} = \frac{\rho \text{ (ohm-cm)}}{100}$$

### A.3.2 Soil Sampling (Miller Box Method)

If a 4-point Wenner measurement cannot be made at a site, then several soil samples may be taken and sent to a grounding consultant with the capability to perform a Miller Box test. The recommendations of the grounding consultant should be followed in obtaining the soil samples, but generally these soil samples should be:

- Obtained from multiple depths starting at three (3) feet underground.
- Obtained from multiple locations within the site.
- Sealed in an air tight container, labeled, and sent to the grounding consultant.

It should be noted that this method is much less accurate than the 4-point test method and should only be used when absolutely necessary.

# APPENDIX B GROUNDING SYSTEM RESISTANCE MEASUREMENTS

## B.1 REASONS FOR MEASURING THE GROUND SYSTEM RESISTANCE

The resistance of the site grounding system should be measured before the site equipment is attached and powered up. It is important to measure the resistance of either a newly installed grounding system or an existing grounding system to verify that it meets the design specification for the site. This initial resistance measurement also establishes a baseline against which future measurements may be compared as the grounding system ages.

The grounding system resistance should also be measured at least annually as part of the site preventive maintenance. Corrosion and/or direct lightning strikes to the site may cause degradation in the integrity and performance of the grounding system. It is important to periodically test the grounding system's performance since it determines the effectiveness of the site surge suppression devices, helps eliminate system noise, and provides for personnel safety. In areas highly prone to lightning, the ground system resistance should be measured more frequently.

## B.2 METHODS OF MEASURING GROUND SYSTEM RESISTANCE

There are two different methods for measuring the ground system resistance. One is the 3-point fall-of-potential method that is based on the *IEEE Standard 81-1983, IEEE Guide for Measuring Earth Resistivit*y, *Ground Impedance, and Earth Surface Potentials of a Ground System*. The second is the clamp-on meter method. Both methods can provide accurate resistance measurements when they are properly understood, applied and performed.

Unfortunately, with both methods it is easy to make an inaccurate test that provides "desired" results. Few ground systems are going to provide less than a 1 ohm ground unless specifically designed to do so. Test results that are too good to be true probably are. For example, a 0.7 ohm ground resistance on a rocky mountain top.

It is very important to understand how each method works and the criteria in which it is applicable. Each test method will be detailed below, but here is a brief description of when one test might be used over the other.

The 3-point fall-of-potential test requires the grounding system to be physically disconnected from the AC utility neutral. This test is most often used to make the initial ground resistance measurement on a newly installed grounding system. For an existing grounding system, the site will usually have to be shutdown, which is not always possible. The 3-point fall-of-potential test also requires test electrodes to be driven at intervals across a space of at least five times (preferably 10 times) the diameter of the widest part of the grounding system under test. A graph of the measurements across this space is required to determine the validity of the test and the system resistance.

The clamp-on meter method requires that the grounding system be connected to the AC utility neutral. The clamp-on method is the easiest method of testing the grounding system on an existing site that is in operation. It requires only one measurement and gives a digital display of the resistance. For the clamp-on meter method to provide an accurate measurement, the measurement must be made at a point where there are no neutral to ground bonds downstream of the measurement point and no metallic loop path. If a site is not designed with a single point grounding system, this may be extremely difficult if not impossible. The clamp-on test will also not work if there is excessive current on the AC neutral.

Ideally, for a new site installation, the 3-point fall-of-potential test would be done after the grounding system is installed. After the equipment is installed and the AC utility power connected, a clamp-on meter test would be made. The results of the two tests should be within 10% of each other.

If a valid 3-point fall-of-potential test or clamp-on meter test cannot be performed, then contact Harris Systems Engineering or a grounding consulting firm for assistance. Sites do exist where a valid grounding system resistance test cannot be made. In these instances the grounding system resistance may have to be approximated through a reverse engineering process. This is usually possible only on a newer ground system. A grounding consulting firm should be consulted in these cases.

### B.2.1 3-Point Fall-of-Potential Method

The 3-point fall-of-potential method uses a test meter to pass a known alternating current between the ground system under test and a test probe placed at a distance of at least five times (preferably 10 times) the ground system width away from the site. The meter measures the voltage drop between the grounding system and a second probe that is driven at specific intervals. The test meter uses Ohm’s Law to calculate a resistance value. These resistance values must be graphed to decide if a valid test was performed and to determine the actual resistance of the grounding system.

#### B.2.1.1 Theory

The three points of the 3-point fall-of-potential test consist of:

- The grounding system under test
- The current test probe placed at a distance of at least five times (preferably 10 times) the sphere of influence of the site grounding system. Evaluating the graph resulting from the test measurements is the only way to know if the distance was adequate to produce a valid test result.
- The voltage probe that is driven at equally spaced intervals along a straight line between the grounding system test point and the current probe.

During the 3-point fall-of-potential test, a constant current is passed through the earth between the current probe and the ground system under test. The voltage probe is used to measure the voltage drop through the earth between itself and the ground system under test. Knowing the constant current being injected and the measured voltage drop at the voltage probe, the test meter uses Ohm’s Law to calculate a resistance displayed in ohms.

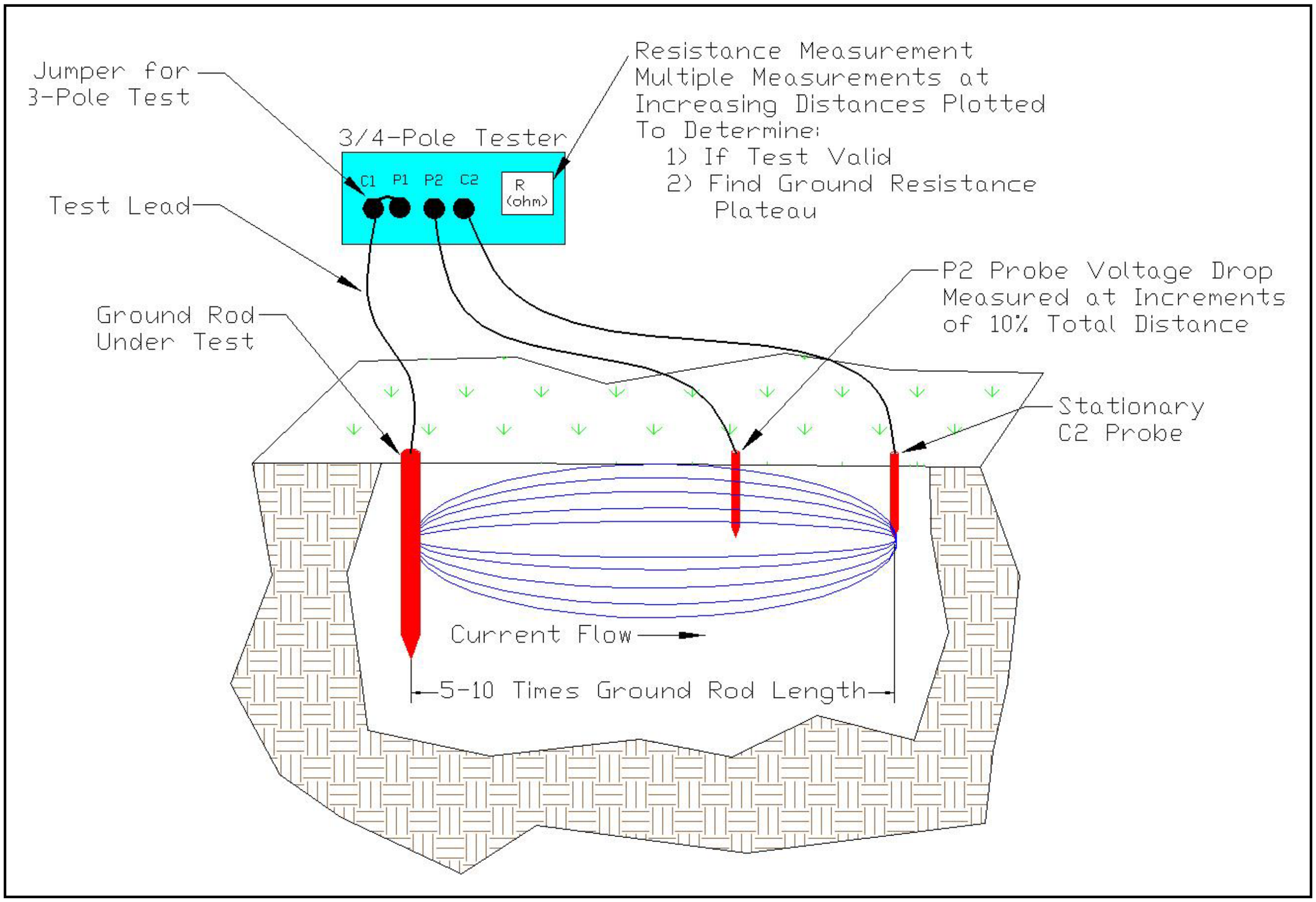



**Figure B-1: 3-Point Fall-of-Potential Test Theory**

The resistance is measured at several points along a straight line at equally spaced intervals that are approximately 10% of the total distance between the ground system under test and the current probe. These measurements are graphed to determine if a valid test was performed and to determine the resistance of the grounding system if the test was valid. See Section B.2.1.6 for details on interpreting this graph, but here a brief explanation to explain why the current probe distance and the multiple voltage probe measurements are needed.

### B.2.1.2 Effects of Sphere of Influence on Measurements

A grounding electrode has a sphere of influence in the soil around it. The radius of the effective sphere of influence of a grounding electrode is approximately equal to the electrode depth, as shown in Figure B-2.

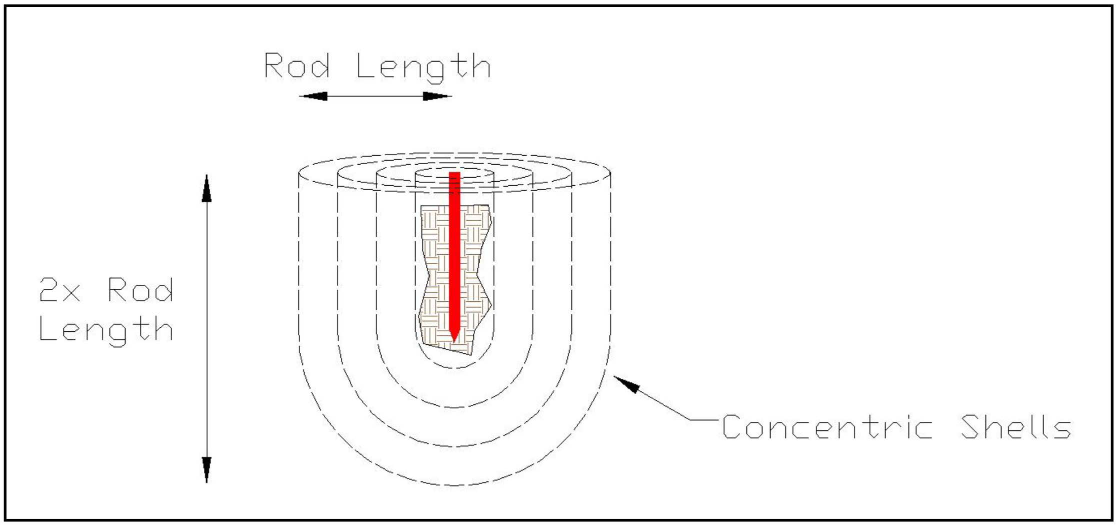



**Figure B-2: Sphere of Influence of a Single Ground Rod**

For multiple grounding electrodes bonded together, such as a site grounding system, the radius of the effective sphere of influence is equal to the distance at the widest part of the grounding system. For a site with a guyed tower, this radius would be equal to the distance between the guy wire anchors.

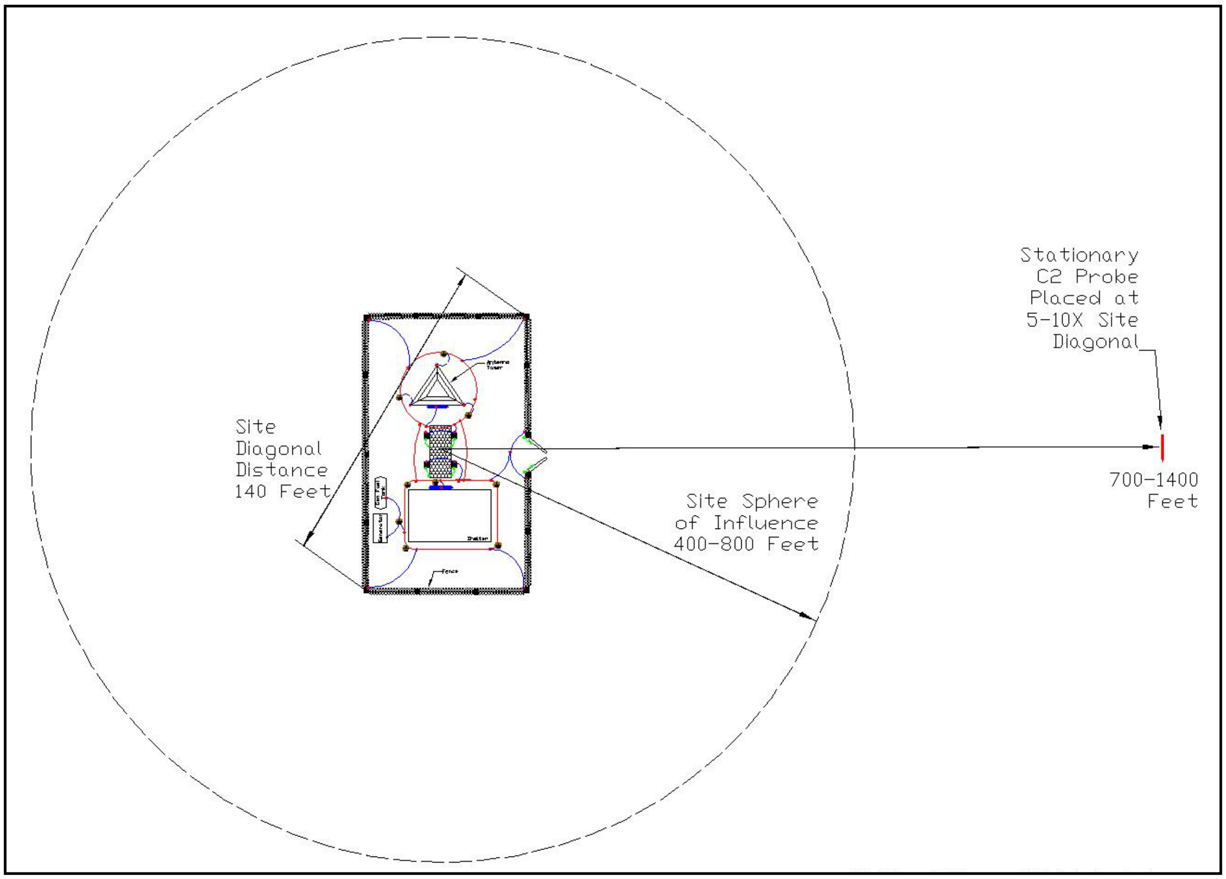



**Figure B-3: Sphere of Influence of Site Grounding Electrode System and Correct C2 Test Probe Placement**

This means that the measurements made within the grounding system's sphere of influence are affected by the grounding system electrodes. The measurements made close to the current probe are affected by its sphere of influence. The measurements somewhere in the middle should be very close to each other forming a plateau and be very close to the actual resistance of the grounding system under test, as indicated in Figure B-4.

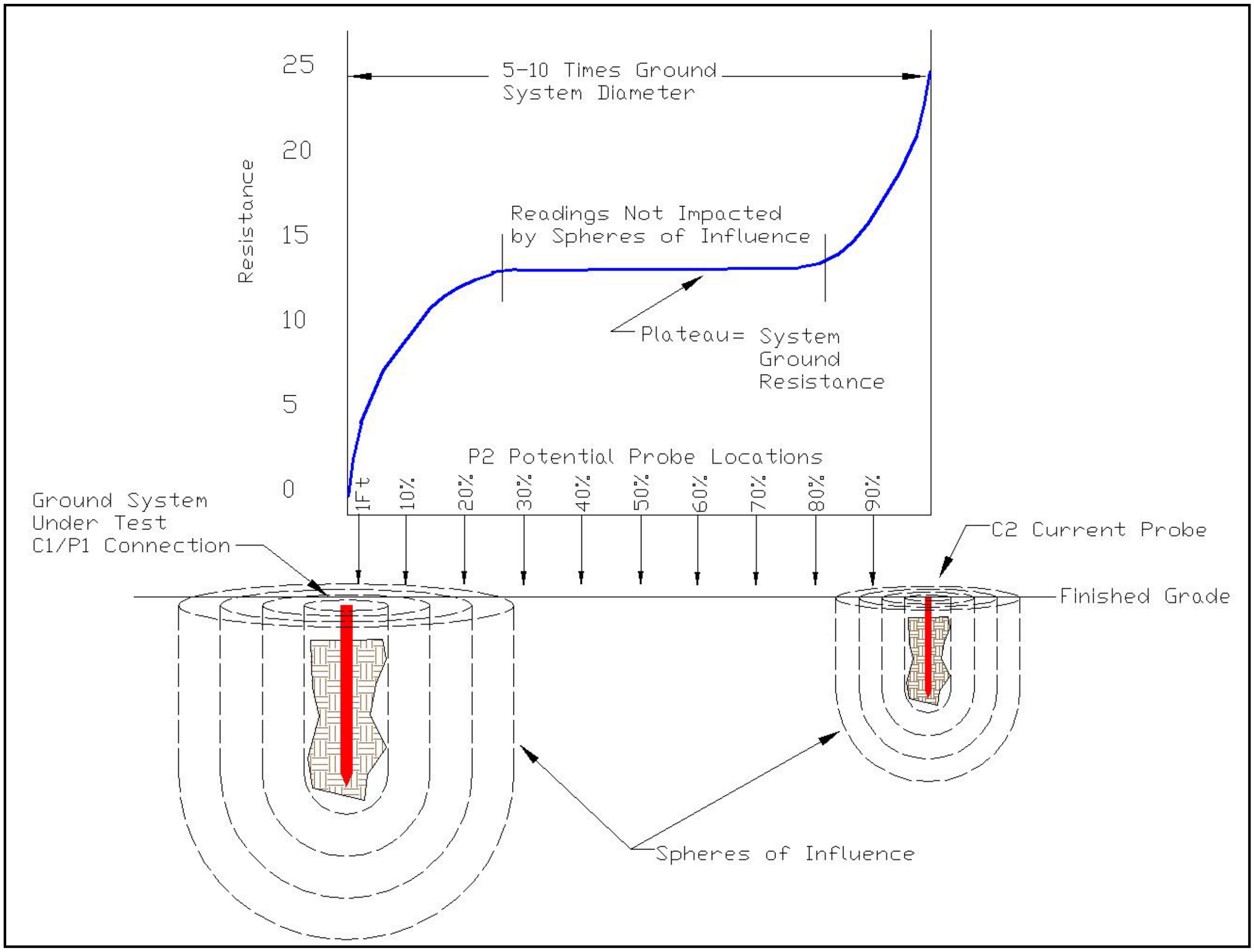



**Figure B-4: Valid 3-Point Fall-of-Potential Test Measurements Graph**

If the graph of the measurements does not have the plateau as seen in Figure B-4, then the test was invalid. Most often this is caused by the current probe (C2) not being placed far enough away from C1/P1 to be outside the grounding system's sphere of influence, as shown in Figure B-5 and the graph in Figure B-6.

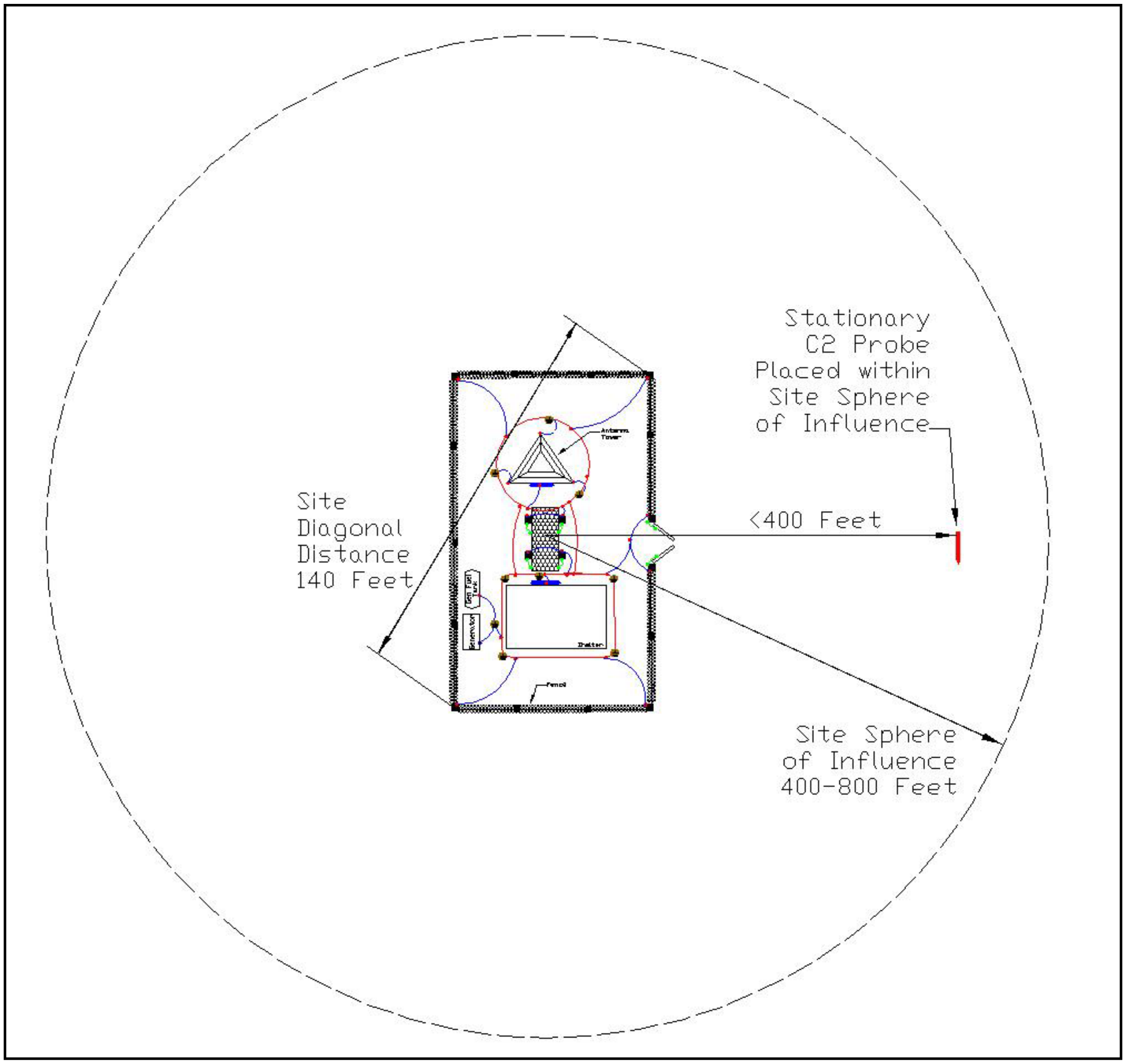



**Figure B-5: Sphere of Influence of Site Grounding Electrode System (C2 Test Probe Placed within Ground System's Sphere of Influence)**

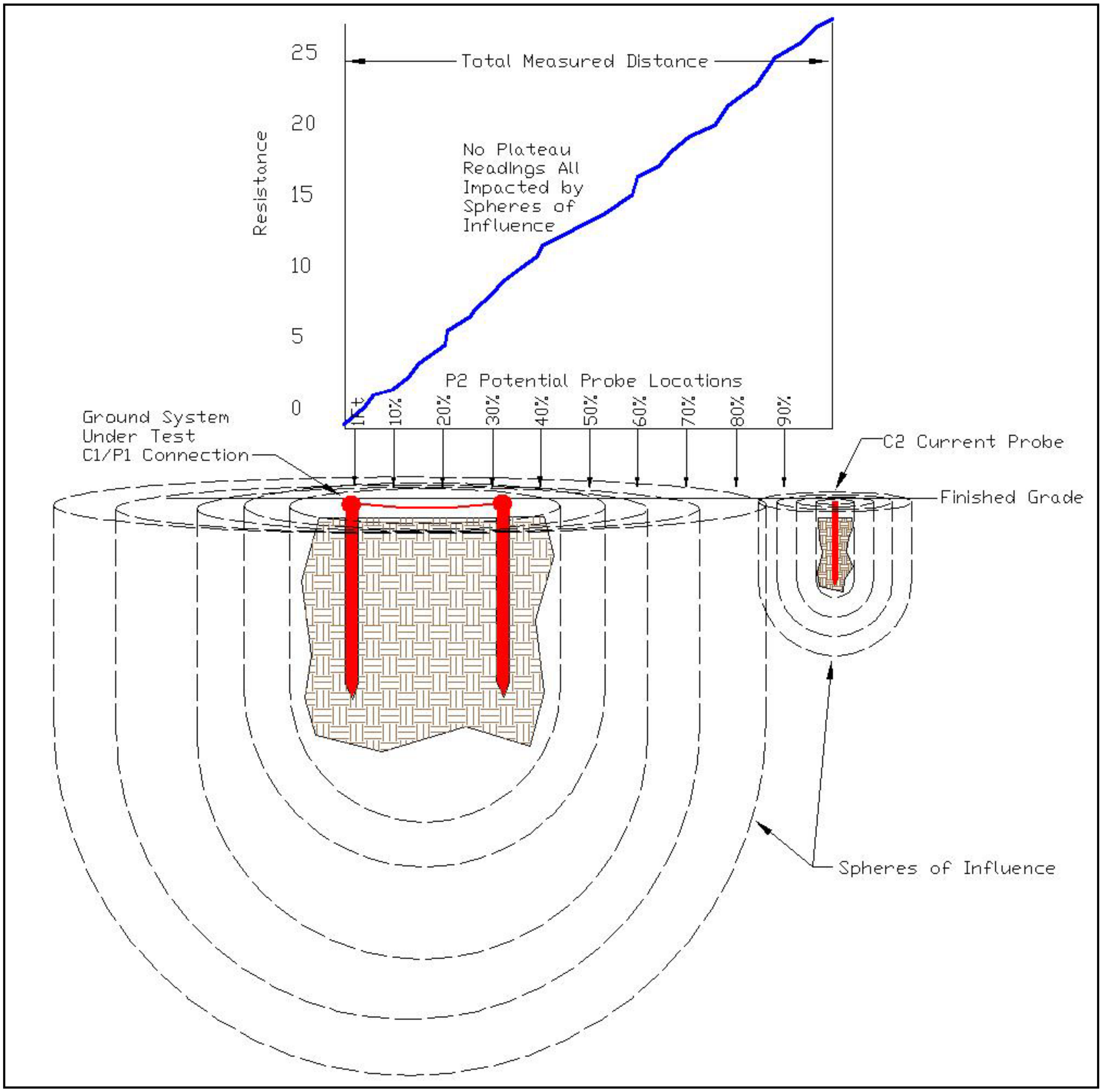



**Figure B-6: Invalid 3-Point Fall-of-Potential Test Measurements Graph (C2 Test Probe Placed within Ground System's Sphere of Influence)**

If the grounding system is not disconnected from the AC utility neutral, then the "grounding system" being tested includes the intended ground system and the almost infinite AC utility grounding at every utility pole. Since the current probe can never be placed outside the sphere of influence of all the AC utility grounds, a valid test can never be made with this method. The AC utility ground would also be measured in parallel to the intended ground system resulting in very low resistance measurements, as shown in Figure B-7.

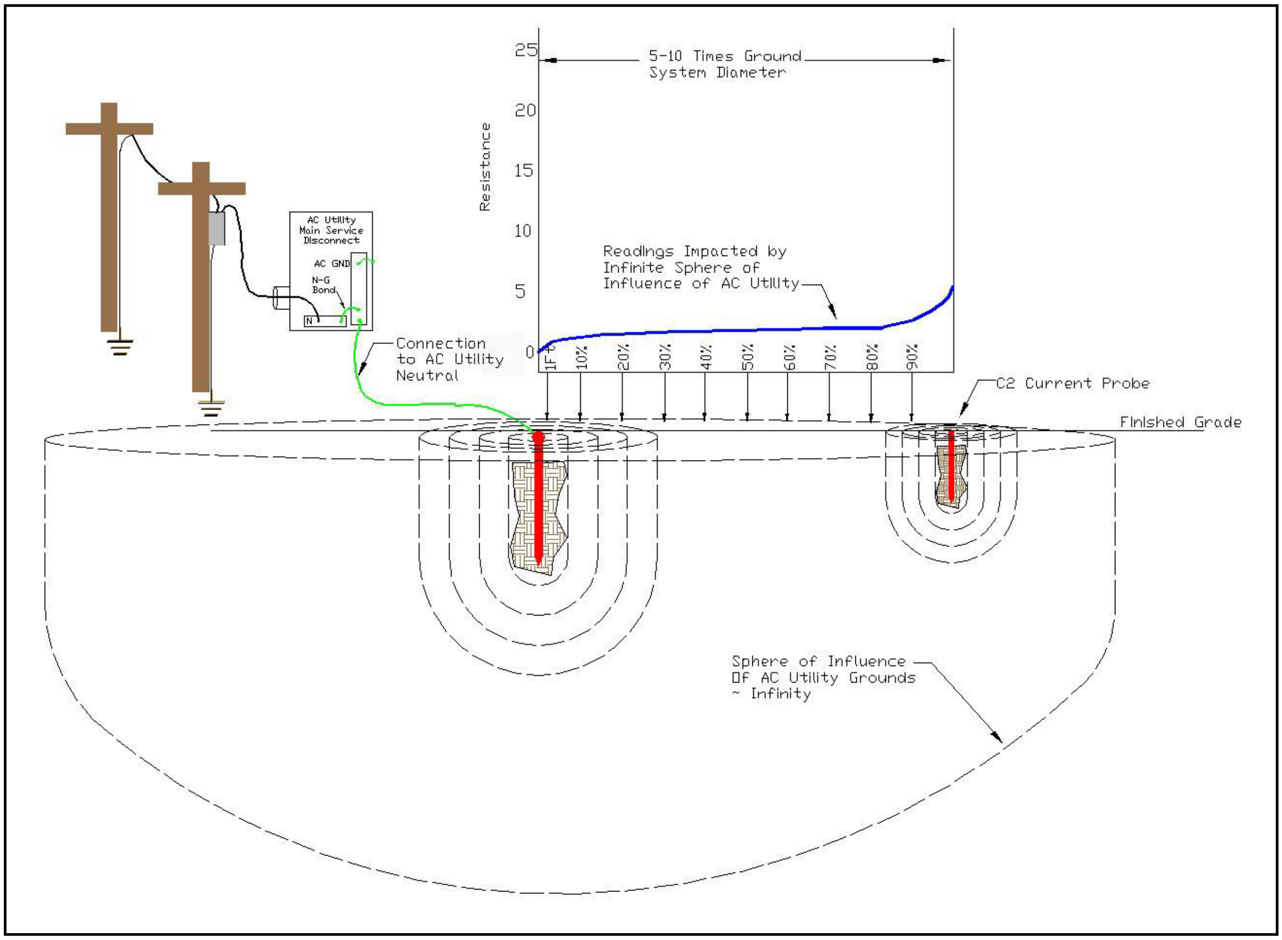



**Figure B-7: Invalid 3-Point Fall-of-Potential Test Measurements Graph (Ground System Connected to AC Utility Neutral)**

### B.2.1.3 Equipment Required

- A 3/4-pole digital ground resistance meter with an up-to-date calibration and an operation manual (Contact Harris Systems Engineering for specific testing product information.)
- Two metallic test probes at least 18 inches long (In sandy soil, longer test probes may be required to obtain a measurement.)
- Three lengths of insulated conductor with clips for connecting the 3/4-pole meter to the test probes and ground system under test
- Tape measure at least 100 feet long
- Hammer for driving test probes

- Safety glasses, rubber gloves, rubber-soled shoes, and/or rubber safety mat
- Copy of site grounding plan
- Test sheet for recording measurements and graphing results

#### B.2.1.4 3-Point Fall-of-Potential Testing Methodology

The grounding system under test must be electrically isolated from the AC utility neutral, all telco connections, building steel, water pipes, etc. for the test to be valid.

If an additional grounding system was added to an existing site or multiple-occupant site, this requires that either the grounding system is tested prior to being bonded to the existing site grounding systems or that all AC utility neutrals present at the site must be electrically isolated.

At an existing or multi-occupant site, which portion of the grounding system was tested should be noted on the testing form. This information should also be accounted for in measuring sphere of influence. If deep well grounding is utilized, the sphere of influence of the deep well may be greater than that of the site diameter. The larger sphere of influence should be used.

The test meter connection point to the grounding system should be at the External Ground Bar (EGB) or Tower Ground Bar (TGB) to allow for a good connection to the site's grounding system. If distance is limited for the C2 test probe to be located far away from the site, a tower ground connection on an outer edge of the site may be used, if a connection can be made.

Measurements made in wet soil without standing water are valid since surface moisture rarely reaches more than 18 inches under the surface. Underground metallic objects that run parallel to a test measurement may distort test readings. For this reason, taking a second set of measurements in a different direction is highly recommended, especially if underground metallic objects are present.

Making measurements directly underneath overhead power lines should be avoided.

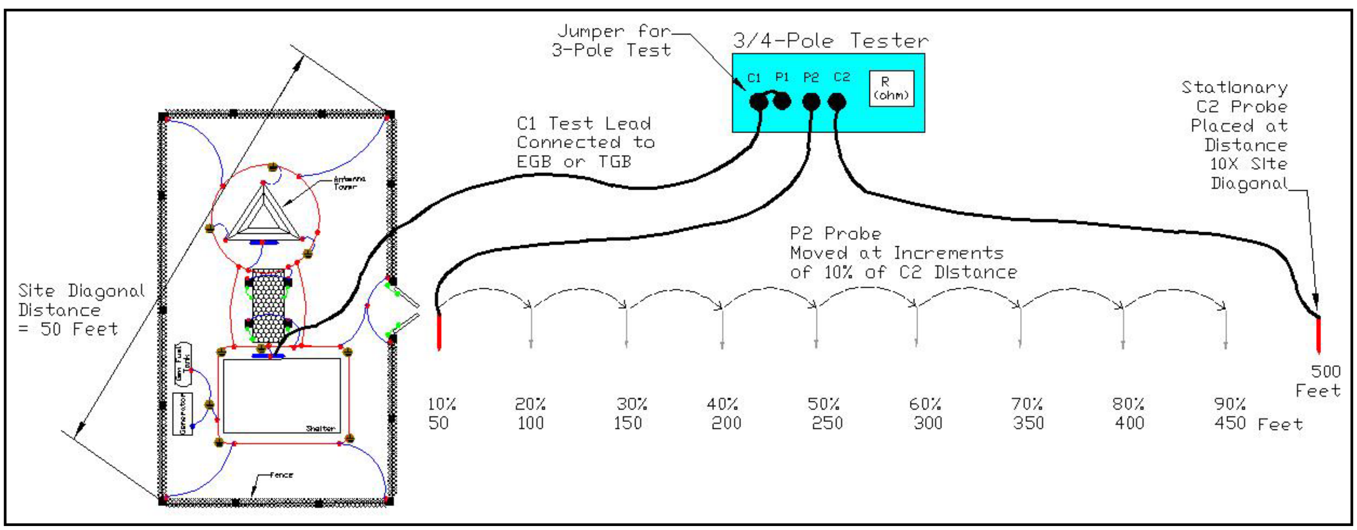



**Figure B-8: 3-Point Fall-of-Potential Test Methodology**

### B.2.1.5 3-Point Fall-of-Potential Testing Safety

**The grounding system must be electrically isolated from the AC utility neutral for the test to be valid.** For an operating site or a multi-occupant site, permission must be obtained to shutdown equipment to physically disconnect from the AC utility neutral.

If attempting to run the site on battery or generator backup power during testing, extreme care should be taken. A fault on the power system could cause unexpected current to flow on the ground system while the test is in progress. Rubber gloves, rubber-soled shoes, and rubber safety mats should be utilized during testing if the site is not fully powered down.

3-point fall-of-potential ground system measurements should never be conducted when there is threat of thunderstorms in the immediate area.

**Only qualified personnel should disconnect the ground from the AC neutral. The ground should be checked for current prior to disconnection. The ground should never be disconnected from a live circuit. Severe injury or death could result.**

There must be access to soil for a distance of at least five times (preferably 10 times) the widest distance of the grounding system under test. Care should be taken to obtain permissions to make measurements if this distance extends beyond the site property boundaries. Care should also be taken to verify there are no hazards present within this distance, such as roadways, etc.

### B.2.1.6 3-Point Fall-of-Potential Test Procedure

The grounding system must be electrically isolated from the AC utility neutral for the test to be valid. Otherwise, the resistance measured is actually that of the grounding system under test and all of the AC utility grounds in parallel which results in a very low reading.

The following test procedure is to be used as a guideline. The user’s manual for the particular test meter being used should be referred to for detailed operating instructions.

NOTE

The grounding system must be disconnected from the AC utility neutral for the 3-point fall-of-potential test to be valid.

1. De-energize the main AC electrical system after obtaining permission.

2. Isolate the grounding system under test from the AC utility neutral, all telco connections, and any other supplemental grounds such as building steel, water pipes, etc.

3. Identify the direction in which the test is going to be conducted and the test meter connection point on the grounding system under test.

4. Connect the metal strip between the first current terminal and the first voltage terminal on the test meter. This connection is used to convert some 4-pole test meters to a 3-pole test meter.

5. Connect an insulated conductor between the first current terminal and the ground system under test.

6. Place the current probe in the ground at a measured distance at least five times (preferably 10 times) the diameter of the sphere of influence of the grounding system under test. This probe should be driven at least 12 inches into the ground.

7. Connect an insulated conductor between the current test probe and the test meter's second current terminal.

   Enter this current test probe distance on the test sheet. (If using the automated 3-point fall-of-potential spreadsheet available from Harris systems engineering, entering this current probe distance will result in the various voltage probe distances being calculated automatically.)

8. Starting at the end closest to the ground system under test, place the voltage test probe in the ground along a straight line with the current probe using the tape measure as a guide. The first location for the voltage test probe should be approximately 2% of the distance between the C2 current test probe and the ground system connection point. The voltage test probe should be inserted into the ground to the same depth as the current test probe.

9. Connect an insulated conductor between the voltage test probe and the test meter's second voltage terminal. See Figure B-8 for details.

10. Set the 3-pole test meter to the lowest test current setting and the highest resistance range.

11. Press the test button and read the test meter's digital display. If the display shows an error, adjust the resistance range to the lowest setting that provides a stable reading without error indications. If the adjusting the resistance range does not eliminate the error, increase the test current setting and start again. When a measurement is shown, allow the reading to stabilize.

**The meter's test current poses a shock hazard if the test probes or terminals are touched while the meter's test button is pushed.**

   If the reading is unstable or displays an error indication, check the connections and ensure that the resistance range is at the highest setting. The resistance range and test current settings may be adjusted until a combination is found that provides a stable reading without error indications. Some meters may have a separate error indication if there is excessive electrode resistance and/or transient noise.

   In very high resistivity soil, water may be poured around the test probes to achieve a better electrical connection without influencing the test results. If adding water does not help, longer test probes may have to be used. Again, they should be driven to equal depths.

12. Record the voltage test probe distance and the test meter reading on the test sheet (available in Section C.4). On some test meters any readings on the 2K ohm and 20K ohm scales must be multiplied by 1000 to obtain the true reading. See the test meter operating manual to verify if this is necessary or not.

13. Repeat steps 9 through 12 for the different voltage test probe distances along a straight line between the ground system connection point and the current test probe. These distances should be approximately 2%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 98% of the C2 probe distance moving away from the ground system under test. (If using the automated 3-point fall-of-potential spreadsheet, available from Harris Systems Engineering, entering the first current probe distance will result in the spreadsheet automatically calculating the other voltage probe distances.)

14. Graph the above measurements to see if the test was valid. If test was valid, the plateau on the graph represents the resistance of the ground system under test. See Figure B-4. An automated spreadsheet for this purpose is available from Harris Systems Engineering.

### B.2.1.7 Evaluating 3-Point Fall-of-Potential Test Measurements

An automated 3-point fall-of-potential test spreadsheet is available from Harris systems engineering that calculates the voltage probe distances based on the current probe distance. This spreadsheet then graphs the measurements for easy evaluation. The measured resistance values may also be graphed manually using the test sheet in Section C.4.

Except for the first voltage test probe distance near the ground system under test, the other voltage test probe distances are equally spaced at intervals of 10% of the total distance from the ground system connection point to the current test probe. The first voltage test probe location is 2% of the total distance from the ground system connection point to the current test probe.

The test meter resistance measurements are plotted on a graph. The voltage test probe distances, starting with the ground connection point at zero are located along the x-axis. Measured resistance is located along the y-axis.

If the test is valid, there should be a plateau or "flat area" on the graph at approximately 62% of the total distance, as shown in Figure B-9. The resistance at this plateau is the resistance of the grounding system under test.

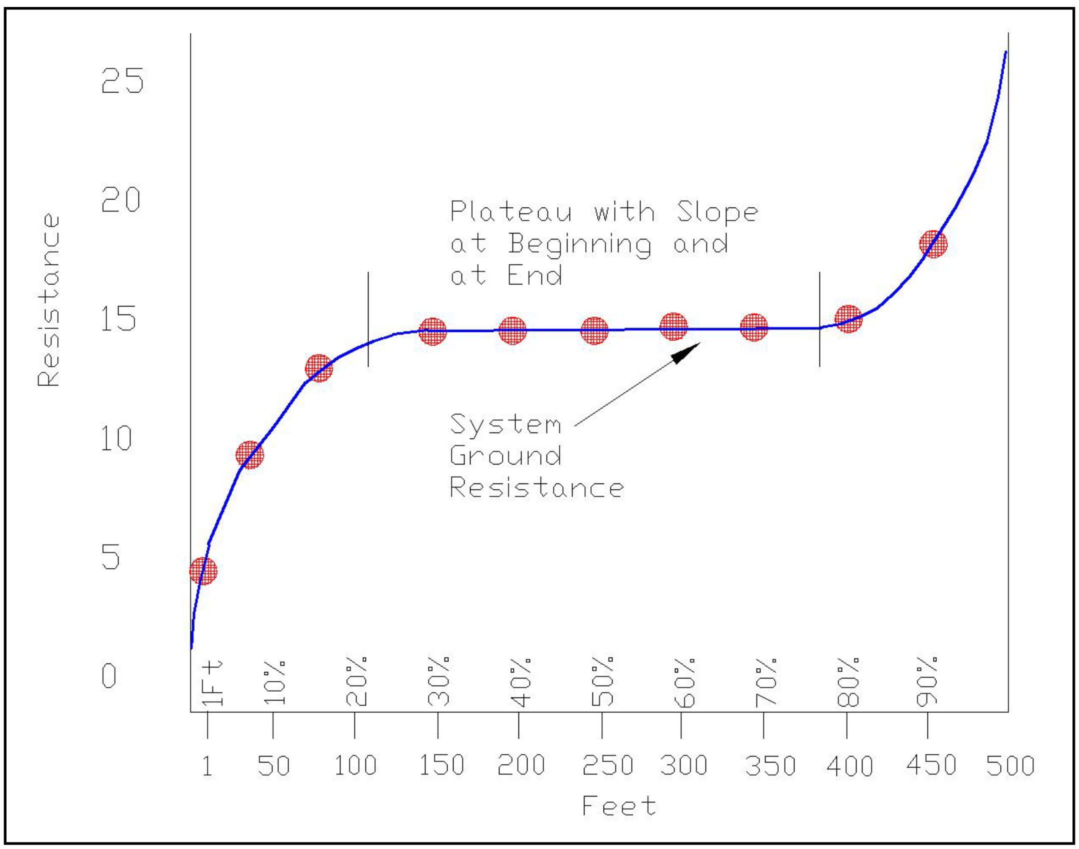



**Figure B-9: Valid 3-Point Fall-of-Potential Test Graph**

If there is no plateau, then the test is considered invalid due to the current test probe being within the sphere of influence of the grounding system, as indicated in Figure B-10.

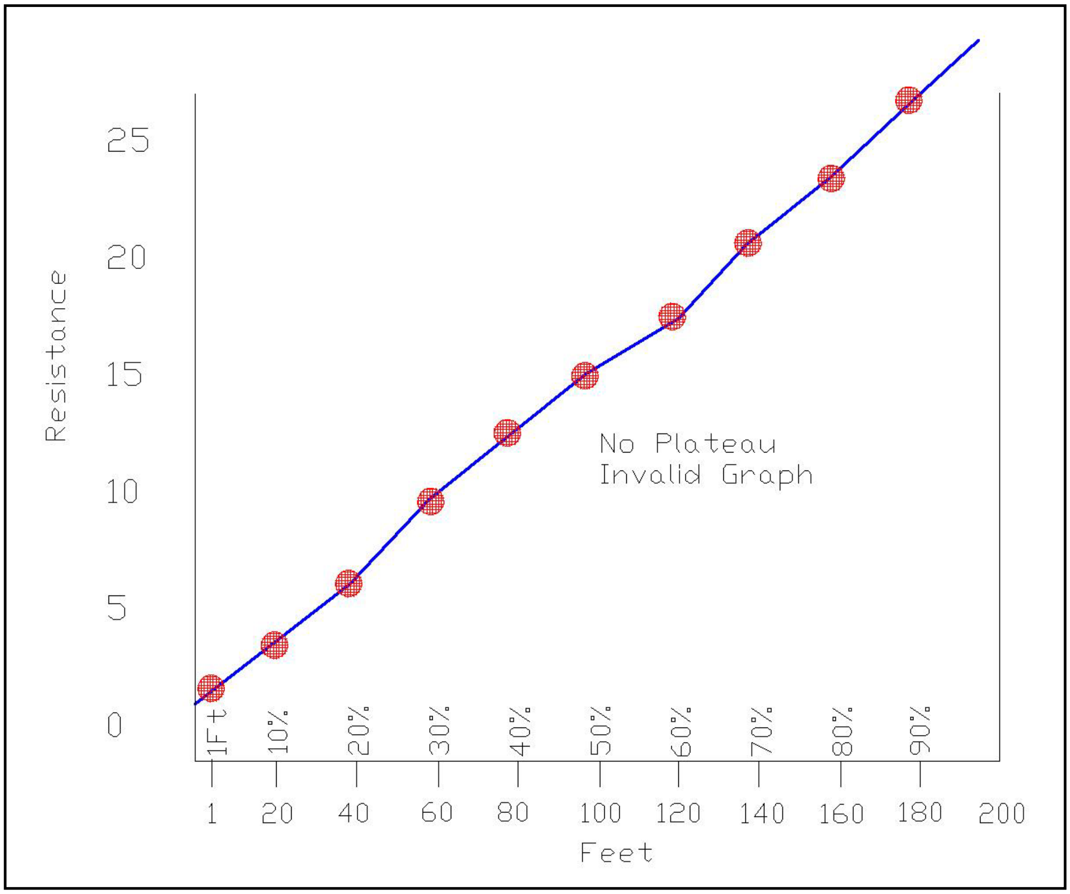



**Figure B-10: Invalid 3-Point Fall-of-Potential Test Graph (Current test probe not outside sphere of influence of grounding system under test.)**

If the plateau is very flat, as shown in Figure B-11, from the beginning with a very low resistance, then the test is considered invalid either because there was a connection to the AC neutral still present or the equipment was still energized.

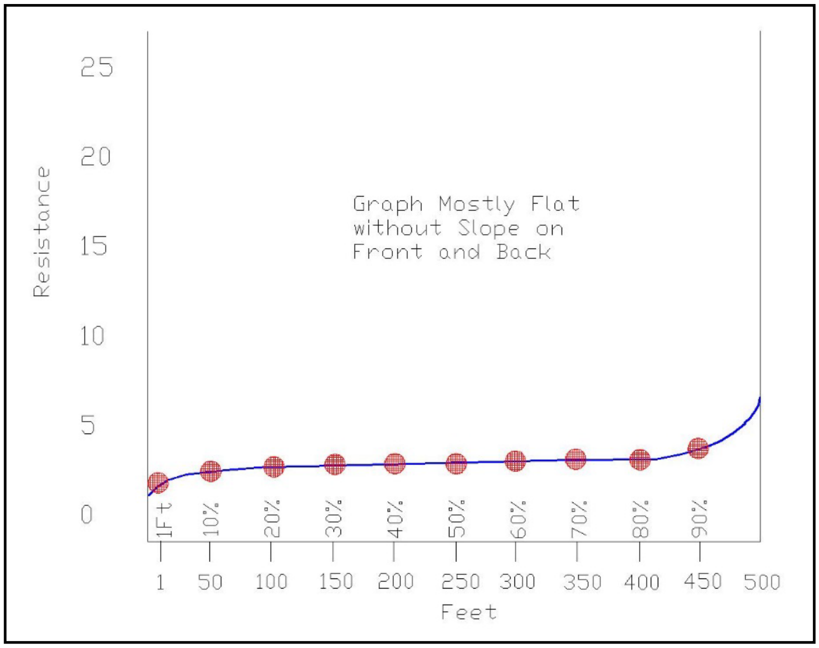



**Figure B-11: Invalid 3-Point Fall-of-Potential Test Graph (AC utility neutral connection to grounding system under test.)**

If the graph has an incline up to a plateau, but there is not a second incline near the current test probe end, as shown in Figure B-12, the test may be questionable due to the possibly that the test was conducted parallel to a nearby underground metallic pipe or conductor. An additional test should be made in a different direction.

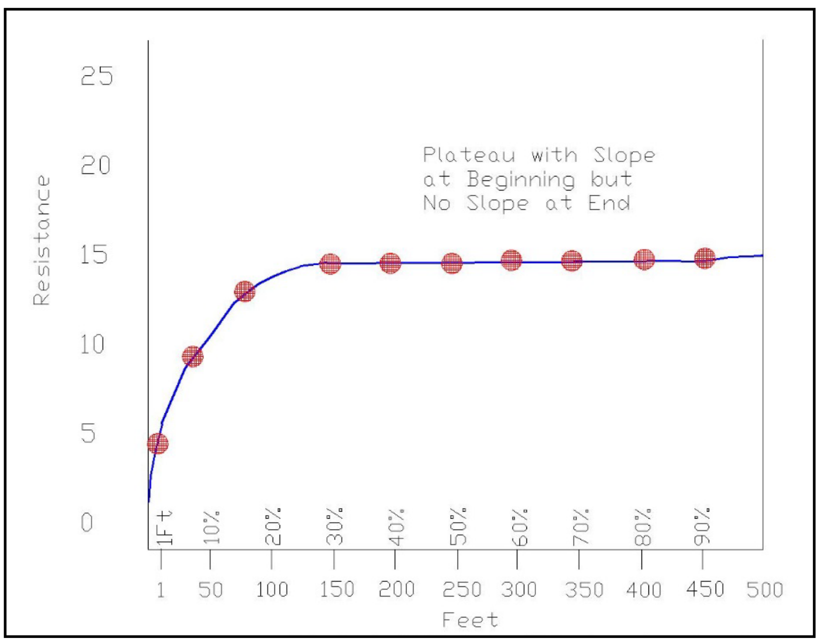



**Figure B-12: Questionable 3-Point Fall-of-Potential Test Graph (No slope after plateau.)**

### B.2.2 Clamp-On Meter Method

The clamp-on meter method has many advantages over the 3-point fall-of-potential test method. There is no need to disconnect from the AC utility neutral. If fact, a connection to the AC utility neutral is required for the clamp-on meter method. It is safer since the meter's jaws are clamped around the conductor and no electrical connection is made. It is also much easier since it provides a one-step measurement of the ground system resistance.

Unfortunately, like the 3-point fall-of-potential test, it is easier to make a bad measurement that looks good than to make a good measurement. Care must be taken to fully understand the theory behind the clamp-on meter method to choose the correct location at which to make a valid measurement.

#### B.2.2.1 Theory

The grounding system under test must be connected to the AC utility neutral. The clamp-on meter method measures resistance of grounding system under test in parallel with all of the utility ground resistances that it "sees" out the AC utility neutral. Since there are many other grounding points on the AC utility neutral, all in parallel, the effective resistance from the utility ground is virtually zero.

The meter induces a high frequency signal with a small fixed voltage into the grounding system. It then measures the current on the return path using two individually shielded magnetic coils. Since the effective resistance of the utility ground seen through the neutral is virtually zero, the measurement made reflects the site's grounding system resistance.

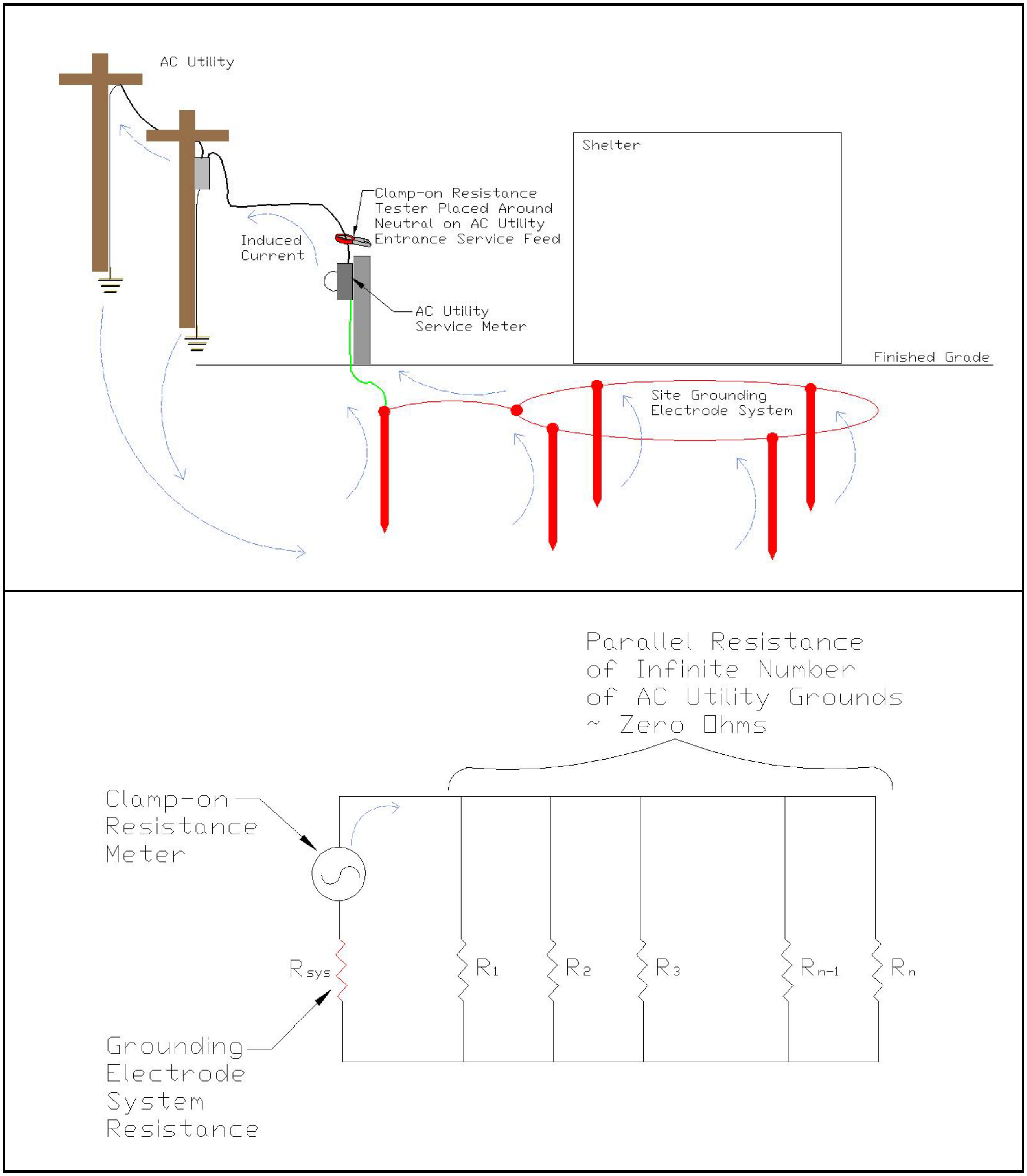



**Figure B-13: Clamp-On Test Meter Theory**

### B.2.2.2 Equipment Required

- Clamp-On ground resistance meter with an up-to-date calibration and an operation manual. (Contact Harris Systems Engineering for specific testing product information.)
- Rubber gloves and rubber-soled shoes or rubber safety mat.

### B.2.2.3 Clamp-On Meter Testing Methodology

The grounding system under test must be electrically connected to the AC utility neutral for the test to be valid. There cannot be excessive current (> 5 amps) or noise (>50 volts) on the AC utility neutral.

NOTE

The site equipment may have to be put on backup power or powered down if no backup power is available. This is to be certain there is not excessive current on the AC neutral due to unbalanced loads. This requires coordination with the site owner and users.

Finding the correct location to make a clamp-on meter test is the key to making a valid measurement. The location must have only one connection between the entire ground system and the AC utility neutral. The path for the induced current flow must go through soil and not have a complete metallic path.

Attention to how the site AC utility power entrance and grounding are configured can allow for easier site ground system clamp-on resistance testing. The most certain location to make a valid clamp-on ground resistance measurement is on the utility power cable entrance on the incoming AC utility neutral conductor.

**Shock hazard exists. Only a qualified electrician should open the AC utility service entrance with proper permissions from the AC utility service provider.**

If the entire site, including the AC utility entrance, has a single attachment point to the ground system, it may be possible to make a valid measurement on the grounding electrode conductor connected to the MGB. This requires that the entire site grounding system and all bonded electrodes are “downstream” of the measurement location. A full understanding the site grounding connections to the AC service is required to be certain this is a valid location.

WARNING

**All site grounding and electrical installation must comply with all applicable National Electrical Codes (NEC) and local codes. If a conflict exists between this document and any of these applicable codes, then those codes take precedence over the guidelines in this document.**

NOTE

The most certain location to make a valid measurement is on the incoming AC utility service neutral conductor.

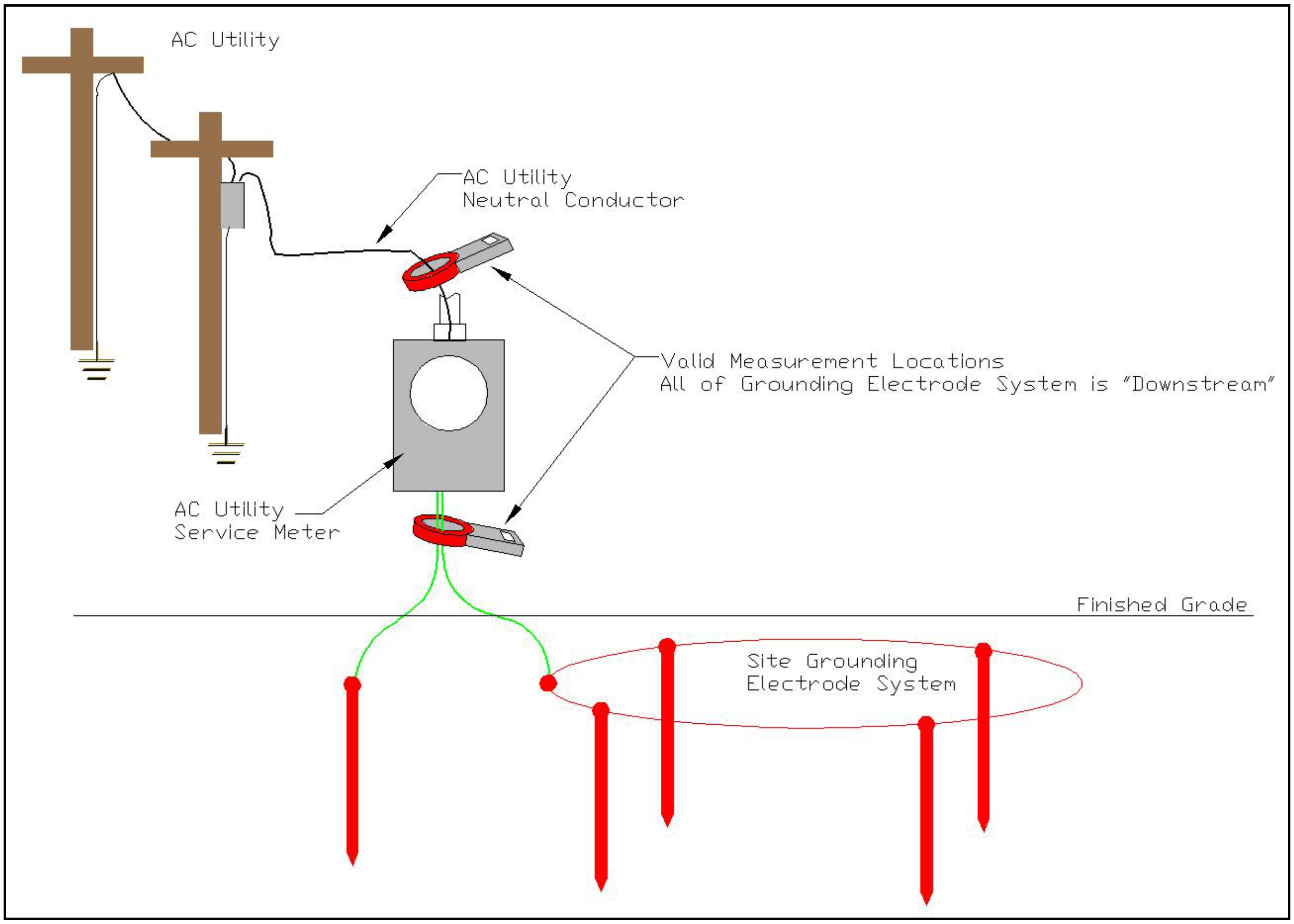



**Figure B-14: Valid Clamp-On Test Meter Measurement Location**


**Figure B-15: Valid Clamp-On Test Meter Measurement Location**

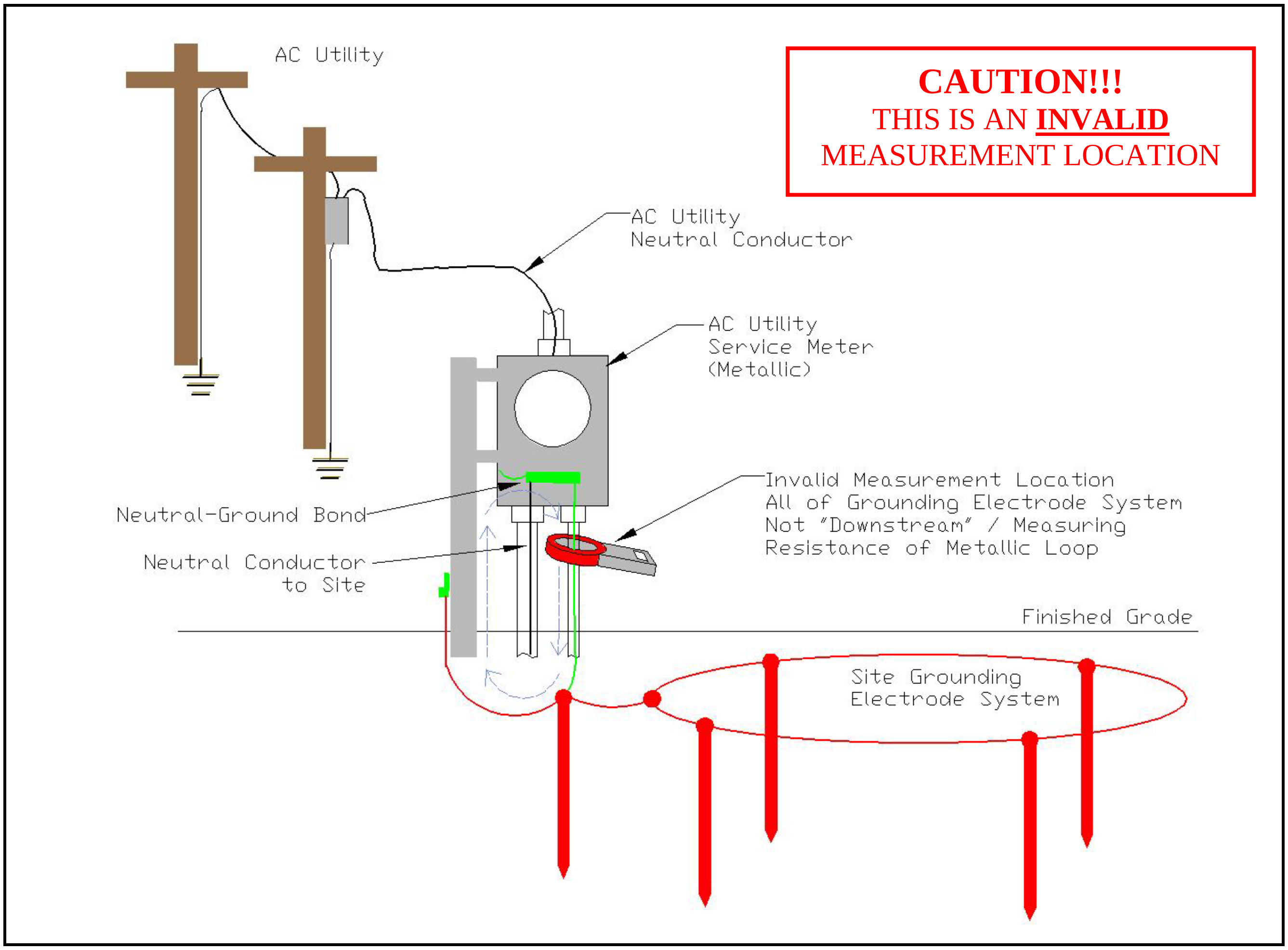



**Figure B-16: Invalid Clamp-On Test Meter Measurement Location – All of Grounding System Not "Downstream"**

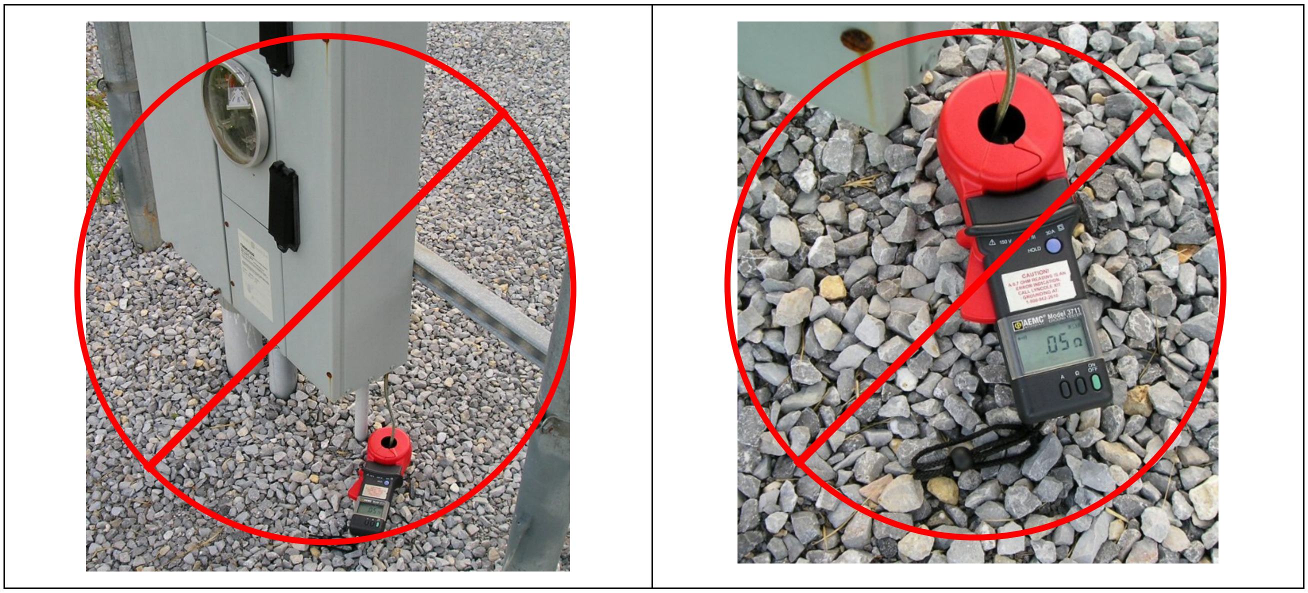


**Figure B-17: Invalid Clamp-On Test Meter Measurement Location Due to Complete Metallic Path**

Care must be taken to consider the “unseen” metallic paths, such as underground metallic grounding conductors and metallic conduit. Clamping the meter onto a tower leg grounding conductor or a fence corner post grounding conductor, although it does verify electrical continuity with the grounding system, only results in the resistance measurement of a metallic loop. (See Section B.3, Ground System Continuity Measurements for information on using a clamp-on ground test meter to verify the mechanical integrity of a grounding connection.)

The clamp-on meter measurement location must be upstream of all connections to the site grounding system. Otherwise, the measured resistance is not valid since the other parallel resistance is not virtually zero.

If the site was not designed and installed with a true single point ground scheme, then the only valid location at which to make a clamp-on meter measurement may be at the service entrance where the incoming neutral is grounded. The correct measurement location would be on the service side of the neutral line, before the neutral-to-ground bond, insuring that there are no additional neutral-to-ground bonds upstream of the measurement location. Measurements at the service entrance should only be made by authorized and qualified personnel.

### B.2.2.4 Clamp-On Meter Test Procedure

The grounding system must be connected to the AC utility neutral for the clamp-on test method to be used. The resistance measured is actually measured in parallel to the resistance of all of the AC utility grounds.

The following test procedure is to be used as a guideline. The user’s manual for the particular test meter being used should be referred to for detailed operating instructions.

NOTE

> The grounding system must be connected to the AC utility neutral for the clamp-on test to be valid.

1. Determine the correct measuring location. (See Section B.2.2.3 Clamp-On Meter Testing Methodology for details.)

2. Check that the clamp-on meter jaws are properly aligned and free from dirt.

3. Check the calibration of the clamp-on meter with the calibration loop supplied by the meter’s manufacturer. Verify that the reading is within the tolerances stated in the user’s manual.

4. Select the clamp-on meter’s current setting. Clamp the test meter’s jaws around the grounding conductor at the selected test location and make a current measurement. If the ground current is greater than 5 amps or the noise exceeds 50 volts, a ground resistance measurement cannot be taken. Care should be taken in making this measurement since excessive current may make the test meter vibrate. Excessive current on the site neutral/ground should be reported to the site owner for maintenance.

   (Note: If the site has a backup power system, it may be possible to switch the site equipment to this backup power system to decrease the current or noise on the ground. This switch should only be made with proper permission.)

5. Select the clamp-on meter's resistance setting. Clamp the test meter's jaws around the grounding conductor at the selected test location and make a resistance measurement.

   (Note: A reading of less than 1 ohm, specifically 0.7 ohms or 0.4 ohms, is generally an indication of an invalid measurement location. See Section B.2.2.5, Evaluating Clamp-On Meter Test Results.)

If the resistance measurement result is valid, record the date, test location, test result, and test conditions (for example, the site had to be put on backup power) on the test sheet.

### B.2.2.5 Evaluating Clamp-On Meter Test Results

The clamp-on test meter displays the actual resistance measurement. No additional measurements, calculations, or graphing are necessary. However, the results should be examined to determine if a valid test was performed.

A reading of less than 1 ohm, specifically 0.7 ohms or 0.4 ohms, is generally an indication of an invalid measurement location. More than likely, a metallic loop of some sort was measured. A 1 ohm grounding system rarely occurs unless it was designed to that specification. The measurement location should be reevaluated.

An overload reading may indicate an open ground conductor or high resistance connections in the grounding system.

## B.3 METHODS OF VERIFYING GROUND SYSTEM INTEGRITY

The clamp-on resistance meter can be used to verify continuity and check for high resistance connections in the grounding system. Clamping the meter onto a tower grounding conductor should provide a reading of less than 1 ohm since it is measuring a metallic loop. An overload reading would indicate that there is an open ground conductor. A reading higher than 1 ohm would indicate a high resistance connection in the grounding system.

It is highly recommended to use this method of verifying the ground system integrity after the initial installation, during site preventive maintenance, and after a lighting strike at the site. This is especially important for each of the tower grounding conductors and all external ground bars that may shunt large surge currents.

If a ground test well is available at the site, clamping the meter around that ground rod does not provide the resistance of the whole grounding system or even that grounding electrode. The reading does provide a measurement that can be taken yearly and compared against past readings to look for degradation of the ground system integrity. This is especially important if it is not possible to easily measure the actual site grounding system resistance.

# APPENDIX C SITE GROUNDING DOCUMENTATION AND INSPECTION

## C.1 SITE GROUNDING DRAWING INFORMATION

When designing the ground system, an initial site grounding installation drawing is developed. The contractor should follow this drawing when installing the grounding system.

These initial design drawings should be marked up during installation with any changes to provide final inputs for the system as-built drawing package. Sample site grounding drawings are attached at the end of this manual.

WARNING

**All lightning and surge protection measures included in a Harris Corporation RF system are submitted as a part of the overall system specification. This specification takes into account the radio installation, equipment to be protected and local conditions. All requirements covered in this specification must be met, unless a specific, written waiver is provided by the customer and agreed to by Harris.**

### C.1.1 Exterior Site Grounding

**The exterior site grounding drawing/drawings should show:**

- All major site structures/components and their orientation within the site boundaries.
- The location of all ground rods along with all of their buried interconnecting conductors.
- The ground rod specification for the type, length, and diameter of all ground rods.
- Location and connection detail for tower ground bar (TGB), exterior ground bar (EGB) or RF entry port, and interior shelter master ground bar (MGB).
- Location of all bonding stubs from the buried grounding system to an above-grade object.
- Detail of the tower leg bonding.
- Fence/gate post bonding and gate to gate post jumpers.
- Ice bridge bonding.
- The size of all buried interconnecting conductors, their routing, and their depth.
- The type of bond (type of exothermic weld or high-compression irreversible crimp connection) to be made at each connection point.
- Location of AC meter entrance and grounding (AC entrance ground rod must be bonded to rest of ground system.).

### C.1.2 Tower/Antenna/RF Transmission Lines

In addition to the antenna height and descriptions, the antenna/RF transmission line drawing should show the locations and bonding detail of the RF transmission line ground kits. It should also show the types of RF surge suppression used and detail on the RF entry port capacity and usage.

### C.1.3 Interior Site Grounding

**The interior site grounding drawing/drawings should show:**

- AC power one-line diagram showing location and detail of all disconnects, breaker/switches, ATS, AC panel-type surge suppression devices, UPS or DC battery banks, power panels, and location of neutral-to-ground bond.
- The location of MGB and any SGB's and their interconnection
- Ground bus conductor home runs and branch routing
- Conductor size and connection detail of all interior grounding conductors
- AC and DC power grounding
- Location of telco entrance and primary surge suppression devices
- Horseshoe halo ground bus conductor routing

## C.2 SITE GROUNDING PICTURES

At the completion of site installation and before filling in any trenches, we recommend taking digital pictures of the various site grounding elements. These pictures may be archived as part of the system documentation. Suggested pictures include:

### C.2.1 Recommended External Grounding Pictures

- External site overall
- Tower leg/base ground connection (each leg)
- Guy anchor grounding (each one if applicable)
- Tower ground bar (overall showing ground bar, RF transmission line ground kits, and connections to ground ring)
- Tower ground bar (detail)
- Tower cable ladder
- Locations of ground kits and any additional tower ground bars above base
- Ice Bridge/Cable support grounding

- RF entry port (overall showing RF entry port, its connection to ground, and RF cables and ground kits)
- External ground bar under RF entry port (if present)
- MGB ground connection exiting shelter going to the external ground ring
- Fence/gate grounding (corners, gate posts, gate jumpers, entry deterrent wiring, etc.)
- Generator grounding and fuel tank grounding if visible
- AC Utility entrance
- Telco entrance
- Any miscellaneous metallic objects on or within 10 feet of shelter (Air conditioner units, exhaust fans, stairs/walkways, handrails, metal support structures, metal hoods over doors or air conditioner units, etc.)

### C.2.2 Recommended Internal Grounding Pictures

- Internal site overall
- Interior view of RF entry port
- RF surge suppression grounding
- MGB (and conductor routing to exterior shelter ground ring)
- Any supplemental ground bars
- AC utility input grounding
- AC surge suppression
- AC disconnects/breaker panels
- Any individual equipment AC surge protection
- Automatic transfer switch wiring/grounding
- UPS grounding
- DC power plant grounding (DC equalization conductor, inverter grounding and neutral-ground bond, battery rack grounding)
- Telco surge suppression grounding
- Alarm/control wiring surge suppression

- Cable ladder/tray grounding/jumpers
- Horseshoe halo ground bus system
- Equipment ground bus “home runs”
- Equipment grounding
- Equipment isolation from floor, if present
- Microwave rack grounding
- Electrical conduit grounding/jumpering
- Raised floor/anti-static floor grounding
- Miscellaneous metallic object grounding (air conditioner vents, exhaust fans, door frames, door, desks, fire suppression system, etc.)

## C.3 4-POINT SOIL RESISTIVITY SURVEY TEST SHEET

This section contains the 4-Point Soil Resistivity Survey Test Sheet that should be used for recording the 4-point soil resistivity test results. Refer to the instructions in Section A.3.1.4 and use the reproducible form on the next page to record your results. Use of this form is not necessary when using the Harris 4-point Soil Resistivity Survey spreadsheet.

HARRIS

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221 Jefferson Ridge Parkway
Lynchburg, VA 24501
Telephone: (434) 455-6600
www.harris.com

4-POINT SOIL RESISTIVITY SURVEY

| | | | |
|---|---|---|---|
| Project Name: | Best County, Site AMDG | Project Numbe | xxx-yyy-zzz |
| Date of Test: | 10/22/2016 | | |
| Site Address: | Fast Hwy, Very Best City, State | | |
| Test Completed by | Joe Tester | Company: | Harris |
| Conditions: | Partly Cloudy, 84F, Soil Surface Dry | Soil: | Compacted Clay |
| Test Instrument: | AVO 5/4 Megger . Serial Numbe 123456 | Calibration Dat | 3/23/2016 |

* YELLOW = Enter Data , GREEN = results

| Test Location | Test Measurements: Probe Spacing A (ft) | Probe Depth B (ft) | Meter Reading R (Ω) | Calculated Soil Resistivity =191.5 *A*R: Soil Resistivity (Ω-cm)* |
|---|---|---|---|---|
| 1 | 5 | 1 | 27.3 | 27863.7 |
| South To North | 10 | 1 | 10.32 | 20104.5 |
| Center of Area | 15 | 1 | 3.78 | 10942.6 |
| | 20 | 1 | 2.65 | 10194.3 |
| | 30 | 1 | 0.23 | 1324.0 |
| | 40 | 1 | 0.12 | 920.3 |
| | 100 | 1 | 0.05 | 957.7 |
| | | | | |
| | | | | |
| 2 | 5 | 1 | 35.4 | 36130.9 |
| West to East | 10 | 1 | 12.44 | 24234.5 |
| South Side of Area | 15 | 1 | 3.12 | 9032.0 |
| | 20 | 1 | 2.68 | 10309.7 |
| | 30 | 1 | 0.19 | 1093.7 |
| | 40 | 1 | 0.13 | 996.9 |
| | 100 | 1 | 0.06 | 1149.3 |
| | | | | |
| | | | | |
| 3 | 5 | 1 | 30.6 | 31231.8 |
| SW to NE | 10 | 1 | 11.42 | 22247.4 |
| Center of Area | 15 | 1 | 3.4 | 9842.5 |
| | 20 | 1 | 2.66 | 10232.8 |
| | 30 | 1 | 0.18 | 1036.2 |
| | 40 | 1 | 0.13 | 996.9 |
| | 100 | 1 | 0.05 | 957.7 |
| | | | | |
| | | | | |
| 4 | 5 | | | |
| | 10 | | | |
| | 15 | | | |
| | 20 | | | |
| | 30 | | | |
| | 40 | | | |
| | 100 | | | |
| | | | | |
| | | | | |

Simplified Wenner formula for Probe Depth A>20B

*Automated spreadsheet soil resistivity calculation uses complete Wenner formula to allow for any probe depth.

**Figure 7-18: Example of 4-Point Soil Resistivity Survey Test Sheet**

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## 4-POINT SOIL RESISTIVITY SURVEY

| | | | |
|---|---|---|---|
| Project Name: | | Project Number: | |
| Date of Test: | | | |
| Site Address: | | | |
| Test Completed by: | | Company: | |
| Conditions: | | Soil: | |
| Test Instrument: | Serial Number: | Calibration Date: | |

* YELLOW = Enter Data , GREEN = results

| Test Location | Test Measurements: Probe Spacing A (ft) | Probe Depth B (ft) | Meter Reading R (Ω) | Calculated Soil Resistivity =191.5 *A*R Soil Resistivity (Ω-cm)* |
|---|---|---|---|---|
| 1 | 5 | 1 | | |
| | 10 | 1 | | |
| | 15 | 1 | | |
| | 20 | 1 | | |
| | 30 | 1 | | |
| | 40 | 1 | | |
| | 100 | 1 | | |
| | | | | |
| | | | | |
| 2 | 5 | 1 | | |
| | 10 | 1 | | |
| | 15 | 1 | | |
| | 20 | 1 | | |
| | 30 | 1 | | |
| | 40 | 1 | | |
| | 100 | 1 | | |
| | | | | |
| | | | | |
| 3 | 5 | 1 | | |
| | 10 | 1 | | |
| | 15 | 1 | | |
| | 20 | 1 | | |
| | 30 | 1 | | |
| | 40 | 1 | | |
| | 100 | 1 | | |
| | | | | |
| | | | | |
| 4 | 5 | | | |
| | 10 | | | |
| | 15 | | | |
| | 20 | | | |
| | 30 | | | |
| | 40 | | | |
| | 100 | | | |
| | | | | |
| | | | | |

Simplified Wenner formula for Probe Depth A>20B

*Automated spreadsheet soil resistivity calculation uses complete Wenner formula to allow for any probe depth.

# C.4 3-POINT FALL-OF-POTENTIAL GROUND SYSTEM RESISTANCE TEST SHEET

This section contains the 3-Point Fall-of-Potential Ground System Resistance Test Sheet that should be used for recording the 3-Point Fall-of-Potential Ground System Resistance test results. Refer to the instructions in Section B.2.1.6 and use the reproducible form on the next page to record your results. Use of this form is not necessary when using the Harris 3-Point Fall-of-Potential Ground System Resistance spreadsheet.

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**3-Point Fall-of-Potential Ground System Resistance Test**

| | | | | | |
|---|---|---|---|---|---|
| **Project Name:** | Best County, Site AMDG | | | **Project Number:** | xxx-yyy-zzz |
| **Date of Test:** | 8/31/2016 | | | | |
| **Site Address:** | Fast Hwy, Very Best City, State | | | | |
| **Test Completed by:** | Joe Tester | | | **Company:** | Harris |
| **Conditions:** | Sunny, 92F, Soil Surface Dry | | | **Soil:** | Compacted Clay |
| **Test Instrument:** | AVO 5/4 Megger | **Serial Number:** | 123456 | **Calibration Date:** | 6/20/2016 |

* YELLOW = Enter Data , GREEN = results , BLUE = select value from drop down list

**Automated Spreadsheet Instructions**

1. **Disconnect AC utility neutral from ground system and select Yes. (Sheet is disabled if box is not set to "Yes" since test would be ir**
2. Enter ground system diagonal distance.
3. Spreadsheet will automatically fill in suggested C2 Probe distances for 5-10 times the diagonal.
4. Enter C2 Probe distance to be used for test. (If a distance is used other than what is available in the pull down box, choose "OTHER" then enter the value in the other distance box that appears.)
5. Enter C1/P1 meter test lead connection point to ground system.
6. Spreadsheet will automatically fill in P2 Probe distances for 10-90% C2 Probe distance.
7. Enter 3-pole test meter measurements for each P2 Probe location.
8. Spreadsheet will automatically graph measurements.

| | |
|---|---|
| 1. Is AC utility neutral disconnected from the ground system under test? | Yes |
| 2. Ground System Diagonal Distance (feet) | 100 * |

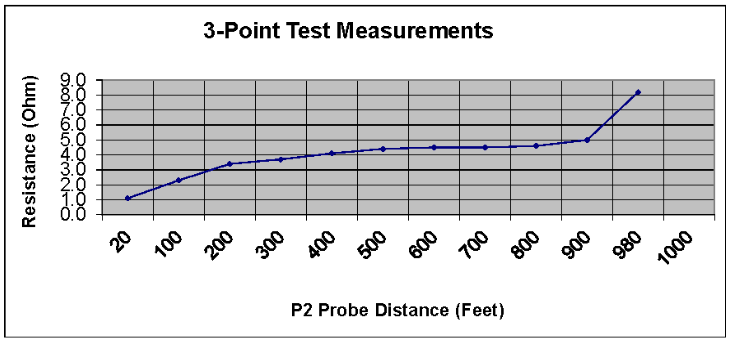
| 3. Suggested C2 Probe Distances Based on Ground System Diagonal Distance | | | | | |
|---|---|---|---|---|---|
| 5X | 6X | 7X | 8X | 9X | 10X |
| 500 | 600 | 700 | 800 | 900 | 1000 |

| | |
|---|---|
| 4. C2 Current Probe Distance Used (feet) | 1000 |
| 5. C1/P1 Connection Point to Ground System Under Test | Gate post ground |

| | Test Measurements | |
|---|---|---|
| **% of C2 Probe Distance** | **P2 Probe Distance (feet) **** | **Meter Reading R (Ω)** |
| 2% | 20 | 1.1 |
| 10% | 100 | 2.3 |
| 20% | 200 | 3.4 |
| 30% | 300 | 3.7 |
| 40% | 400 | 4.1 |
| 50% | 500 | 4.4 |
| 60% | 600 | 4.5 |
| 70% | 700 | 4.5 |
| 80% | 800 | 4.6 |
| 90% | 900 | 5.0 |
| 98% | 980 | 8.2 |
| C2 Total | 1000 | |

* IF "**P2 Probe Distance**" values appear as **#DIV/0!**, select a value other than 0 for **question #2**.

** IF "**P2 Probe Distance**" values appear as **ERROR**, make sure the **AC utility neutral is disconnected** (**question #1**) and select a new value for **question #4**.




3-Point Fall off Potential Automated Form Revised 10_22_16 protected Sample Test 10/22/2016 12:56 PM

**Figure 7-19: Example of 3-Point Fall-of-Potential Test Sheet**

Harris Corporation - RFCD
221 Jefferson Ridge Parkway
Lynchburg, VA 24501
Telephone: (434) 455-6600
www.harris.com

## 3-Point Fall-of-Potential Ground System Resistance Test

| | | | |
|---|---|---|---|
| **Project Name:** | | **Project Number:** | |
| **Date of Test:** | | | |
| **Site Address:** | | | |
| **Test Completed by:** | | **Company:** | |
| **Conditions:** | | **Soil:** | |
| **Test Instrument:** | **Serial Number:** | **Calibration Date:** | |

* YELLOW = Enter Data , GREEN = results , BLUE = select value from drop down list

### Automated Spreadsheet Instructions

1. **Disconnect AC utility neutral from ground system and select Yes. (Sheet is disabled if box is not set to "Yes" since test would be ir**
2. Enter ground system diagonal distance.
3. Spreadsheet will automatically fill in suggested C2 Probe distances for 5-10 times the diagonal.
4. Enter C2 Probe distance to be used for test. (If a distance is used other than what is available in the pull down box, choose "OTHER" then enter the value in the other distance box that appears.)
5. Enter C1/P1 meter test lead connection point to ground system.
6. Spreadsheet will automatically fill in P2 Probe distances for 10-90% C2 Probe distance.
7. Enter 3-pole test meter measurements for each P2 Probe location.
8. Spreadsheet will automatically graph measurements.

| | |
|---|---|
| 1. Is AC utility neutral disconnected from the ground system under test? | |

| | |
|---|---|
| 2. Ground System Diagonal Distance (feet) | * |

| 3. Suggested C2 Probe Distances Based on Ground System Diagonal Distance | | | | | |
|---|---|---|---|---|---|
| 5X | 6X | 7X | 8X | 9X | 10X |
| | | | | | |

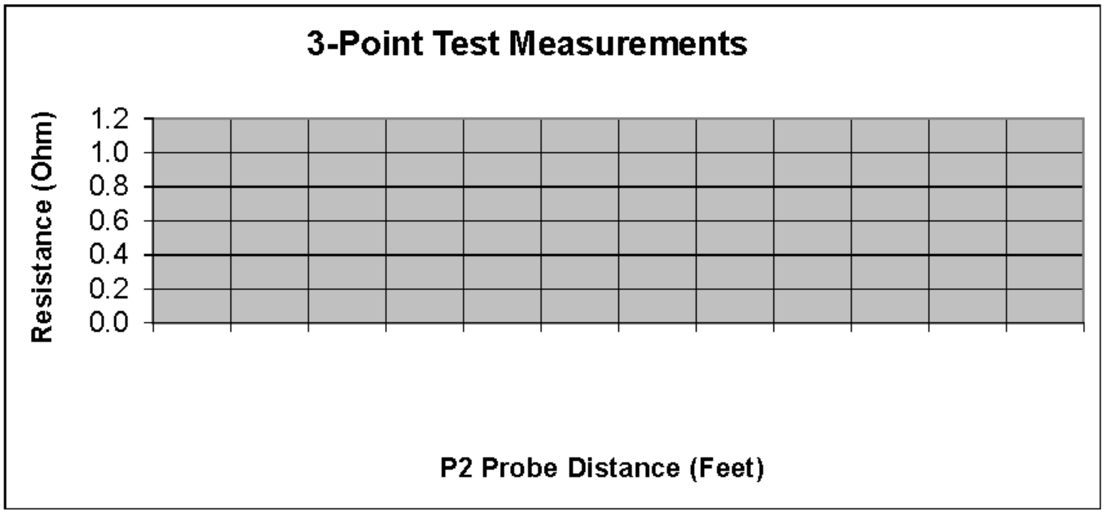
| | |
|---|---|
| 4. C2 Current Probe Distance Used (feet) | |

| | |
|---|---|
| 5. C1/P1 Connection Point to Ground System Under Test | |

| | Test Measurements | |
|---|---|---|
| **% of C2 Probe Distance** | **P2 Probe Distance (feet) **** | **Meter Reading R (Ω)** |
| 2% | | |
| 10% | | |
| 20% | | |
| 30% | | |
| 40% | | |
| 50% | | |
| 60% | | |
| 70% | | |
| 80% | | |
| 90% | | |
| 98% | | |
| C2 Total | | |

* IF "**P2 Probe Distance**" values appear as **#DIV/0!**, select a value other than 0 for **question #2**.

** IF "**P2 Probe Distance**" values appear as **ERROR**, make sure the **AC utility neutral is disconnected** (**question #1**) and select a new value for **question #4**.



## C.5 GROUNDING INSPECTION CHECKLISTS

This section contains checklists that should be used to document the grounding system installation. Photocopy the checklists as required and complete a checklist for each site. The completed checklist should be retained in the site installation folder along with any photographs of the ground system installation.

Items that are not applicable to a particular site should be ignored and marked N/A.

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# GROUNDING INSTALLATION CHECKLIST

**Customer:** ________________________________________ **Date:**________

**Site Name:** _________________________________________ **Page**___ **of** ___

## EXTERIOR SITE GROUNDING

| Item No. | Ref. Section # | Item | Pictures Taken? (Y/N) | Installer Date/Initials | Harris Rep. Date/Initials |
|---|---|---|---|---|---|
| 1. | 3.1. | All grounding electrodes at site bonded together, i.e. AC utility entrance or other ground systems located at site. | | | |
| 2. | 3.2.1. | Grounding electrodes installed properly. | | | |
| 3. | 3.2.4. | Exothermic welds properly done. | | | |
| 4. | 3.2.3. | All grounding conductors routed to buried ground system in a short direct manner observing 8 inch minimum bending radius and all angles greater than 90 degrees. | | | |
| 5. | 3.2.4. | Mechanical connections tight and with antioxidant compound applied between surfaces. | | | |
| 6. | 4.1.1. | Tower ground ring installed properly. | | | |
| 7. | 4.2. | Each tower leg or tower base grounded to tower ground ring properly. | | | |
| 8. | 4.2.2. | For guyed tower, tower guy wires grounded properly. | | | |
| 9. | 4.1.1. | Shelter ground ring installed properly. | | | |
| 10. | 4.1. | Tower and shelter ground rings bonded together. | | | |
| 11. | 4.3.1. | Tower ground bus bar (TGB) bonded to tower ground ring directly. | | | |

| EXTERIOR SITE GROUNDING | | | | | |
|---|---|---|---|---|---|
| **Item No.** | **Ref. Section #** | **Item** | **Pictures Taken? (Y/N)** | **Installer Date/Initials** | **Harris Rep. Date/Initials** |
| 12. | 4.3.2. | RF entry port or exterior ground bus bar (EGB) bonded directly to shelter ground ring. (If EGB used, RF entry port metallic surface bonded to EGB.) | | | |
| 13. | 4.3.3. | Interior master ground bar (MGB) bonded directly to shelter ground ring at same location as RF entry port or EGB. | | | |
| 14. | 4.4. | RF transmission line ground kits installed at top of run near antenna. | | | |
| 15. | 4.4. | RF transmission line ground kits installed at bottom of vertical cable run above drip loop where cable leaves tower. | | | |
| 16. | 4.4. | RF transmission line ground kits (or integrated ground clamps in RF entry port) installed at entrance to shelter. | | | |
| 17. | 3.2.4. | RF transmission line ground kits bonded to ground bars properly, tight with antioxidation compound applied between surfaces and no "piggy-backed" connections. | | | |
| 18. | 4.4.1. | GPS RF transmission line ground kits installed at RF entry port. | | | |
| 19. | 4.6. | Ice bridge/cable tray properly grounded. | | | |
| 20. | 4.7. | Fence corner posts bonded to buried ground system. | | | |
| 21. | 4.7. | Fence gate posts bonded to buried ground system and gates jumpered to gate posts. | | | |
| 22. | 4.8. | Generator and fuel tank grounded properly. | | | |

# GROUNDING INSTALLATION CHECKLIST

**Customer:** ________________________________________ **Date:**_______

**Site Name:** _________________________________________ **Page**___ **of** ___

## EXTERIOR SITE GROUNDING

| Item No. | Ref. Section # | Item | Pictures Taken? (Y/N) | Installer Date/Initials | Harris Rep. Date/Initials |
|---|---|---|---|---|---|
| 23. | 4.9. | All metallic objects mounted on shelter exterior bonded directly to shelter ground ring, i.e. air conditioning units, exhaust fans, stairways, ice shields, external generator plugs, etc. | | | |
| 24. | 4.9. | One shelter anchor tab closest to MGB bonded directly to shelter ground ring. | | | |
| 25. | 4.10. | Any miscellaneous metallic objects within 10 feet of exterior ground system bonded to buried ground system. | | | |
| 26. | Apdx. B | Ground system resistance measured.<br><br>3-point fall-of-potential test result ______<br><br>Clamp-On test result ________ | | | |

**Comments:**

## INTERIOR SITE GROUNDING

| Item No. | Ref. Section # | Item | Pictures Taken? (Y/N) | Installer Date/Initials | Harris Rep. Date/Initials |
|---|---|---|---|---|---|
| 1. | 4.3.3. | Interior master ground bar (MGB) bonded directly to shelter ground ring at same location as RF entry port or EGB. | | | |
| 2. | 5.1.1. | All grounding conductors routed to MGB in a short direct manner observing 8 inch minimum bending radius and all angles greater than 90 degrees. | | | |
| 3. | 5.2.1. | No other direct interior connections to exterior ground system except MGB. | | | |
| 4. | 5.1.2. | All ground connections to MGB bonded to ground bars properly, tight and no “piggy-backed” connections. | | | |
| 5. | 5.1.2. | All other ground connections installed properly, tight with proper surface contact and lock washer placement. | | | |
| 6. | 5.2.2. | Any supplemental ground bars (SGB) bonded directly back to MGB with properly sized conductor. | | | |
| 7. | 5.3.1. | RF surge suppressors grounded directly to RF entry port with integrated surge suppressor grounding. (RF entry port directly bonded to exterior shelter ground ring.) Perform either this step or step 8. | | | |
| 8. | 5.3.2. | RF surge suppressors grounded either directly to MGB or to an RF SGB that is bonded directly to MGB. (RF entry port without integrated RF surge suppressor grounding.) Perform either this step or step 7. | | | |

# GROUNDING INSTALLATION CHECKLIST

**Customer:** ________________________________________ **Date:**_______

**Site Name:** __________________________________________ **Page**___ **of** ___

## INTERIOR SITE GROUNDING

| Item No. | Ref. Section # | Item | Pictures Taken? (Y/N) | Installer Date/Initials | Harris Rep. Date/Initials |
|---|---|---|---|---|---|
| 9. | 5.4.1. | Equipment cabinets grounded to equipment ground bus conductor “home runs” route directly back to MGB. | | | |
| 10. | 5.4.2. | Each piece of equipment in each cabinet grounded to either the rack’s internal ground bus or an equipment ground drop conductor “drop” acts as the cabinet’s internal ground bus. All connections tight. | | | |
| 11. | 5.4.3. | No equipment ground conductors daisy chained between pieces of equipment. | | | |
| 12. | 5.4.4. | Cabinets/racks isolated from conductive floor. | | | |
| 13. | 5.5. | Cable tray/ladder bonded directly to MGB at only one location closest to MGB. No other ground connections are made to horseshoe halo ground bus. | | | |
| 14. | 5.5. | Cable tray/ladder sections jumpered together on both sides. | | | |
| 15. | 5.1.2. | No other ground conductors routed in cable tray/ladder unintentionally making contact with cable tray/ladder due to uninsulated C-tap connections. | | | |
| 16. | 5.6.2. | AC utility entrance grounded to MGB. | | | |
| 17. | 5.8. | DC power plant equalization conductor installed and properly sized. | | | |

| INTERIOR SITE GROUNDING | | | | | |
|---|---|---|---|---|---|
| **Item No.** | **Ref. Section #** | **Item** | **Pictures Taken? (Y/N)** | **Installer Date/Initials** | **Harris Rep. Date/Initials** |
| 18. | 5.8. | DC power system battery racks and DC distribution racks bonded back to MGB. (Battery racks may be jumpered together and have a single connection back to MGB.) | | | |
| 19. | 5.9. | Any separately derived AC systems have a neutral-to-ground bond and a dedicated grounding conductor back to MGB. | | | |
| 20. | 5.9. | Generator neutral-to-ground bond removed. | | | |
| 21. | 5.10. | Any surge suppressors grounded back to MGB and not to horseshoe halo ground bus. No ground connections "piggy backed." | | | |
| 22. | 5.11.1. | Each half of horseshoe halo ground bus has a single connection to MGB and is not connected to the other half of the horseshoe halo ground bus. No direct connections are made from halo ground bus to exterior ground system. | | | |
| 23. | 5.11.2. | All metallic ancillary support equipment bonded to horseshoe halo ground bus. | | | |
| 24. | 5.11.3. | Electrical conduit bonded to horseshoe halo ground bus properly. | | | |
| 25. | 5.11.4. | Raised floor grounded properly. | | | |
| 26. | 5.11.5. | Antistatic floor grounded properly. | | | |

## Comments:

# GROUNDING INSTALLATION CHECKLIST

**Customer:** ________________________________________ **Date:**_______

**Site Name:** _________________________________________ **Page___ of ___**

## SURGE SUPPRESSION INSTALLATION AND GROUNDING

| Item No. | Ref. Section # | Item | Pictures Taken? (Y/N) | Installer Date/Initials | Harris Rep. Date/Initials |
|---|---|---|---|---|---|
| 1. | 6.4.3. | AC surge protection device (SPD) installed on utility breaker panel. | | | |
| 2. | 6.4.6. | AC SPD on utility breaker panel installed properly with short direct connections per manufacturer's recommendations. | | | |
| 3. | 6.4.3. | AC SPD installed before ATS utility input. | | | |
| 4. | 6.4.6. | AC SPD before ATS installed properly with short direct connections per manufacturer's recommendations. | | | |
| 5. | 6.4.3. | AC SPD installed on branch breaker panel. | | | |
| 6. | 6.4.6. | AC SPD on branch breaker panel installed properly with short direct connections per manufacturer's recom-mendations. | | | |
| 7. | 6.4.3. | Individual equipment AC SPDs installed where applicable. | | | |
| 8. | 6.5. | Proper RF surge suppressors installed on all RF transmission lines entering shelter including GPS, unused lines, and test lines. | | | |
| 9. | 5.3. | RF surge suppressors grounded properly to either MGB or to RF entry port if it has integrated RF surge suppressor grounding. | | | |

## SURGE SUPPRESSION INSTALLATION AND GROUNDING

| Item No. | Ref. Section # | Item | Pictures Taken? (Y/N) | Installer Date/Initials | Harris Rep. Date/Initials |
|---|---|---|---|---|---|
| 10. | 6.6.1. | Any copper telecommunications lines entering shelter have primary surge suppression installed at shelter entrance. | | | |
| 11. | 6.6.1. | Telco primary SPDs are properly grounded back to MGB. | | | |
| 12. | 5.7. | Telecommunications lines entering shelter have shield grounded and any unused pairs on cable are grounded. | | | |
| 13. | 6.6.2. | Secondary telco SPDs are installed close to equipment to be protected. | | | |
| 14. | 6.6.2. | Secondary telco SPDs are properly grounded per manufacturer's recom-mendations. | | | |
| 15. | 6.7. | Data communications SPDs installed close to equipment to be protected where applicable. | | | |
| 16. | 6.8. | DC SPD's installed close to equipment to be protected where applicable. | | | |
| 17. | 6.9. | All alarm inputs and control outputs entering/exiting shelter have proper SPDs installed. | | | |
| 18. | 6.10. | Tower lighting controllers have proper surge suppression installed. | | | |
| 19. | 6.11. | All miscellaneous cabling entering shelter for CCTV, cable TV, security card readers, etc. have proper surge suppression installed. | | | |

## Comments:

# APPENDIX D SITE GROUNDING PREVENTIVE MAINTENANCE

Preventive maintenance should be performed on all Harris installations yearly (minimum). In addition to performing preventive maintenance on the site equipment, is also important to perform preventive maintenance on the grounding system components to ensure continued site operation and protection.

NOTE

If a site takes a known lightning hit, these checks should also be performed to verify the grounding system or surge suppression devices at the site were not damaged.

**The following actions are recommended:**

1. Measure the grounding electrode system resistance.

   This measurement should be logged each time it is taken after the initial installation. Drastic changes in the grounding system resistance may indicate damage to the ground system. Gradual increases in ground system resistance are an indication of the ground system beginning to corrode or experiencing minor damage due to lightning hits. Ground systems do have a finite useful lifetime. If a ground test well is present, a measurement (has no particular meaning except compared to itself each year) should be made yearly and compared for changes.

2. Physically inspect all visible grounding conductors and connections.

3. Use clamp-on meter to verify integrity of all tower, guy anchor, and external ground bar connections, and AC grounding electrode.

4. Check all accessible lug connections for tightness.

   Though not required, external lug connections, including connections to external ground bars, may be removed, cleaned, and have new coatings of antioxidant applied, before reinstallation.

5. Check tightness of all internal ground connections at both ground bars and at the opposite connection end.

6. Verify any surge suppression that provides an indication of providing protection are in good working order. Consider replacement of SPDs based on manufacturer’s recommendations.

7. Check tightness of RF surge suppressor connections to RF cables.

8. Check that ground connections to RF SPDs are tight.

9. Check that the AC power panel connections are tight and that the neutral-to-ground bond is also tight.

10. Check all DC power connections at both the batteries and at the equipment.

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# APPENDIX E GROUNDING ELECTRODE SYSTEM DESIGN

## E.1 OBJECTIVE

The objective of a grounding electrode system design is to achieve the desired site ground resistance target. For most Harris installations this target is 5 ohms or less. (See Section 3.1 for exceptions to this target.) Depending on the soil resistivity at the site, space availability, and the depth of rock under the soil surface, achieving this goal may be relatively easy or very difficult.

By performing a basic grounding system design ahead of time, the designer can determine the best method for achieving the ground resistance target. For many sites, following these basic techniques should produce a site grounding design with a high confidence of achieving the target ground system resistance. When the basic design techniques described in this section do not produce a ground system with the target ground resistance or space for the grounding electrode system is limited, you should contact Harris Systems Engineering or a grounding consultant for guidance.

NOTE

The grounding electrode system design techniques described in this section provide an estimated theoretical value for the ground system resistance of a given number of grounding electrodes in homogeneous soil in the chosen arrangement. The actual ground system resistance should be measured after installation using the techniques in Appendix B to verify that the target was met.

## E.2 THEORY

Grounding electrode system design is based on two basic concepts:

- The sphere of influence of a grounding electrode, and
- The ground resistance of multiple interconnected ground rods have a lower ground resistance than a single rod.

In theory, a 5/8 inch diameter ground rod driven into homogeneous 20,000 ohm-cm soil 10 feet deep would present 66 ohms of resistance to ground. Driving it 20 feet deep would yield 37 ohms. Extending the depth to 30 feet would yield about 26 ohms.

Using four interconnected ground rods that are each 10 feet long, driven into the same soil area 10 feet deep and 20 feet apart, the ground resistance becomes 23 ohms. Burying the interconnecting wire below the soil surface further reduces the ground resistance to less than 20 ohms.

Lower ground resistance is, therefore, more rapidly achieved by installing multiple, interconnected ground rods.

### E.2.1 Sphere of Influence

A grounding electrode, or rod, has a sphere of influence on the soil around it with a radius equal to its length and a depth equal to its length.

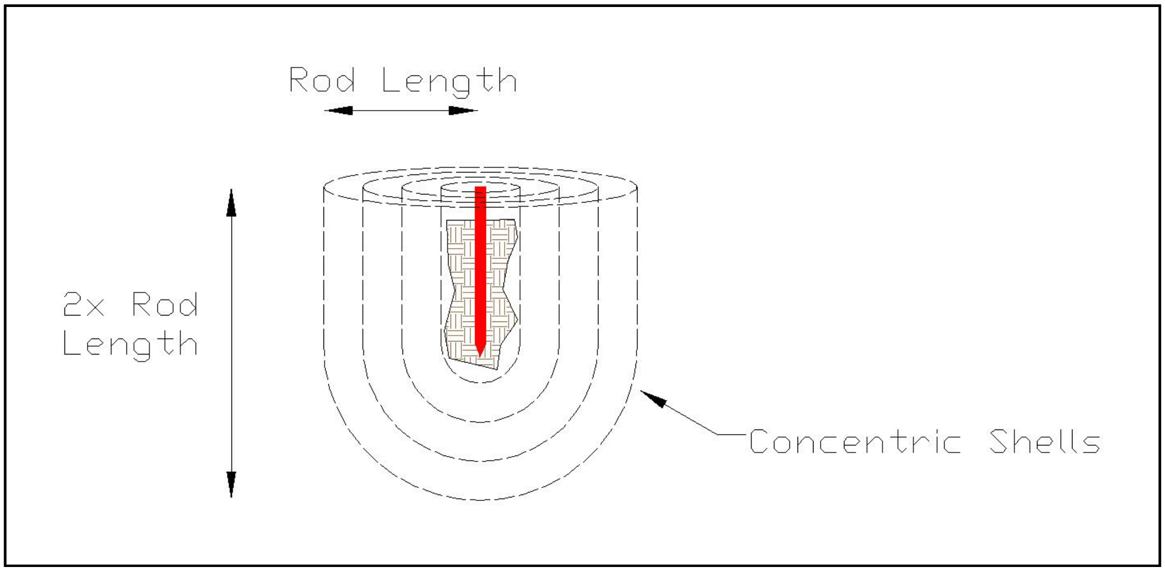



**Figure E-1: Grounding Electrode Sphere of Influence**

The sphere of influence affects how effective multiple grounding electrodes are when placed next to each other and interconnected. When two electrodes are spaced too closely, both electrodes exert an influence on the charge in the same soil reducing the net amount of current that each can dissipate into the soil surrounding it. For maximum benefit, multiple grounding electrodes should be placed at least 2.2 times their length apart. This number is commonly rounded to 2 times their length.

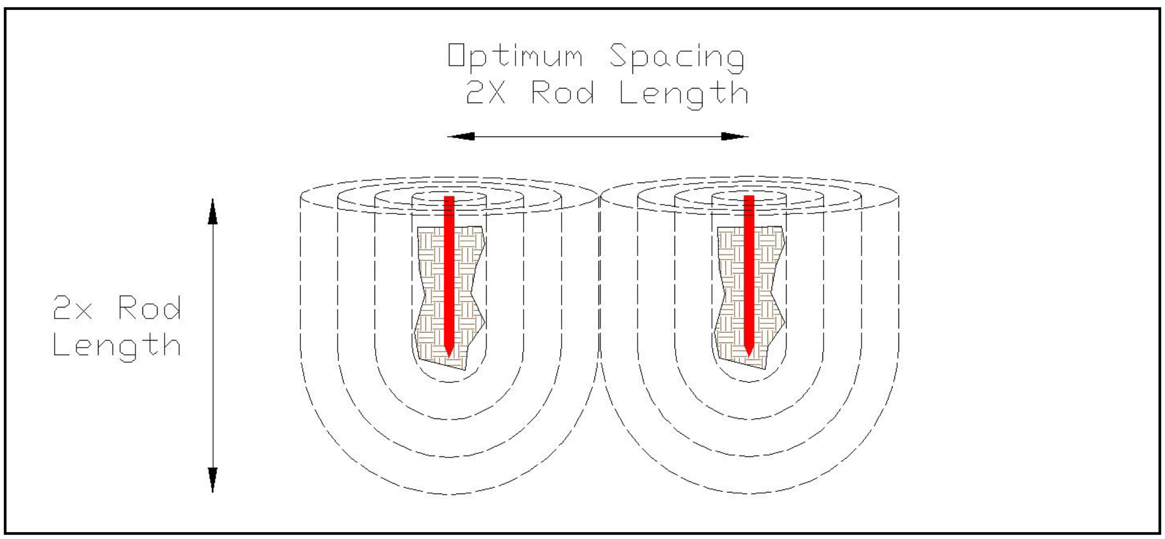



**Figure E-2: Minimum Grounding Electrode Spacing for Maximum Benefit**

The sphere of influence theory is important in both grounding electrode system design and also in ground system resistance measurements.

### E.2.2 Soil Resistivity

As discussed in Appendix A, soil resistivity varies with type of soil, moisture content, and temperature variations. Making soil resistivity measurements using the 4-Point Wenner test method at different probe spacings gives the average resistivity of the soil from the surface to a depth equal to the probe spacing. A set of readings taken with various probe spacings gives a set of resistivities indicating whether there are distinct layers of different soil or rock, their respective resistivities, and the depth of the upper layer.

To minimize the effect that changes in surface moisture levels and soil temperature have on the grounding electrode system resistance, grounding electrodes must be installed at least 30 inches under finished grade or below the frost level, whichever is deeper.

## E.3 STANDARD SITE GROUNDING SYSTEM DESIGN METHOD

Most Harris installations consist of a stand-alone shelter and a tower. This shelter and tower are located on a defined area of land. Taking soil resistivity measurements at different locations in the defined area gives a picture of the resistivity of the different soil layers both in different areas and at different layers under the site.

Multiple grounding electrodes are installed and interconnected together to form the shelter and tower ground rings. Tower ground radials may be used or radials may extend to the fence corners.

Knowing the worst case soil resistivity at a given depth at which a grounding electrode will be installed, the ground resistance of a single grounding electrode (rod) may be calculated. Multiple rods in parallel yield lower resistance to ground than a single rod. Adding a second rod does not, however, provide a total resistance of half of a single rod, unless the two are several rod lengths apart.

Using equations detailed in *IEEE Std. 142-1982 IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, the theoretical ground resistance of these various grounding components may be calculated. Finally an equivalent resistance of each of the components' resistance in parallel may be calculated to give the theoretical ground resistance of the site ground system.

**NOTE**

The grounding electrode system design techniques described in this section provide a basic theoretical value for the ground system resistance of a given number of grounding electrodes in homogeneous soil in the chosen arrangement. The actual ground system resistance should be measured after installation using the techniques in Appendix B to verify that the target was met. Varying soil resistivity of different soil layers, lack of specific soil resistivity data at exact grounding electrode installation locations, and variances of ground system installation from the design, may result in lower or higher actual measured ground resistance measurements.

### E.3.1 Required Inputs

The minimum inputs required to do a grounding system design are:

- The site soil resistivity measurements and
- The site plat with shelter, tower, and fence locations.

It is also useful to know if additional right-of-ways exist at the site. Access to the geological survey may also be useful in determining the depth of the different soil layers, how deep any large expanses of rock may be located, and how deep the water table may be.

## E.3.2 Standard Design Process

### E.3.2.1 Overview

Complex computer modeling programs exist to aid in the design of grounding electrode systems. These computer programs use the soil resistivity at multiple soil layers to calculate the ground resistance of complex grounding electrode system configurations. These programs are often used in the design of AC power distribution substation ground grids. Grounding consultants have access to these more precise computer modeling tools when they are needed if difficult site conditions exist.

For average soil resistivity sites (< 15,000 ohm-cm soil resistivity), a more basic technique may be used to estimate the resistance of a grounding electrode system design. This basic technique involves:

1. Determining a worst case soil resistivity value to use for the calculations based on the electrode lengths being used.

2. Based on the site configuration, determining the minimum number of grounding electrodes that must be installed.

3. Finding the theoretical ground resistance of a single electrode at a given depth in soil with that resistivity.

4. Finding the ground resistance of the multiple interconnected electrodes forming the shelter ground ring and tower ground ring.

5. Finding the parallel resistance of the two ground rings when they are interconnected.

6. Evaluating the theoretical estimated ground resistance of the design against the target ground system resistance to determine if further iterations of the design process are required.

These calculations may be done manually or an automated spreadsheet available from Harris may be used to make the process and possible iterations easier and faster.

NOTE

These ground system design techniques and calculations result in an estimated ground system resistance value only. No inherent guarantee is implied when these techniques or the automated Harris grounding system design spreadsheet are used to estimate the ground system resistance.

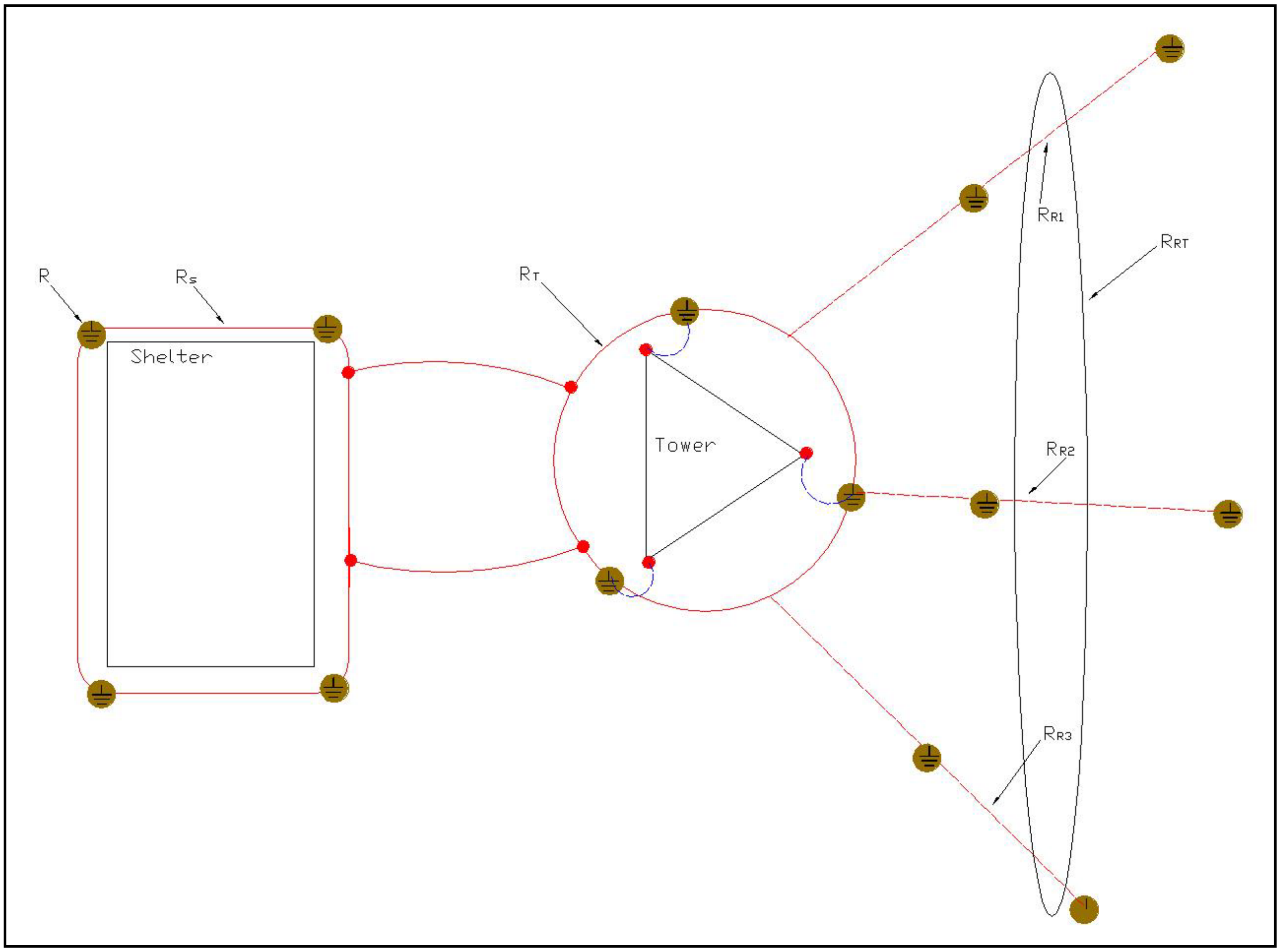



**Figure E-3: Overview of Different Components of Site Grounding System Design**

### E.3.2.2 Identifying Potential Grounding Electrode Installation Difficulties

The soil resistivity measurements at the different depths should be used to evaluate the presence of rock or other high resistivity soil layers at the site. The geologic survey, if available, may also be used to identify potential issues.

If extensive rock layers are encountered near the surface with little or top soil, see Section E.4.1 for details on how to proceed. Contact Harris Systems Engineering should additional guidance be needed.

### E.3.2.3 Verifying Space is Available for Standard Grounding Electrode System Arrangement

The shelter and tower locations on the site plat should be identified. Adequate space for the shelter and tower ground rings should be verified. See Section 4 for the specific requirements for grounding various types of towers and where the ground rings should be located in relation to the shelter and the tower.

### E.3.2.4 Determining the Minimum Number of Grounding Electrodes Required at a Site

At minimum, a ground ring should be located around the shelter with a ground rod located at each corner. A ground ring should also encircle the tower with a minimum of three ground rods spaced at equal distances around the ring. More ground rods may be required depending on the type of tower and the size of the ground rings. See Section 4 for to determine the exact number of ground rods required.

### E.3.2.5 Using Soil Resistivity Measurements to Choose Initial Grounding Electrode Parameters

Several useful pieces of information are available from the soil resistivity measurements:

- If extensive rock layers are located near the surface with little or top soil, see Section E.4.1 for details on how to proceed.
- If the soil resistivity measurements at a particular depth begin to rise sharply, the grounding electrode lengths used in the design should be less than this depth.
- If the soil resistivity measurements at a particular depth begin to decrease sharply, longer grounding electrodes may be considered for the design if needed.
- If the soil resistivity measurements decrease steadily at increasing depths, then longer grounding electrodes may be used if the original grounding system resistance needs to be reduced or if additional grounding system resistance seasonal stability is desired.

The worst case soil resistivity measurements either for a particular area of the site or a particular depth should be used in estimating the ground resistance of a single electrode.

### E.3.2.6 Estimating the Resistance of a Single Grounding Electrode

The beginning of calculating the ground resistance of the multiple site ground rods that are interconnected together is to calculate the ground resistance of a single vertical ground rod.

Two different methods are available for estimating the ground resistance of a single vertical ground rod.

One method is to calculate a value using H.B. Dwight's formula:

$$R(\text{ohms}) = [\rho/2\pi L] * [\ln(4L/a) - 1]$$

where: R = Resistance of a single ground rod (ohms)

$\rho$ = Soil resistivity in (ohm-cm)

L = Ground rod length in (cm)

a = Ground rod diameter in (cm)

H.B. Dwight's formula with the rod length in feet and its diameter in inches:

R(ohms) = [ρ/192L] * [ln(48L/a) – 1]_ where: R = Resistance of a single ground rod (ohms)

ρ = Soil resistivity in (ohm-cm)

L = Ground rod length in (feet)

a = Ground rod diameter in (inches)

This is the same formula used in Harris's automated spreadsheet.

A second method is to use a ground rod nomograph, (see the example in Figure E-4), and a straight edge to arrive at an approximate single ground rod resistance. (Use the nomograph sheet provided in Figure E-5.)

The ground resistance of the interconnecting wire on the ground ring is not used for both simplicity and the fact its fluctuations in resistance due to moisture and temperature are greater throughout the year. This yields a more conservative estimation.

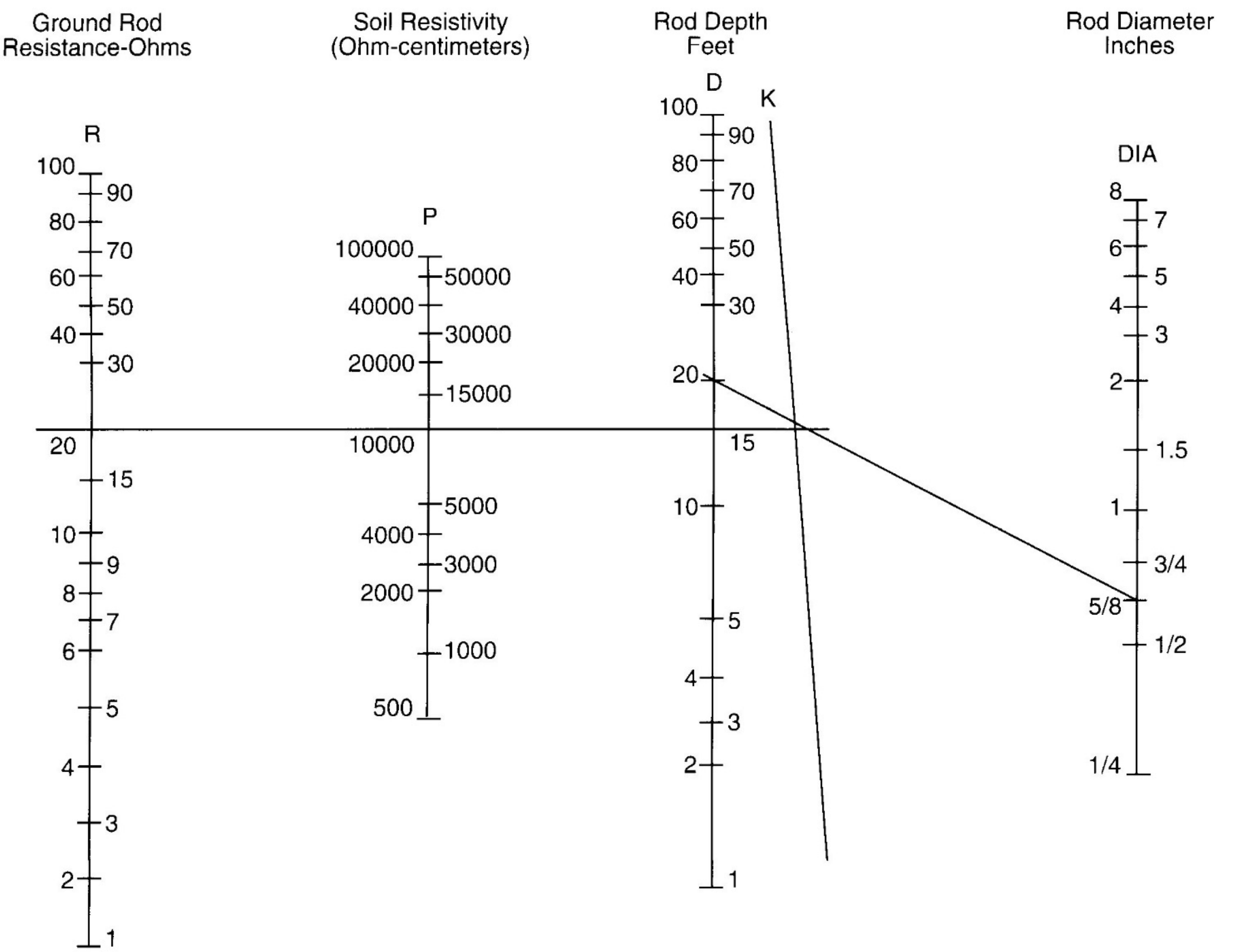
For ease of calculation, a simple multiplying factor is used to determine the ground resistance of the multiple rods interconnected to form a ground ring. For this multiplying factor to be valid, the multiple rods must be spaced at least one rod length apart in a line, circle, hollow triangle, or square. This spacing distance is measured in a straight line between two ground rods.

Additional rods placed within periphery of a shape will not reduce the grounding resistance below that of the peripheral rods alone.

**Table E-1: Multiplying Factors for Multiple Interconnected Ground Rods***

| Multiplying Factors for Multiple Interconnected Rods | |
|---|---|
| **Number of Rods (n)** | **Multiplying Factor (F)** |
| 2 | 1.16 |
| 3 | 1.29 |
| 4 | 1.36 |
| 8 | 1.68 |
| 12 | 1.80 |
| 16 | 1.92 |
| 20 | 2.00 |
| 24 | 2.16 |

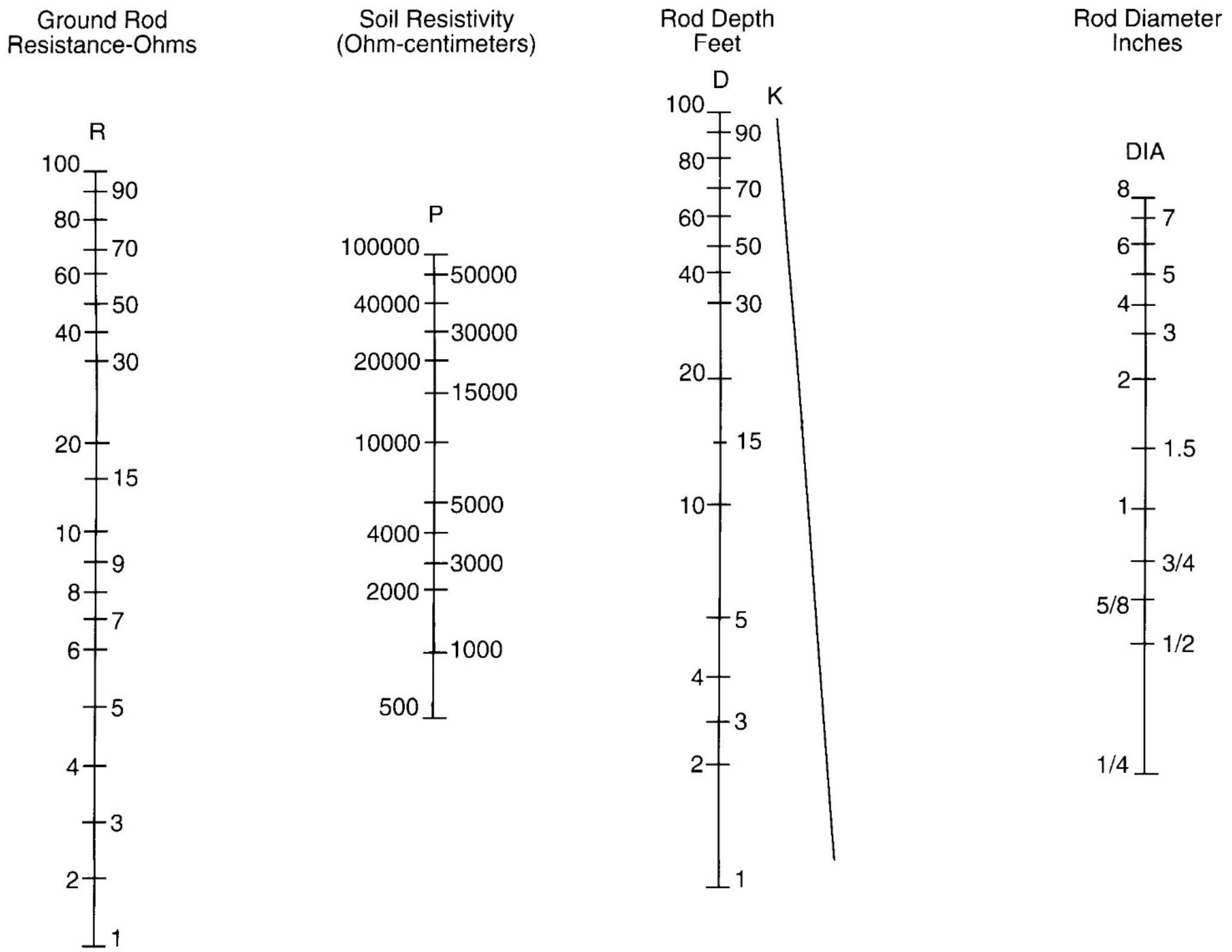
*(From *IEEE Std. 142-1982 IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*)




Represents an example of a 20 ohm, 20 foot ground rod.

1. Select required resistance on R scale.
2. Select apparent resistivity on P scale.
3. Lay straightedge on R and P scale, and allow to intersect with K scale.
4. Mark K scale point.
5. Lay straightedge on K scale point and DIA scale, and allow to intersect with D scale.
6. Point on D scale will be the rod depth required for resistance on R scale.

**Figure E-4: Grounding Nomograph Example**




1. Select required resistance on R scale.
2. Select apparent resistivity on P scale.
3. Lay straightedge on R and P scale, and allow to intersect with K scale.
4. Mark K scale point.
5. Lay straightedge on K scale point and DIA scale, and allow to intersect with D scale.
6. Point on D scale will be the rod depth required for resistance on R scale.

**Figure E-5: Grounding Nomograph**

### E.3.2.7 Estimating the Resistance of Shelter Ground Ring

Once the estimated ground resistance of a single vertical ground rod is found, the ground resistance of each of the ground rings encircling the shelter and the tower are estimated separately. The space between the ground rods is measured in a straight line and not along the circumference of the ground ring.

Resistance of the shelter ground ring formed by interconnected ground rods spaced one rod length apart in a hollow circle:

$R_S$(ohms) = (R/n)*F where: $R_S$ = Resistance of shelter ground ring (ohms)

R = Ground resistance of a single rod in (ohms)
n = Number of ground rods

F = Multiplying factor for number of interconnected ground rods (See Table E-1).

### E.3.2.8 Estimating the Resistance of Tower Ground Ring

Once the estimated ground resistance of the shelter ground ring is found, the same technique is used to estimate the ground resistance of the tower ground ring. Again, the space between the ground rods is measured in a straight line and not along the circumference of the ground ring.

Resistance of the tower ground ring formed by interconnected ground rods spaced one rod length apart in a hollow circle:

$R_T$(ohms) = (R/n)*F where: $R_T$ = Resistance of tower ground ring (ohms)

R = Ground resistance of a single rod in (ohms)
n = Number of ground rods

F = Multiplying factor for number of interconnected ground rods (See Table E-1).

### E.3.2.9 Estimating the Resistance of the Tower Ground Radials

If tower ground radials are used, the resistance of each ground radial should be calculated separately using the same technique used for the shelter and tower ground rings.

Resistance of a tower ground radial formed by interconnected ground rods spaced one rod length apart in a straight line:

$R_R$(ohms) = (R/n)*F where: $R_R$ = Resistance of tower ground radial (ohms)

R = Ground resistance of a single rod in (ohms)
n = Number of ground rods

F = Multiplying factor for number of interconnected ground rods (See Table E-1).

The total equivalent resistance of each of the tower ground radials is calculated as parallel resistances:

$$R_{RT}(\text{ohms}) = \frac{1}{(1 / R_{R1}) + (1 / R_{R2}) + (1 / R_{R3})}$$

where: $R_{RT}$ = Parallel resistance of all tower ground radials (ohms)

$R_{R1}$ = Resistance of tower ground radial #1 (ohms)
$R_{R2}$ = Resistance of tower ground radial #2 (ohms)
$R_{R3}$ = Resistance of tower ground radial #3 (ohms)

### E.3.2.10 Calculating Parallel Resistance of All Grounding Electrode System Components

The final step in calculating the total estimated ground system resistance is to calculate the parallel resistance of each of the site ground system components: the shelter ground ring, the tower ground ring, and the tower ground radials if present.

The total equivalent resistance of the site ground system components together is calculated as parallel resistances:

$$R_{Total}(\text{ohms}) = \frac{1}{(1 / R_S) + (1 / R_T) + (1 / R_{RT})}$$

where: $R_{Total}$ = Parallel resistance of all site ground components (ohms)

$R_S$ = Resistance of shelter ground ring (ohms)
$R_T$ = Resistance of tower ground ring (ohms)
$R_{RT}$ = Parallel resistance of all tower ground radials (ohms)

### E.3.2.11 Ground System Design Estimation Example

1. The following soil resistivity measurements are taken at a site:

| Depth (ft) | Soil Resistivity Measurements (ohm-cm) | | |
|---|---|---|---|
| | Test #1 | Test #2 | Test #3 |
| 5 | 26140 | 28142 | 33896 |
| 10 | 19763 | 23823 | 20945 |
| 15 | 10858 | 8962 | 9820 |
| 20 | 10150 | 10264 | 10183 |
| 30 | 1321 | 689 | 879 |
| 40 | 919 | 77 | 132 |

2. The site will consist of a shelter and a self supporting tower with three legs.

   It is determined that the minimum ground rod/ring configuration at the site is:

   a) a shelter ground ring with four ground rods (one at each corner)

   b) a tower ground ring with three ground rods (one at each leg)

   Additionally, space is available for two tower ground radials:

   c) Radial 1 to have three ground rods

   d) Radial 2 to have four ground rods

3. Due to the tower leg concrete footing depths, 20 feet long, ¾ inch diameter ground rods will be used for the tower ground ring and all other ground rods used will be 10 feet long, ¾ inch diameter ground rods.

4. The single 10 foot ground rod resistance is estimated based on the worst case 10 feet depth average soil resistivity measurement of 23,823 (ohm-cm). The calculation yields: $R_{10feet}$ = 77 ohms.

   The single 20 foot ground rod resistance is estimated based on the worst case 20 feet depth average soil resistivity measurement of 10,264 (ohm-cm). The calculation yields: $R_{20feet}$ = 18 ohms.

5. The shelter ground ring will consist of four 10 foot long ground rods spaced approximately 20 feet apart. The calculation for $R_{shelter}$ = 26 ohms.

   The tower ground ring will consist of three 20 foot long ground rods spaced approximately 40 feet apart. The calculation for $R_{tower}$ = 8 ohms.

6. The first tower ground radial will consist of three 10 feet long ground rods spaced approximately 20 feet apart. The calculation for $R_{radial\ 1}$ = 33 ohms.

   The second tower ground radial will consist of four 10 foot long ground rods spaced approximately 20 feet apart. The calculation for $R_{radial\ 2}$ = 26 ohms.

   The parallel resistance of the two tower ground radials is $R_{radial}$ = 15 ohms.

7. The total estimated site ground system resistance is the parallel resistance of the shelter ground ring, the tower ground ring, and the tower ground radial resistances.

   $$\begin{aligned} R_{total} &= R_{shelter} \parallel R_{tower} \parallel R_{radial} \\ &= 26 \parallel 8 \parallel 15 \\ &= 4.3 \text{ ohms} \end{aligned}$$

Again, this is an estimated ground system resistance value. Actual measured site ground system resistance after installation may be higher or lower than this value.

### E.3.2.12 Evaluating the Estimated Grounding Electrode System Resistance Against the Target

The total estimated site grounding electrode system resistance should be evaluated against the target ground system resistance. One of the following outcomes may result:

1. The design goal is estimated to be met with the current design.

In this case the ground system design parameters and site grounding electrode and ring locations should be documented. See Appendix C.

2. The estimated ground system design did not achieve the target ground system resistance.

   If the estimated ground resistance is reasonably close, another iteration of the design process should be done using one or more of the following enhancements:

   - longer ground rods
   - larger diameter ground rods
   - adding tower ground radials if they were not originally considered
   - using more ground rods to reduce the spacing between rods on the ground rings if the original design had them more than one rod length apart, or
   - adding additional ground radials off the shelter ground ring.

If the estimated ground system resistance was not close to the target or site constraints make the design more complex than described, contact Harris Systems Engineering or a grounding consultant for assistance in achieving the target ground resistance.

NOTE

The grounding electrode system design techniques described in this section provide an estimated theoretical value for the ground system resistance of a given number of grounding electrodes in homogeneous soil in the chosen arrangement.

The actual ground system resistance should be measured after installation using the techniques in Appendix B to verify that the target was met. Varying soil resistivity of different soil layers, lack of specific soil resistivity data at exact grounding electrode installation locations, and variances of ground system installation from the design, may result in lower or higher actual measured ground system resistance.

No inherent guarantee is implied when these techniques or the automated Harris grounding system design spreadsheet are used to estimate the ground system resistance.

# E.4 GROUNDING ELECTRODE ARRANGEMENTS FOR SPECIAL SITUATIONS

## E.4.1 Solid Rock Encountered Close to Surface

If solid rock is encountered at a site, one or more techniques described in this section may be employed to reduce the ground resistance. Contact Harris Systems Engineering or a grounding consultant for additional assistance.

- Ground rods can be installed at a 45 degree angle or even laid horizontally in a trench pointing away from the ground rings. See Section 3.2.1.2. Filling these trenches with ground enhancing materials or concrete increase the effectiveness of this technique.

- When rock is encountered, it is acceptable to bore 4 inch x 10 foot hole into the rock, set ground rods and fill the holes with either ground enhancing material or concrete.

- A vertical electrolytic ground rod may be installed in a bored hole or a horizontal rod in a trench.

- Ground radials may be run away from the site and buried as deep as allowed by the available top soil. Surrounding these radials with ground enhancing material or concrete can greatly increase their effectiveness.

- If the ground radials described above reach to an area of deeper soil, grounding electrodes may be installed in these areas and bonded to the ground radial. Larger size conductor should be considered in this instance.

- Ground plates may be used in place of vertical ground rods.

- If a buried solid shelf of rock exists but ground rods can be driven at least 4 feet deep, then all ground rods should be driven as far as possible. Additional ground rods should be driven in between these rods such that the distance between the rods is twice their driven depth apart.

NOTE

Any variances from the original site grounding drawings should be red-lined so the site as-built drawings accurately reflect what was installed. If a site ground system design was modeled, these variances also need to be sent back to the engineer for the model to be updated.

- Any concrete footings and foundations may be utilized as concrete-encased electrodes as detailed in Section 3.2.1.6. These electrodes should not be the only ground system electrodes utilized.

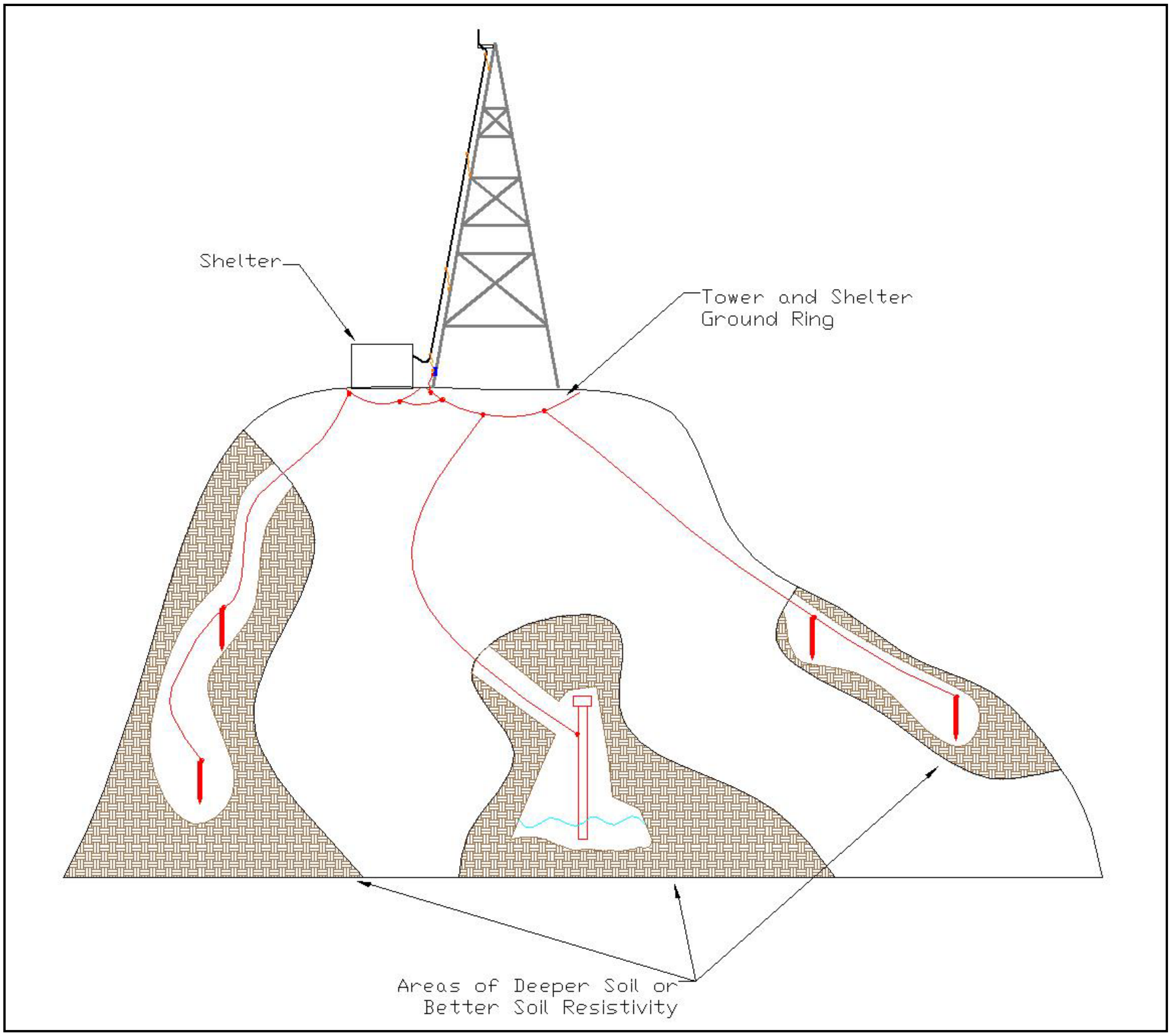



**Figure E-6: Ground Radials Extending to Lower Soil Resistivity Areas away from Site**

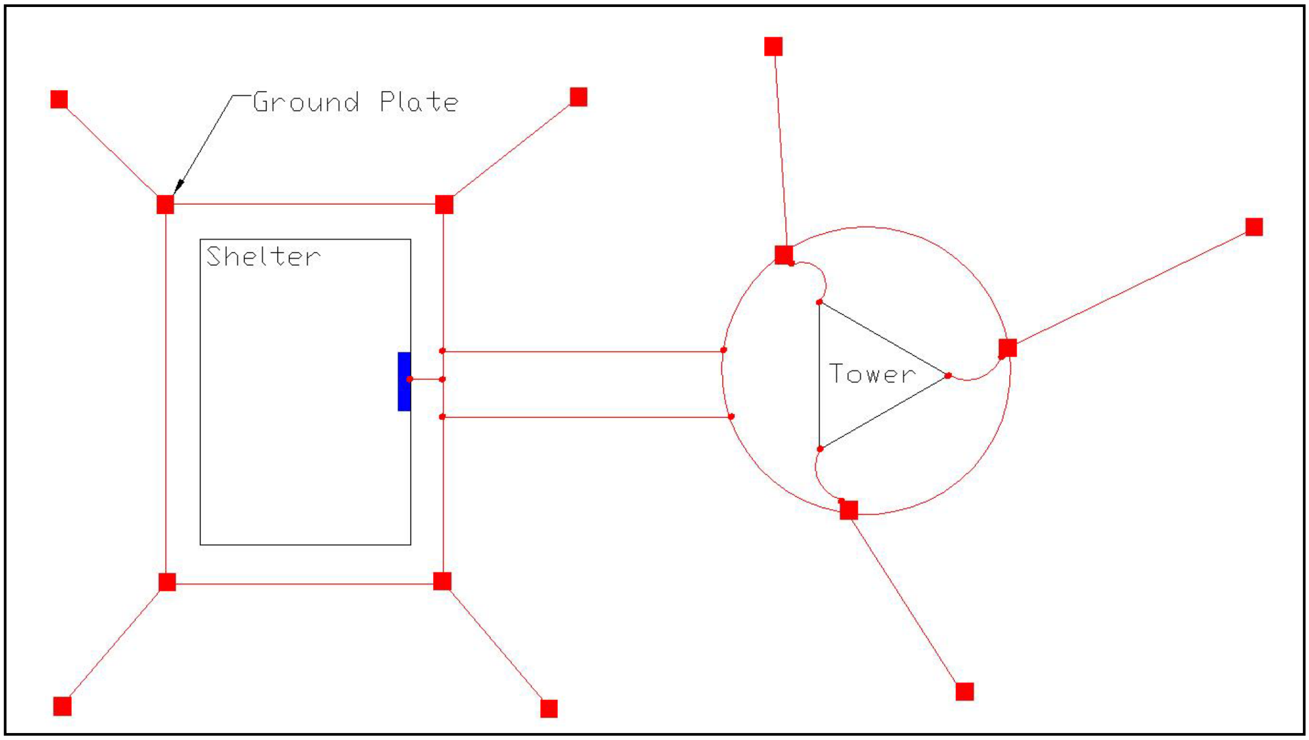



**Figure E-7: Ground Plates Used in Place of Vertical Grounding Electrodes**

- A deep well ground may be installed. See section 3.2.1.4. Using the same idea, if a water well is located within a reasonable distance and it has a metallic well casing, a ground conductor may be connected to this well casing.

**Figure E-8: Example of Connection to Abandoned Metallic Well Casing to Lower Ground System Resistance**

### E.4.2 Ground System Installation in High Soil Resistivity Area

Installing a ground system in an area with high soil resistivity such as limestone, sand, or coral will require techniques similar to those described in Section E.4.1. Contacting a grounding consult is highly recommended in these circumstances.

### E.4.3 Small Space for Grounding Electrode System

In an urban environment, a standard ground system electrode spacing and arrangement may not be possible. In these cases, we highly recommend using electrolytic ground rods. Grounding electrodes may also be installed in a straight line away from the tower or site and interconnected together. Grounding electrodes may also be interconnected to form a grid in the space allowed.

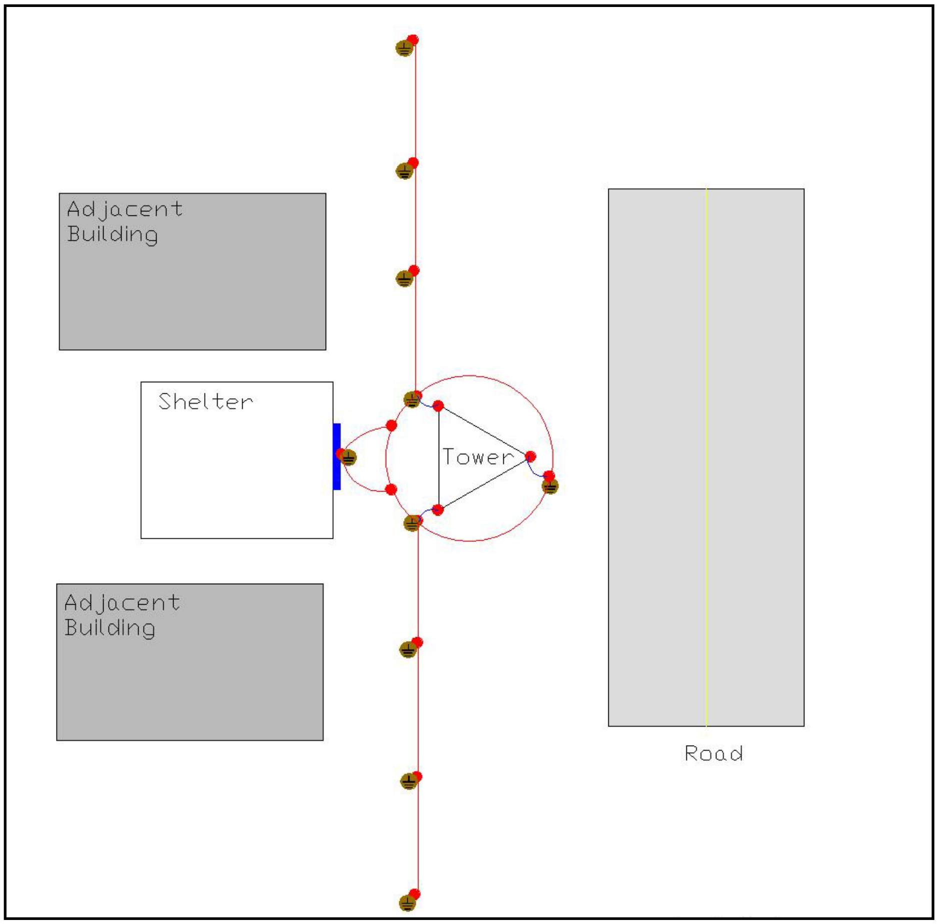



**Figure E-9: Grounding Electrodes Located in Line away from Tower Due to Limited Space**

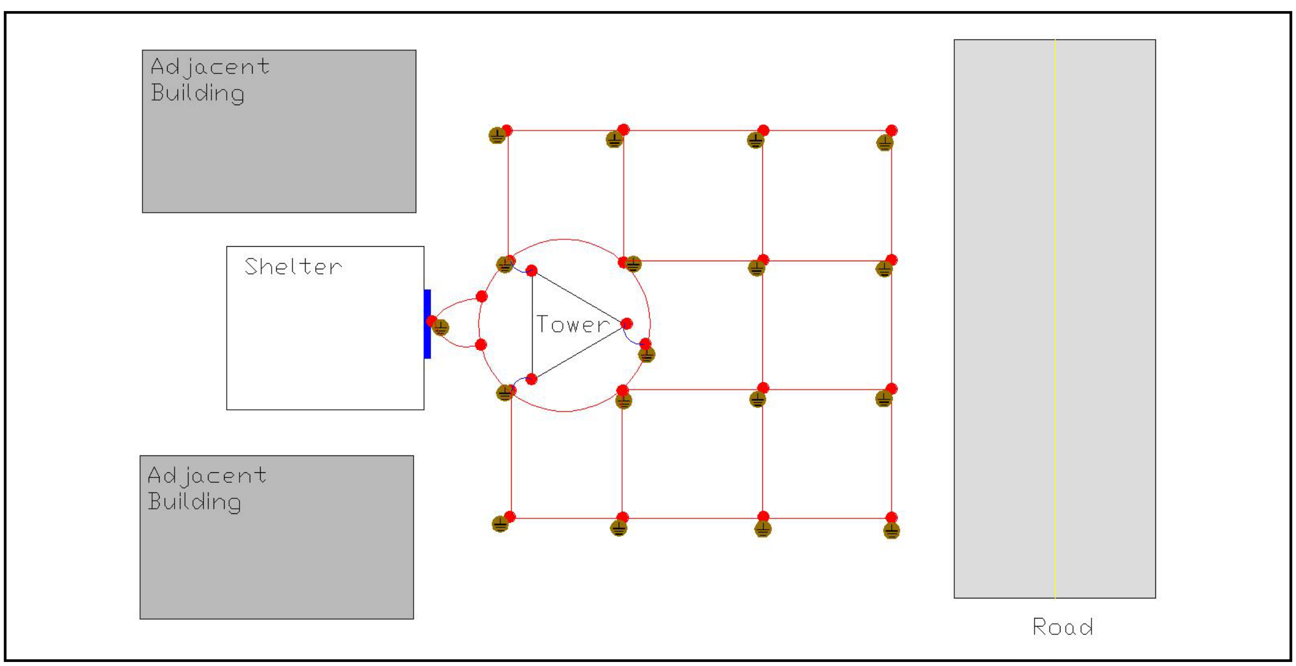



**Figure E-10: Grounding Electrodes Located in Grid around Tower Due to Limited Space**

### E.4.4 Ground System Covered by Asphalt or Concrete

Covering a ground system with asphalt or concrete prevents moisture from reaching the soil underneath. This increases the ground resistance of grounding electrode system over time. When this situation cannot be prevented, electrolytic ground rods are highly recommended.

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# APPENDIX F ADDITIONAL INDUSTRY STANDARD INFORMATION

## F.1 NATIONAL ELECTRIC CODE (NFPA 70 NEC) - 2017

All Harris installations must be installed per NEC code and any applicable local electrical codes. The following sections are intended for information only. The latest revision of the NEC code should always be consulted directly during site installation.

### F.1.1 AC Entrance Terminology

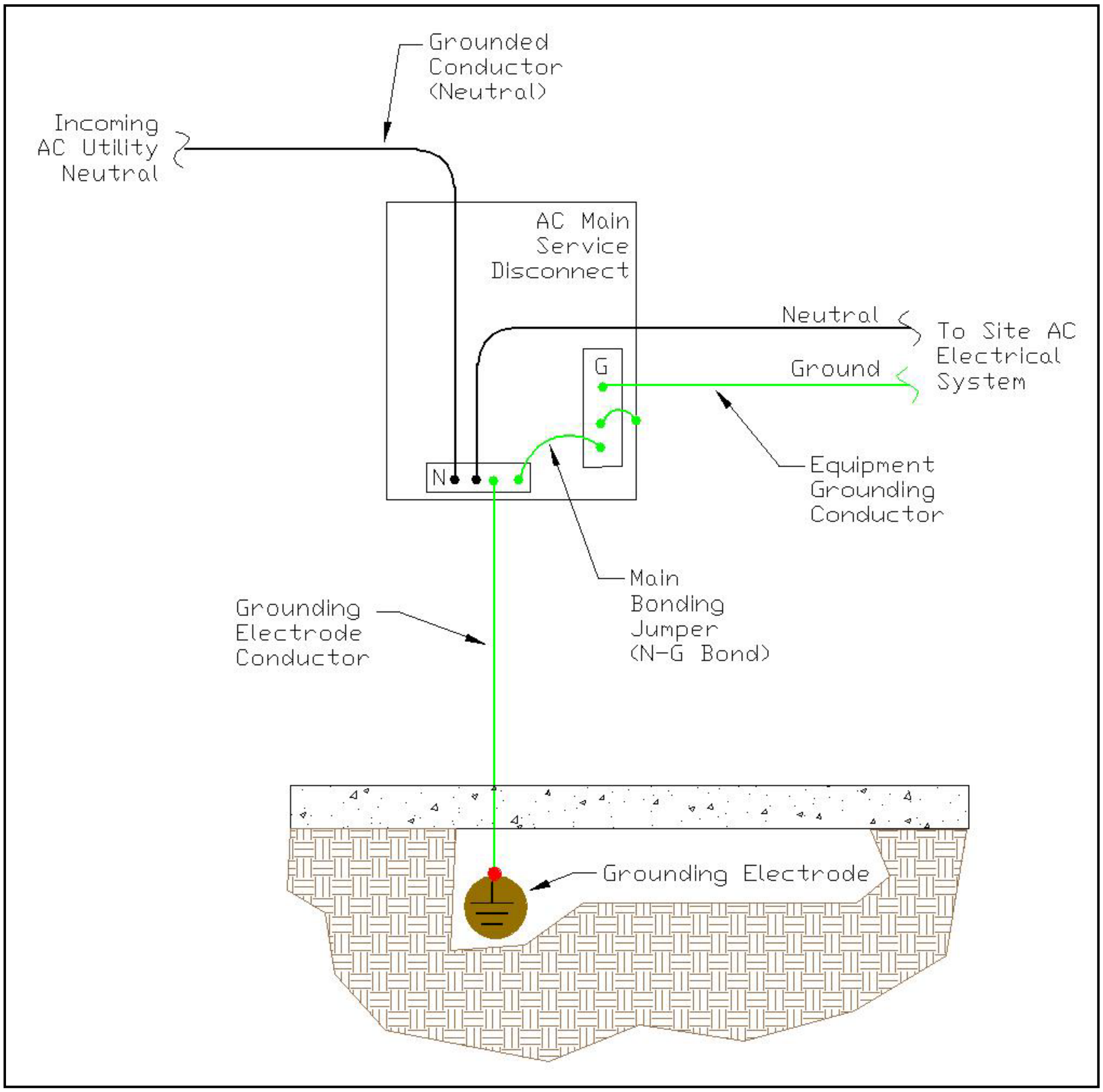


**Figure F-1: NEC Single Phase AC Bonding Terminology (For Information Only)**

### F.1.2 Sizing of Grounding Electrode Conductor for AC Electrical Systems

Sizing of the grounding electrode conductor for AC electrical systems is covered by *NEC code Article 250.66*, which includes *Table 250.66*. The following is an excerpt of *Table 250.66*.

**Table F-1: Sizing of Grounding Electrode Conductors (For Information Only)**

| Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors (AWG/kcmil) | | Size of Grounding Electrode Conductor (AWG/kcmil) | |
|---|---|---|---|
| **Copper** | **Aluminum or Copper-Clad Aluminum** | **Copper** | **Aluminum or Copper-Clad Aluminum** |
| 2 or smaller | 1/0 or smaller | 8 | 6 |
| 1 or 1/0 | 2/0 or 3/0 | 6 | 4 |
| 2/0 or 3/0 | 4/0 or 250 | 4 | 2 |
| Over 3/0 through 350 | Over 250 through 500 | 2 | 1/0 |
| Over 350 through 600 | Over 500 through 900 | 1/0 | 3/0 |
| Over 600 through 1100 | Over 900 through 1750 | 2/0 | 4/0 |
| Over 1100 | Over 1750 | 3/0 | 250 |

### F.1.3 Sizing of Grounding Electrode Conductor for DC Power Systems

Sizing of the DC equalization grounding electrode conductor for DC power systems is covered by *NEC code Article 250.166*.

There are several different situations covered in *NEC 250.166*. This section should always be referenced directly during installation.

For general information purposes, most Harris DC power systems that are two wire systems <50 Volts should have the DC equalization ground conductor sized to be no smaller than the largest conductor supplied by the DC power system, and not smaller than #8 AWG copper conductor.

## F.2 AC POWER SURGE PROTECTION STANDARDS OVERVIEW

Using the measures of performance provided in *UL 1449 – Third Edition or later* and the *IEEE C62.41.1™-2002, C62.41.2™-2002,* and *C62.45™-2002* standards, it is possible to make a meaningful comparison of SPDs, and objectively judge which devices are most effective in attenuating transient voltage surges of the sort most likely to occur in the intended application environments. More details on these standards follow.

### F.2.1 UL 1449 – Third Edition

*UL 1449 – Third Edition (Standard for Surge Protective Devices)*

This standard is now an ANSI standard that provides both safety testing and some performance testing. NEMA LS-1 has now been obsoleted.

Its Voltage Protection Rating (VPR) allows you to compare the performance of two AC SPDs. Voltage Protection Rating (VPR) is assigned to an SPD model by UL from a table based on the average of the measured limiting voltage from 3 impulses of a 6kV/3kA surge. The VPR is required to be marked on an AC SPD for each mode. The measured voltage protection level is rounded up to the following VPR assigned levels:

| | | | | | |
|---|---|---|---|---|---|
| 330V peak | 600V peak | 900V peak | 1500V peak | 2500V peak | 5000V peak |
| 400V peak | 700V peak | 1000V peak | 1800V peak | 3000V peak | 6000V peak |
| 500V peak | 800V peak | 1200V peak | 2000V peak | 4000V peak | |

Duty cycle testing is done at a given Nominal Discharge Current Rating ($I_n$). The manufacturer chooses the Nominal Discharge Current at which their SPD will be tested.

Type 1 – 10kA or 20kA

Type 2 – 3kA, 5kA, 10kA, or 20kA

The complete SPD is subjected to 15 surges at the chosen current one minute apart with rated voltage applied between surges. The let through voltage or VPR for a 6kV, 3kA surge is recorded before and after the test and must not deviate more than 10%.

To limit the possibility of frequent SPD replacements, a Maximum Continuous Operating Voltage (MCOV) of at least 125% of nominal voltage should be specified.

There is also now a Short Circuit Current Rating (SCCR) test defined for SPDs. The SPD is tested to be able to safely withstand this amount of current for 7 hours or interrupt this amount of current.

Refer to Table 6-1 and Figure 6-12 for UL 1449 AC SPD Type definitions.

### F.2.2 ANSI/IEEE C62.41.1 – 2002

***ANSI/IEEE C62.41.1 – 2002 (Guide on the Surge Environment in Low-Voltage (1000V and less) AC Power Circuits)***

Contains comprehensive information on surges and the environment in which they occur.

Two different scenarios distinguish between induced surges and direct lighting flash conducted surges.

- Scenario I describes surges coming from any source that are induced upon an installation or are generated within the installation by load switching. These surges are considered to be the majority of surge events.

- Scenario II covers surges that are associated with a possible direct lightning flash to a building, and with surge current that exits the building via the service entrance.

The surge environment is described using:

- Three location categories (C, B, or A) according to their position from the building service entrance. (These location categories apply only to induced surges in Scenario I.)

- Level of exposure to major sources of surges: lightning and load switching. These exposure levels are expressed from 1-3 (low to high).

This guide provides a surge environment description that serves as the basis for defining the waveforms in *ANSI/IEEE C62.41.2-2002*.

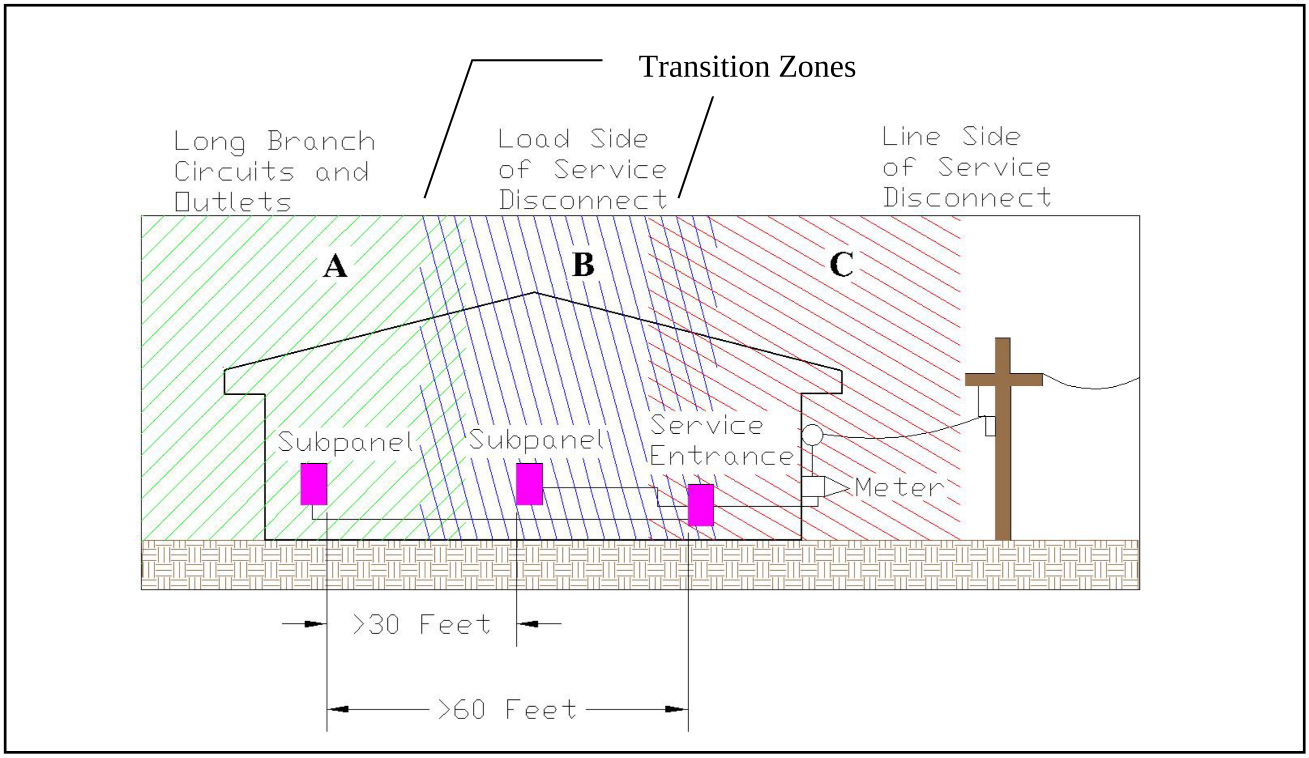


**Figure F-2: IEEE C62.41.1-2002 Location Categories**

### F.2.3 ANSI/IEEE C62.41.2 – 2002

***ANSI/IEEE C62.41.2 - 2002 (Recommended Practice on Characterization of Surges in Low-Voltage (1000V and less) AC Power Circuits)***

Presents recommendations on the selection of surge waveforms, amplitudes of surge voltages and currents used to evaluate equipment immunity and performance of SPDs.

It offers four waveforms that may be used as a simplified representation of a surge environment. They provide varying stress levels, as determined by the test waveforms and amplitudes, that may be selected to suit a particular SPD application. Two standard waveforms for general applications and two additional waveforms for special applications are recommended.

- The first standard waveform is the 0.5 µs/100 kHz “ring wave.” It is important in testing the SPDs higher-frequency response to transients created within a facility by interrupted load currents. This waveform is most applicable to SPDs used in *IEEE C62.41.1-2002* categories A and B away from the AC service entrance inside a building.

- The second standard waveform is the 1.2/50/8-20 µs “combination wave.” It defines two stress types: a voltage stress when the equipment presents a high impedance (open-circuit) and a current stress when the equipment presents a low impedance (short-circuit). This waveform is most applicable to SPDs used in *IEEE C62.41.1-2002* categories C and B.

- The first special application waveform is the 10/1000 µs “long wave.” It describes the *IEEE C62.41.1-2002* scenario II environment of a direct conducted lightning strike. This waveform is most applicable to SPDs used in *IEEE C62.41.1-2002* category C at the building AC service entrance.

- The second special application waveform is the “electrical fast transient burst.” Electrical fast transients occur as a result of arcing contacts in switches and relays used in inductive loads. This waveform is most applicable to SPDs used in *IEEE C62.41.1-2002* categories C and B.

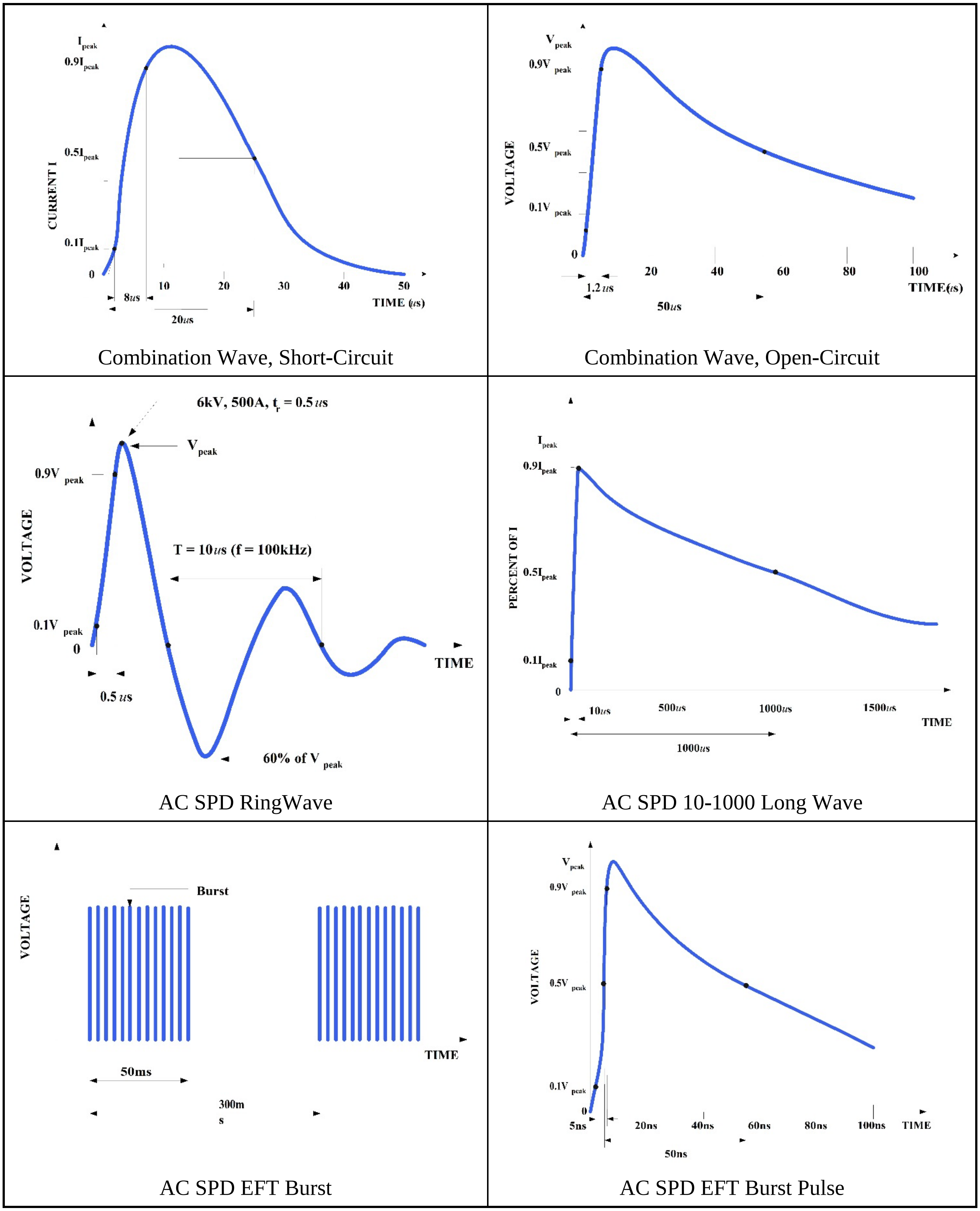


**Figure F-3: IEEE C62.41.2-2002 AC SPD Waveforms**

### F.2.4 ANSI/IEEE C62.45 – 2002

***ANSI/IEEE C62.45 -2002 (Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000V and less) AC Power Circuits)***

This section focuses on surge testing procedures, using the simplified waveform representations from A*NSI/IEEE C62.41.2-2002* to obtain reliable measurements and operator safety.

> Underwriters Laboratories, Inc. uses these guidelines as a reference in their performance and safety testing (*UL 1449 – Third Edition*) of SPDs.

This recommended practice specifies testing methodologies using off-the-shelf hardware. Test results should be repeatable in any adequately equipped UL testing laboratory. The "let-through" voltage or voltage protection level of an AC SPD is measured using *IEEE C62.41.2 – 2002* waveforms to approximate actual line transients. Each SPD will demonstrate a unique "signature" with each specified waveform input. These signatures can be compared by waveform. The lower and cleaner (implying smooth and without significant harmonic content) the signature, the better the performance.

Compliance with life cycle testing in accordance with *IEEE C62.45-2002* should also be used to ensure that SPDs have been tested with at least 10-1000 sequential impulses.

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# APPENDIX G GLOSSARY

| | |
|---|---|
| **Air Terminal** | Metallic rod used on top of structures as part of a lightning protection system. Also called a lightning rod. |
| **AC (Alternating Current)** | Electrical current which reverses direction repeatedly and rapidly due to a change in voltage that occurs at the same frequency. |
| **Ampere (AMP)** | Unit of current measurement - One ampere is the amount of current that will flow through a one ohm resistor when one volt is applied. |
| **Ancillary Support Equipment** | Equipment, such as air conditioning, fire suppression, etc., necessary for proper, reliable, and safe operation of the principal communications equipment |
| **ANSI** | American National Standards Institute |
| **Antenna** | Device that permits transmission and reception of radio frequency energy through space. |
| **Antioxidation Compound** | Oxide inhibiting joint compound applied between two surfaces to be connected together to improve electrical conductivity and enhance the integrity of the connection. |
| **ATS (Automatic Transfer Switch)** | High-current AC switch that automatically transfers a site’s AC main power connections from utility power to emergency backup power, usually from a generator, when a loss of power is sensed. |
| **AWG (American Wire Gauge)** | Standard used to describe the size of a wire. The larger the AWG number, the smaller diameter the described wire. Wires larger than 4/0 are measured using MCM ratings. |
| **Backfill** | Process of packing dirt into an open trench after conduits or pipes are installed. |
| **BET (Building Entrance Terminal)** | High surge current capacity telecommunications SPD installed as primary protection at the building entrance. |
| **Bi-Phase AC Feed** | Common AC feed configuration obtained by either a single center tapped transformer or by grounding one phase of a three-phase delta transformer. The former, often called single or split phase, is the common AC power feed for most non-industrial applications in North America. It contains two hot phases, 180 degrees from each other, with a center tap neutral return. Normally supplied as two 120 volt single phases with 240 volts available across both phases. The neutral return is usually earth grounded. |

| | |
|---|---|
| **Blue Sky Failure** | Equipment failure for no apparent reason occurring during fair weather conditions as a result of a previous lightning strike or surge event that did not disrupt operation or cause catastrophic failure at time of original event. |
| **Bonded** | Permanent joining of metallic parts to form an electrically conductive path. |
| **Bonding Jumper (Conductor)** | Conductor to ensure electrical conductivity between metal parts. |
| **Boot** | Waterproof, flexible sleeve installed around cables that pass through the wall of a communications site building. A boot is often associated with waterproofing and protecting RF transmission cables where they enter a shelter through the RF entry port. |
| **Burndy Connector** | Specific brand of high-compression irreversible crimp connector used in grounding applications. |
| **Bus Bar** | Metal bar used to carry electrical currents either to supply electrical circuits or to divert such currents to ground. Also see **Master Ground Bar (MGB).** |
| **C-tap** | C-shaped metallic compression connector used to join multiple conductors. The connector must be sized for the number and size of the conductors to be joined and installed with a high-compression crimp tool. |
| **Cable Ladder** | Open steel structure, suspended from the ceiling horizontally or mounted to a wall, providing an orderly means of support and routing for wires and cables throughout a room. It may also refer to vertically mounted steel structure on a tower for supporting cables going up the tower. |
| **Cable Duct/Tray** | Enclosed structure providing an orderly means of support and routing for wires and cables throughout a room. It may be located below a raised floor, suspended from the ceiling, or mounted on top of a row of equipment cabinets. |
| **Cadweld®** | Specific brand of exothermic weld often used generically to refer to any exothermic weld product or the actual process of exothermic welding. |
| **Combiner** | Passive device allowing multiple transmitters on different frequencies to use a single RF transmission line and antenna. |
| **Common Mode** | Signals or signal components referenced to ground. |
| **Compression Lug** | Grounding connector installed on the end of a conductor using a high-compression tool. |

| | |
|---|---|
| **Concrete-Encased Electrode** | Grounding electrode consisting of reinforcing rods and wire contained in a concrete footing. Electrical connections are made directly to the metal reinforcing rods. Concrete-encased electrodes are also called Ufer grounds. |
| **Conductor** | Substance offering little resistance to the flow of electrical currents. Copper wire is the most common form of conductor. |
| **Core Drilling** | Special drilling process creating a large diameter, circular hole through a concrete wall or floor. |
| **Coulomb** | Measurement of charge – Quantity of electricity that passes any point in an electric circuit in one second when the current is maintained constant at one ampere. |
| **Counterpoise** | Buried length of conductor usually around a tower or building. Same as a ground ring. |
| **Coupling** | Association of two or more signals in such a way that power or signal information is transferred from one to another. Coupling may take place through four different means: capacitive, inductive, resistive, or direct. |
| **Crimp Connection** | High-pressure mechanical compression connection between two conductors or a conductor and a termination connector. |
| **Crowbar** | To turn-on and clamp close to ground level |
| **Current** | Flow of electricity in a circuit measured in amperes. |
| **Current Rating** | Current-carrying capability of a conductor or wire - The National Electrical Code establishes current ratings for wire sizes and types for various applications. |
| **Daisy Chain** | Method of connecting conductors from one piece of equipment directly to a second piece of equipment and on to a third piece of equipment in a series arrangement such that removing the second connection point interrupts the ground path from the first piece of equipment to the third. |
| **Demarcation Point** | Telephone or utility point of presence at a facility dividing utility assets and maintenance responsibilities from customer assets and maintenance responsibilities. |
| **DC (Direct Current)** | Electrical current that flows in only one direction. |
| **Differential Mode** | Referenced only between conductors (not referenced to ground) |
| **Down Conductor** | Conductor used to bond lightning protection system on a building or tower to the buried ground system. |

| | |
|---|---|
| **Downrunner** | In a multipoint interior grounding system, the four corners of interior halo ground are often connected to the exterior buried ground system. The conductor used at each of the four corners are called downrunners or sometimes down conductors. This multipoint interior grounding system is no longer recommended for Harris installations. |
| **Driven Rod** | Metallic pipe or solid stake driven into the earth to provide a direct path to ground. It may be made of copper-clad steel, solid copper, or galvanized steel. A driven rod is one type of a grounding electrode. |
| **Drop** | Grounding conductor originating from a ground bus conductor “home run” going to a piece of equipment or cabinet. |
| **Duplexer** | RF filtering system separating the transmit and receive frequency, so equipment can transmit and receive simultaneously on a single antenna. |
| **E1** | Time division multiplexed digital link using 32 time slots with a speed of 2.048Mb/s. |
| **Earth** | Synonymous with ground |
| **Easement** | Interest in real property which is owned by another that entitles the holder to a specific limited use or enjoyment of the owner’s property. |
| **EDACS** | Enhanced Digital Access Communications System – Harris proprietary radio communications system |
| **Effectively Grounded** | Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of a voltage potential that may result in undue hazard to connected equipment or to personnel. |
| **EGB (External Ground Bar)** | Ground bus bar mounted on the exterior of a building below the RF entry port to provide a bonding point for multiple grounding conductors, specifically the RF transmission line ground kit connections. The EGB is bonded directly to buried external ground system, specifically the shelter ground ring. |
| **Electrolytic Ground Rod** | Ground rod in which the ability to dissipate charge is enhanced by chemical reaction with the soil. |
| **EMI (Electro Magnetic Interference)** | Broad spectrum noise or interfering signals |
| **EMP (Electro Magnetic Pulse)** | Very fast pulse (RF) which can be captured by antennas and long unshielded lines. Usually referred to as the manmade generation by detonation of a nuclear bomb at a high altitude. Sometimes referred to as NEMP, HEMP, etc. Lightning can also generate an EMP near the strike, referred to as LEMP. |

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| **EMT (Electrical Metallic Tubing)** | Metallic conduit tubing used for housing electrical conductors. |
| **ESD (Electrostatic Discharge)** | High-voltage, low-current electrical discharge resulting from the buildup of static charge between two surfaces. |
| **Ethernet** | Local Area Network (LAN) protocol specifying physical and lower software layers. |
| **ETSI** | European Telecommunications Standards Institute |
| **Exothermic Weld** | Method of permanently bonding two pieces of metal together with a controlled heat reaction resulting in a molecular bond. Commonly referred to as a Cadweld. |
| **Exposure Level** | Assessment of a communications site's risk of damage due to lightning based on its geographic location and the site's criticality to overall system operation. |
| **Faraday Shield** | Electrostatic (E field) shield made up of a conductive or partially conductive material or grid. A Faraday cage effectively shields the equipment inside the shelter from outside radiated RF energies. |
| **GFCI (Ground Fault Circuit Interrupter)** | Type of electrical receptacle to prevent electrical shock - It monitors the amount of electrical current flowing out and back in the wires of a branch circuit. If the device detects an unbalanced electric current flow, it immediately opens the circuit. |
| **GPS (Global Positioning System)** | Receiver system using high-precision signals from multiple satellites to provide exact position and timing references. |
| **Ground** | 1) Common reference point with a potential that does not change as a function of current supplied to it or withdrawn from it.<br>2) Conducting connection, whether intentional or accidental, between an object and the earth, or to some conducting body that serves in place of the earth. |
| **Grounding Conductor** | Means for bonding an object to the site grounding electrode system. |
| **Grounding Electrode** | Generic term for any NEC Article 250.52 defined means for providing an electrical connection to ground. Driven ground rods, electrolytic ground rods, concrete-encased electrodes, building steel, ground rings, ground plates, etc. are all types of grounding electrodes. |
| **Grounding Electrode Conductor** | Conductor connecting the incoming AC utility entrance neutral-ground bond to the grounding electrode. A grounding electrode conductor is also required at the neutral-ground bond on the output of a separately derived system. |

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| **Grounding Electrode System** | Buried system of interconnected grounding electrodes acting together as an integrated whole providing a lower ground resistance than a single grounding electrode. |
| **Ground Impedance** | Ground resistance and inductance/capacitance (reactance) value of the grounding system - The impedance of a typical grounding conductor increases as a function of frequency. |
| **Ground Loop** | Difference in electrical potential between two different interconnected points in a site's grounding system. A ground loop is usually caused by a conductive object being bonded to the ground system at more than one point, resulting in a potential between the two bond points. |
| **Ground Potential Rise** | Rapid localized rise in the ground potential due to a lightning strike or high voltage ground fault when the ground system cannot dissipate the surge current adequately. |
| **Ground Resistance** | Resistance value of a given ground rod or ground system - usually measured using a 3-point fall of potential test or a clamp-on meter test. (S**ee Appendix B, Grounding System Measurements.)** |
| **Ground Ring** | Buried length of conductor usually surrounding a structure or tower. The ground ring usually interconnects grounding electrodes installed along its path. |
| **Ground Rod** | Buried metallic rod used as a direct path to ground. It can be made of copper-clad steel, solid copper, galvanized steel or copper pipe filled with natural earth salts. A ground rod is one type of a grounding electrode. |
| **Ground Test Well** | Buried port allowing inspection of a connection to the grounding electrode system. |
| **H-Tap** | H-shaped metallic compression connector used to join multiple conductors. The connector must be sized for the number and size of the conductors to be joined and installed with a high-compression crimp tool. |
| **Halo** | Ring of ground conductor installed in a structure, usually just below the ceiling, to facilitate interconnection of ancillary equipment to ground. |
| **Home Run** | Ground bus conductor originating from the MGB or an SGB run along a row of equipment to provide convenient connecting points for each cabinet or piece of equipment. |

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| **Horseshoe Halo** | Ground bus conductor, made up of two separate halves each originating at the MGB, installed in a structure, usually just below the ceiling, to facilitate interconnection of ancillary equipment to ground. The horseshoe halo ground bus is a split or open halo ground bus, with the separation opposite the MGB creating the two halves. |
| **Ice Bridge** | Protective shield over a horizontal cable run between a tower and a shelter designed to prevent damage to cables from falling ice. |
| **IEEE (Institute of Electrical And Electronics Engineers)** | Professional society for electrical and electronic engineers |
| **IGZ (Isolated Ground Zone)** | Interior site grounding configuration in which equipment grounding is electrically isolated from the general facility grounding. |
| **Impedance** | Total opposition (resistance and reactance) a circuit offers to the flow of alternating current at a given frequency. |
| **Insertion Loss** | Device's RF power loss across a stated frequency range when inserted in series with a signal path. |
| **Joule** | Unit of energy - One joule for one second is equal to one watt of power. A joule is (current x voltage x time). |
| **Leakage Current** | Undesirable flow of current through or over a surface of an insulating material. |
| **Let-Through Voltage** | Voltage (at a specified current) allowed through a surge suppression device when the device is activated during a surge. |
| **Lightning Protection** | Air terminals, down conductors, and dedicated grounding electrode system designed to safely conduct lightning surge currents to ground. |
| **Lug** | Conductor termination allowing convenient connection to a bus bar or other object with one or two bolts or screws. |
| **MTS (Manual Transfer Switch)** | High-current AC switch that can be manually actuated to transfer a site's AC main power connections from utility power to emergency backup power, usually from a generator. |
| **Maximum Surge Current** | Maximum single surge current (for a specified waveform) a device can handle without failure during the conduction of the waveform and which ends the device's life. |
| **MCM (or KCMIL)** | 1000 Circular Mils; the standard for measuring the size of electrical wire larger than 4/0 AWG. Typical wire sizes are 250, 350, 500, and 750 MCM. The greater the MCM, the greater the diameter and ampacity of the wire. |

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| **MCOV (Maximum Continuous Operating Voltage)** | Maximum designated root-mean-square (RMS) value of power-frequency voltage that may be applied continuously between the terminals of an SPD. |
| **Mechanical Clamp** | Device mechanically tightened onto a conductor to secure it to another grounding element. |
| **Meter Pedestal** | Mounting base structure for the incoming AC utility electric service meter at communications site. |
| **MGB (Master Ground Bar)** | Single metal bar mounted inside a shelter or building to which all interior ground connections ultimately terminate. The MGB provides the ground reference inside the shelter since it is also connected to the exterior grounding electrode system. |
| **Mode** | AC line or conductor |
| **MOV (Metal Oxide Varistor)** | Surge suppression device in which resistance across the device markedly decreases when the voltage across the device reaches a specified threshold. |
| **Multicoupler** | RF device providing multiple outputs of a single RF input. |
| **Multimeter** | Test instrument used to measure voltage, current, and resistance. |
| **Multi-Strike Capability** | Surge suppression device designed to withstand a direct strike event and survive to work again. |
| **NEC (National Electrical Code)** | Governing code in the United States containing safety guidelines for all non-utility electrical installations. It is developed by the National Fire Protection Association (NFPA) and updated every three years. |
| **NFPA (National Fire Protection Association)** | Organization publishing standards such as the National Electrical Code (NEC) and the Lightning Protection Standards (NFPA 780). |
| **NEMA (National Electrical Manufacturers Association)** | Organization publishing standards for every sort of electrical device |
| **Noise** | Signal abnormality collectively referring to various kinds of high-frequency impulses that ride on the normal signal waveform. Noise can range from a few millivolts to several volts in amplitude creating erratic behavior in an electronic circuit. Noise may be generated by lightning, RF transmissions, or switching power supplies. |
| **Nomograph** | Arrangement of axes used for determining a variable by drawing a line which intersects known points on associated axes. |
| **NO-OX-ID®** | Specific brand of antioxidation compound. |

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| **Ohm** | Unit of measurement of electrical resistance |
| **Ohm's Law** | Formula establishing the relationship between voltage, current and resistance - usually expressed as **V = I x R** where V is the voltage, I is the current, and R is the resistance. |
| **OpenSky** | Wireless communication system that enables simultaneous data and voice communications between wireless devices (portable radios, mobile radios, etc.) and fixed end systems (dispatchers, voice consoles, etc.), using an IP compatible network. Harris TDMA radio communications system |
| **P25** | APCO Project 25; common name for the TIA-102 suite of specifications |
| **P25$^{IP}$ (P25 to the power of IP)** | Harris's Internet Protocol (IP)-based mobile radio communications system developed for users requiring Project 25 (P25) compliant systems. |
| **PANI (Surge Energy Producers, Absorbers, Non-Isolated Ground, and Isolated Ground)** | Method of bonding conductors to the MGB in a specific order, depending on their origin. Connection order is meant to provide maximum isolation for sensitive equipment grounds from surge producing grounds. |
| **Phase** | Type of electric service provided by the AC utility. Typical AC services include single-phase (for residential and small commercial facilities) and three-phase (for large commercial and industrial facilities). |
| **Plat** | Document depicting the legal ownership boundaries of a specific parcel of land. |
| **Plenum** | Compartment or chamber inside a building to which one or more air ducts are connected and forming part of the air distribution system. |
| **Potential** | Difference in voltage between two points in a circuit or between two objects. |
| **Power** | Measurement of electrical work usually measured in watts and expressed as (Voltage x Current). |
| **PSTN** | Public Switched Telephone Network. |
| **Pulse Life** | Number of surges of specified voltage, current amplitude, and wave shapes that may be applied to an AC surge suppression device. The pulses are sufficiently spaced in time to preclude the effects of cumulative heating. |
| **Rack** | Standard upright open mounting frame used for supporting equipment. |
| **Receiver Multicoupler** | RF device providing multiple outputs of a single RF input. |

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| **Resistance** | Opposition to the flow of current in an electrical circuit expressed in ohms. |
| **Resistivity** | Measure of the resistance of a material to electric current through its volume. |
| **RF** | Radio frequency - any and all frequencies that can be radiated as an electromagnetic wave (plane wave). |
| **RF Entry Port** | Location in a shelter or building where the RF transmission cables pass through the wall - The RF entry port is usually a device installed in a cutout in the wall providing weatherproofing and protection for multiple sizes and shapes of RF transmission cables. An RF entry port may be sized for a single cable or for multiple cables. Some RF entry ports integrate clamps for the RF cable shields and grounding straps for bonding the RF entry port to the exterior ground system. |
| **RFI (Radio Frequency Interference)** | Broad spectrum noise or interfering signals. |
| **RF Transmission Line** | Physical cable connection, either impedance-matched coaxial cable or semi-rigid/rigid waveguide, between RF elements (such as a repeater and an antenna). |
| **SAD (Silicon Avalanche Diode)** | Surge suppression device in which resistance across the device markedly decreases when the voltage across the device reaches a specified threshold. |
| **Safety Ground** | AC electrical ground wire "green wire" providing a ground path for a possible AC voltage ground fault. The safety ground should only carry current when there is a ground fault. |
| **Sag** | AC power under-voltage condition lasting more than one cycle. A sag is the opposite of a surge. |
| **Sandwich Bus Bar** | Two bus bars bolted together with thin copper straps captured between them. The bus bars provide a solid surface to attach other grounding conductors. This arrangement allows copper straps to be securely attached to a buried ground ring. |
| **Separately Derived System** | AC power system derived from a transformer or converter winding. No direct electrical connection exists between the input and output of the power system so the neutral-ground bond must be reestablished on the output. |
| **Service Entrance** | Point where the AC utility enters a facility. |

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| **Service Entrance Conductors** | Conductors running from the customer service equipment to the box or transition cabinet closest to the building, or to the weatherhead for overhead services. Service entrance conductors are distinct from service laterals that run from the Utility to the box or transition cabinet. Service entrance conductors are the responsibility of the property owner. The Utility maintains the service lateral conductors to the service point. |
| **Service Neutral Conductor** | Neutral, or common wire, usually grounded at both the distribution transformer and the service entrance means. Single-phase service uses two hot wires and one neutral conductor. Three-phase service uses three hot wires and one neutral conductor. |
| **Service Type** | Type of AC service provided by the AC utility provider to a site. |
| **SGB (Supplementary Ground Bar)** | Metal bus bar mounted inside a shelter or building providing a collection point for multiple ground connections from a remote room or from dense collection of similar types of devices within the same room. The SGB is directly connected back to the MGB serving as a extension. |
| **Shelter** | Permanent structure built on a foundation containing the communications equipment and its necessary ancillary support equipment. |
| **Shelter Ground Ring** | Buried ring of wire conductor surrounding the equipment shelter or building at a communications site. The ground ring bonds grounding electrodes together that encircle the shelter. |
| **Shield** | 1) Metallic housing, screen, or cover that substantially reduces the coupling of electric and electro-magnetic fields into or out of a cable, conductor, or circuit.<br><br>2) Physical barrier preventing the accidental contact of an object or person with parts or components operating at hazardous voltage levels. |
| **Shunt Protector** | Surge protection device connected in parallel, not series. No power or signal passage through unit. |
| **Single Phase** | Simplest AC power configuration having one or two hot conductors, a return neutral conductor, and a safety ground conductor. Both voltage waveforms on the hot conductors are in phase. 240 VAC is available between the two hot conductors, or 120 VAC is available between one hot conductor and neutral conductor. |
| **Skin Effect** | Tendency of RF currents to flow on/near the surface of a conductor. |

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| **Soil Resistivity Test** | Test measuring the resistivity of soil at a specific location. |
| **SPD (Surge Protection Device)** | Device installed between two conductors or between a single conductor and ground to protect equipment against surges, spikes and other over voltages. |
| **Spike** | Fast AC power over-voltage condition lasting less than one cycle with typically more than twice the line voltage. Power spikes are usually caused by lightning, utility switching, static discharges, or switching of large electrical loads. |
| **Stub** | Grounding conductor bonded to the buried exterior ground system that is left unterminated above ground after initial installation in expectation of providing a ground connection for an object to be installed at a later date. |
| **Surge** | AC power over-voltage condition lasting longer than one cycle. A surge is usually more dangerous than a spike because of the duration, rather than the magnitude of the over-voltage. A surge is the opposite of a sag. |
| **Swell** | Longer AC power over-voltage condition with duration lasting between one cycle to a few seconds. |
| **T1** | Time division multiplexed digital link using 24 time slots with a speed of 1.544Mb/s. |
| **TDM (Time Division Multiplexed)** | Communication scheme in which data from several sources share a common link. Each source is allotted access to the link on a sequential time access basis. The aggregate of all the time slots for a given period is referred to as a “frame”. |
| **Telco** | Telephone company. |
| **Telecommunications** | Transmission, emission, and reception of information by cable, radio, optical, or other electromagnetic systems. |
| **Telecommunications Main Ground Bar** | Bus bar placed in a convenient and accessible location for grounding nearby telecommunications and other electronic equipment. The telecommunications main ground bar is ultimately bonded back to the building’s MGB. |
| **TGB (Tower Ground Bar)** | Ground bus bar mounted at the bottom of a tower to provide a bonding point for multiple grounding conductors, specifically the RF transmission line ground kit connections located at the drip loop where the lines leave the tower. The TGB is bonded directly to the buried external ground system, specifically the tower ground ring. |

**Three Phase** AC utility feed power configuration having three hot conductors with phases 120 degrees apart. The wye configuration uses a fourth wire as a grounded neutral return. The delta configuration has no reference to ground so it is more susceptible to high surge currents. Three phase power configurations are most often used for large facilities or industrial facilities.

**TIA** Telecommunications Industry Association

**Tower** Structure supporting one or more antennas at a communications site.

**Tower Ground Ring** Buried ring of wire conductor surrounding the tower at a communications site. The ground ring bonds grounding electrodes together that encircle the tower.

**Transfer switch** High-current AC switch that transfers a site's AC main power connections from utility power to emergency backup power, usually from a generator. The switch may actuate automatically when a loss of power is sensed, or it may be actuated manually.

**TVSS (Transient Voltage Surge Suppressor)** Device installed between two conductors or between a single conductor and ground to protect equipment against surges, spikes and other over voltages. Another name for an SPD.

**Turn-On Time - Gas Tube "Firing"** Amount of time between when the ramp voltage barely exceeds the turn-on voltage of the device and the point at which 50% of the peak voltage is achieved during the turn-on (crowbar) process.

**TTA (Tower Top Amplifier)** Weatherproof RF receive amplifier module mounted on the tower adjacent to the receive antenna. It is used to boost receive signal levels.

**Ufer Ground** Grounding electrode consisting of reinforcing rods and wire contained in a concrete footing. Electrical connections are made directly to the metal reinforcing rods. Ufer grounds are more properly called concrete-encased electrodes.

**UL (Underwriter's Laboratory)** Non-profit organization established by the insurance industry to test devices, materials and systems for safety.

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| **UPS (Uninterruptible Power Supply)** | Power system providing AC line power to equipment if primary power fails. A UPS converts DC power from a set of batteries to AC line power. Only a UPS provides protection from primary power under-voltages and sags.<br><br>Two types of UPS designs exist, online and offline. Online, true double conversion, units use the primary power only to charge its batteries. The UPS output is always provided from its batteries. Offline UPS designs pass primary power through to its output and only switch to power provided from its batteries when a loss of primary power is sensed. Though offline UPS designs may provide some filtering from primary power transients, an online UPS provides the maximum protection from primary power transients. |
| **Volt** | Unit of measure of electromotive force **-** The difference of potential required to make a current of one ampere flow through a resistance of one ohm. |
| **Voltage Rating** | Designated maximum permissible operating voltage between an SPD's terminals at which it is designed to perform. |
| **VPL (Voltage Protection Level)** | Voltage at which clamping occurs in an SPD |
| **VSWR (Voltage Standing Wave Ratio)** | Ratio of the amplitude or voltage at a voltage maximum to that of an adjacent voltage minimum in a stationary wave system (such as a coaxial cable). |
| **Watt** | Unit of measurement of electrical power or rate of work equal to one joule per second. |

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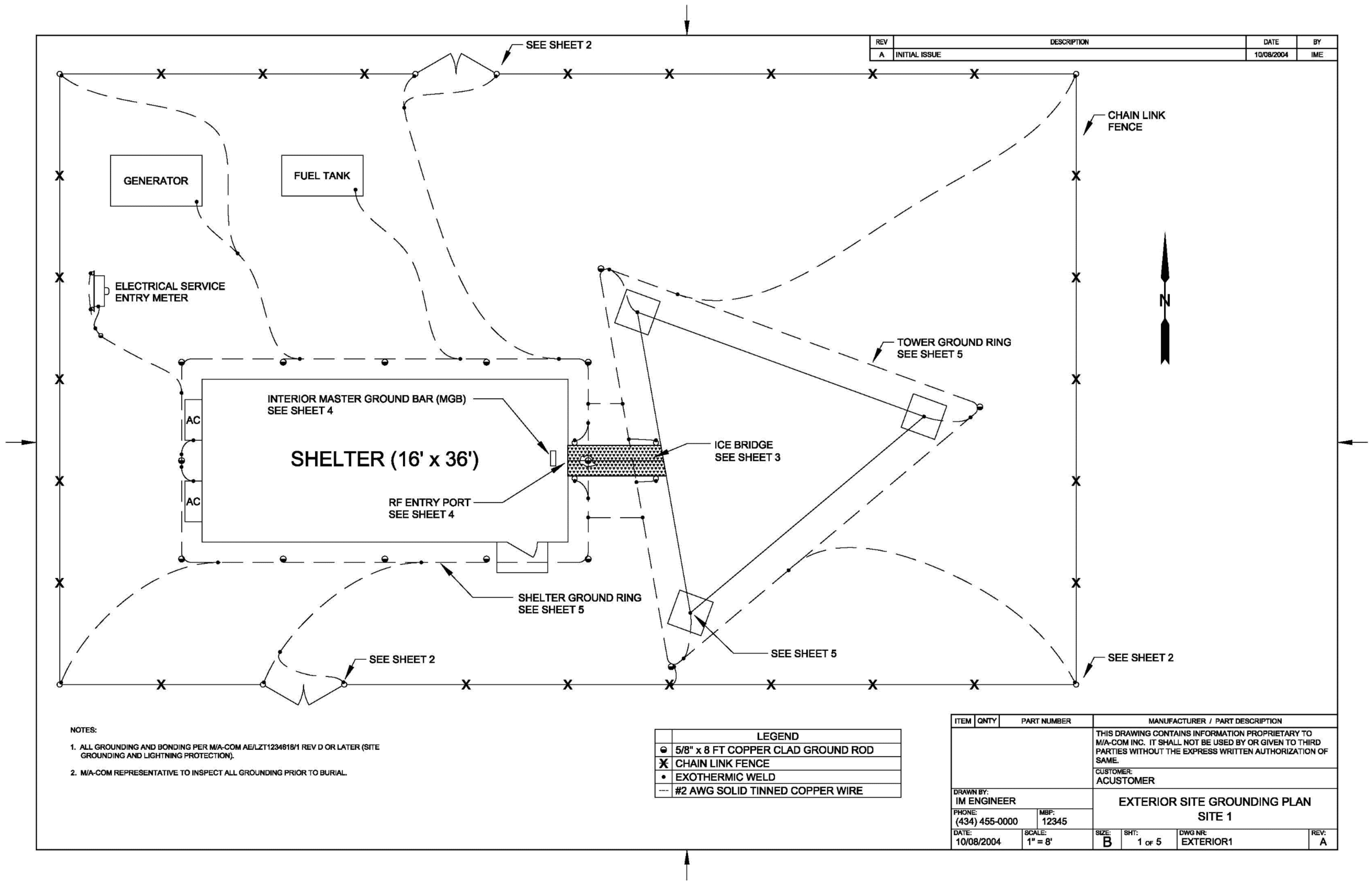
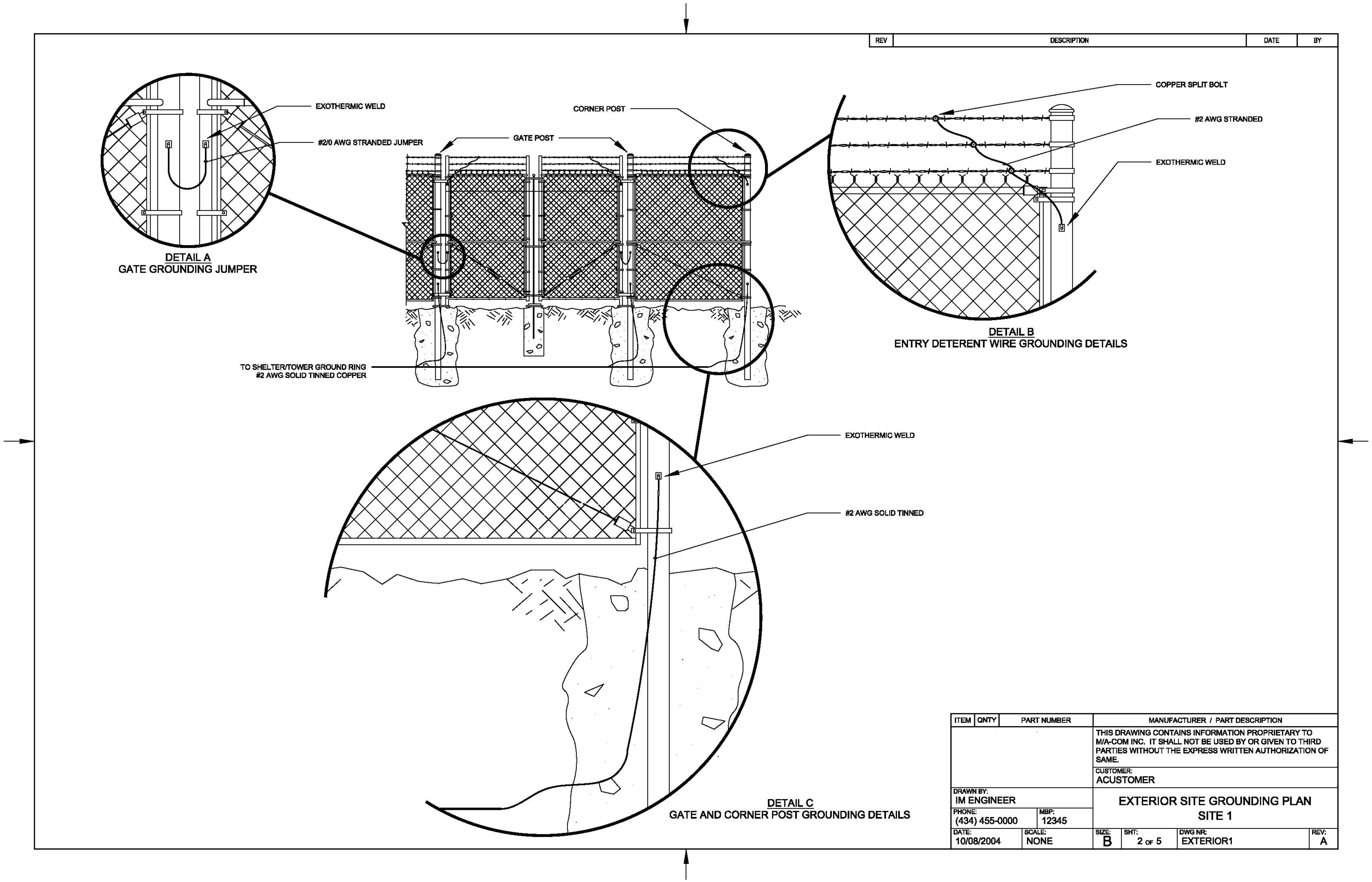
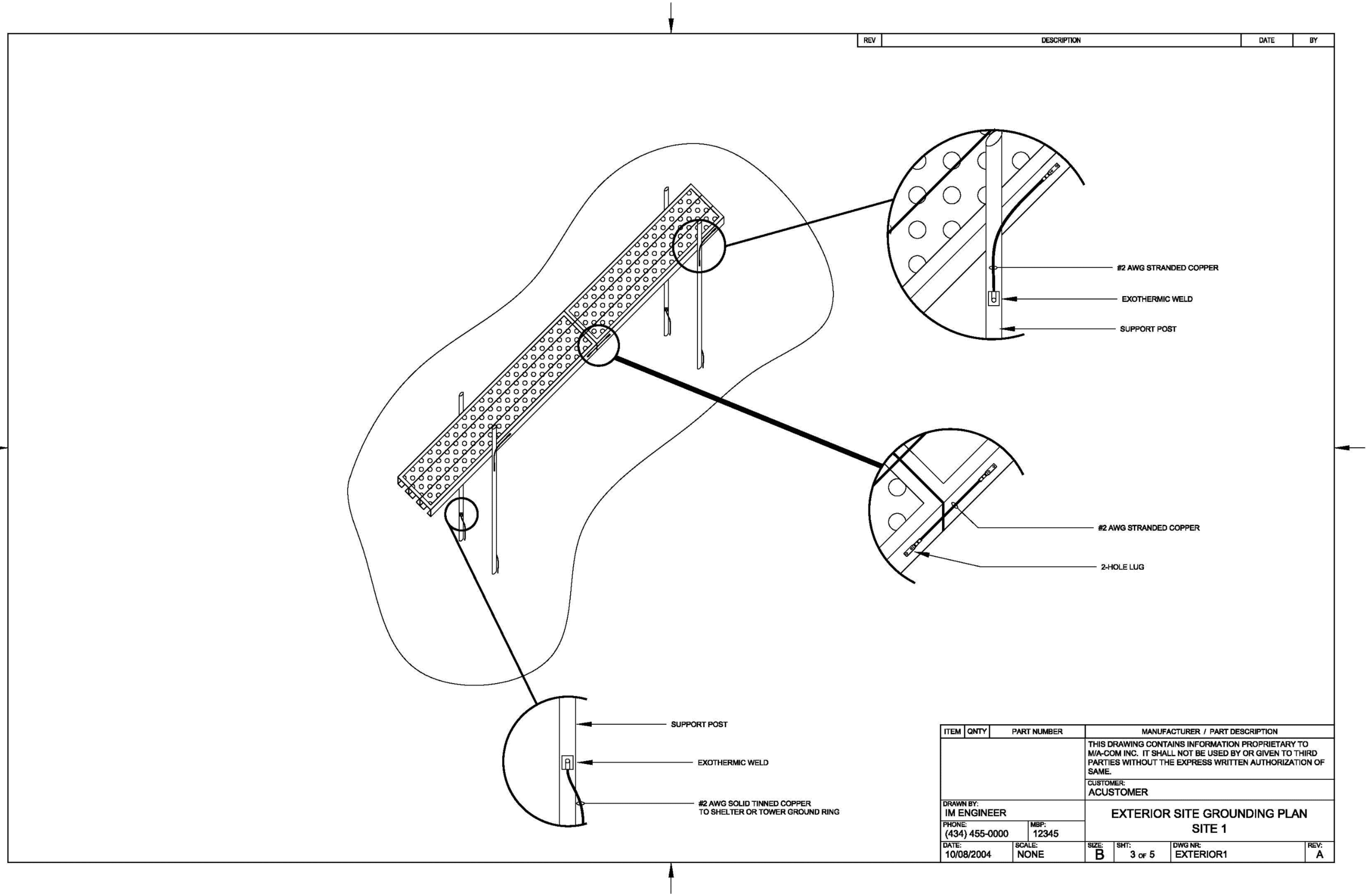
# APPENDIX H SAMPLE GROUNDING DESIGN DRAWINGS




REV
DESCRIPTION
DATE
BY
EXOTHERMIC WELD
#2/0 AWG STRANDED JUMPER
DETAIL A
GATE GROUNDING JUMPER
CORNER POST
GATE POST
TO SHELTER/TOWER GROUND RING
#2 AWG SOLID TINNED COPPER
COPPER SPLIT BOLT
#2 AWG STRANDED
EXOTHERMIC WELD
DETAIL B
ENTRY DETERENT WIRE GROUNDING DETAILS
EXOTHERMIC WELD
#2 AWG SOLID TINNED
DETAIL C
GATE AND CORNER POST GROUNDING DETAILS
ITEM
QNTY
PART NUMBER
MANUFACTURER / PART DESCRIPTION
THIS DRAWING CONTAINS INFORMATION PROPRIETARY TO M/A-COM INC. IT SHALL NOT BE USED BY OR GIVEN TO THIRD PARTIES WITHOUT THE EXPRESS WRITTEN AUTHORIZATION OF SAME.
CUSTOMER:
ACUSTOMER
DRAWN BY:
IM ENGINEER
PHONE:
(434) 455-0000
MBP:
12345
EXTERIOR SITE GROUNDING PLAN
SITE 1
DATE:
10/08/2004
SCALE:
NONE
SIZE:
B
SHT:
2 OF 5
DWG NR:
EXTERIOR1
REV:
A


REV
DESCRIPTION
DATE
BY
#2 AWG STRANDED COPPER
EXOTHERMIC WELD
SUPPORT POST
#2 AWG STRANDED COPPER
2-HOLE LUG
SUPPORT POST
EXOTHERMIC WELD
#2 AWG SOLID TINNED COPPER
TO SHELTER OR TOWER GROUND RING
ITEM
QNTY
PART NUMBER
MANUFACTURER / PART DESCRIPTION
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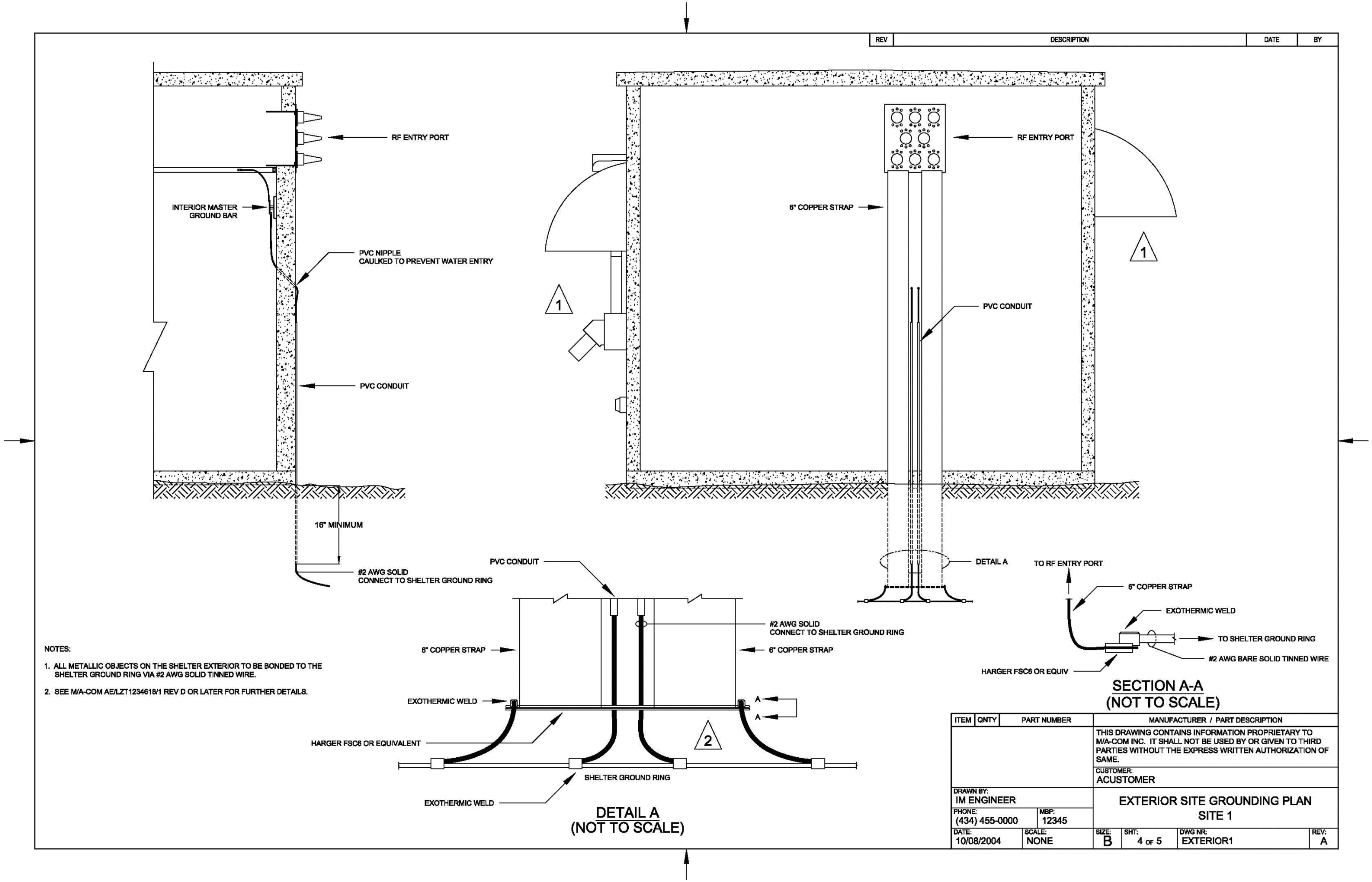
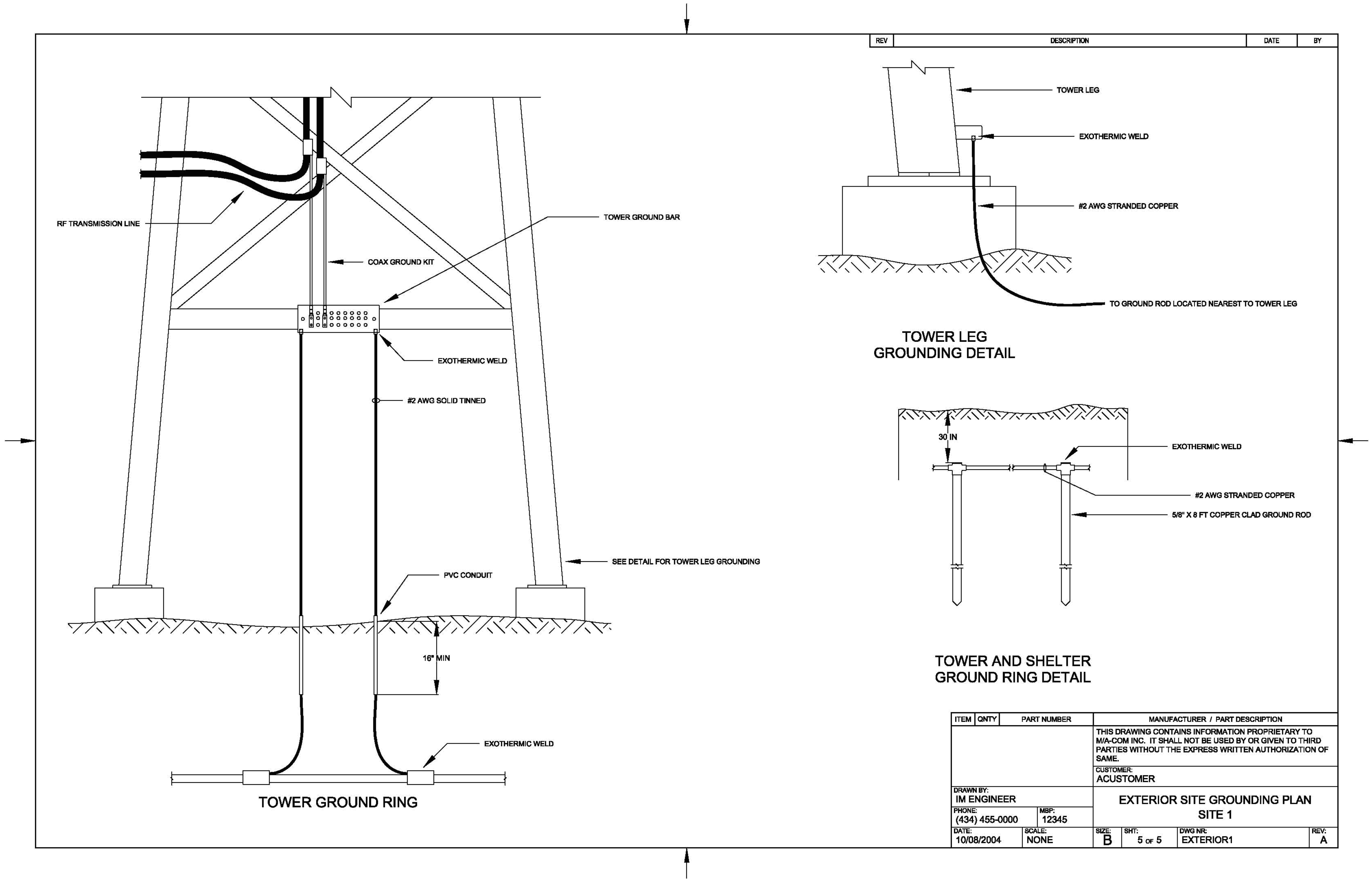
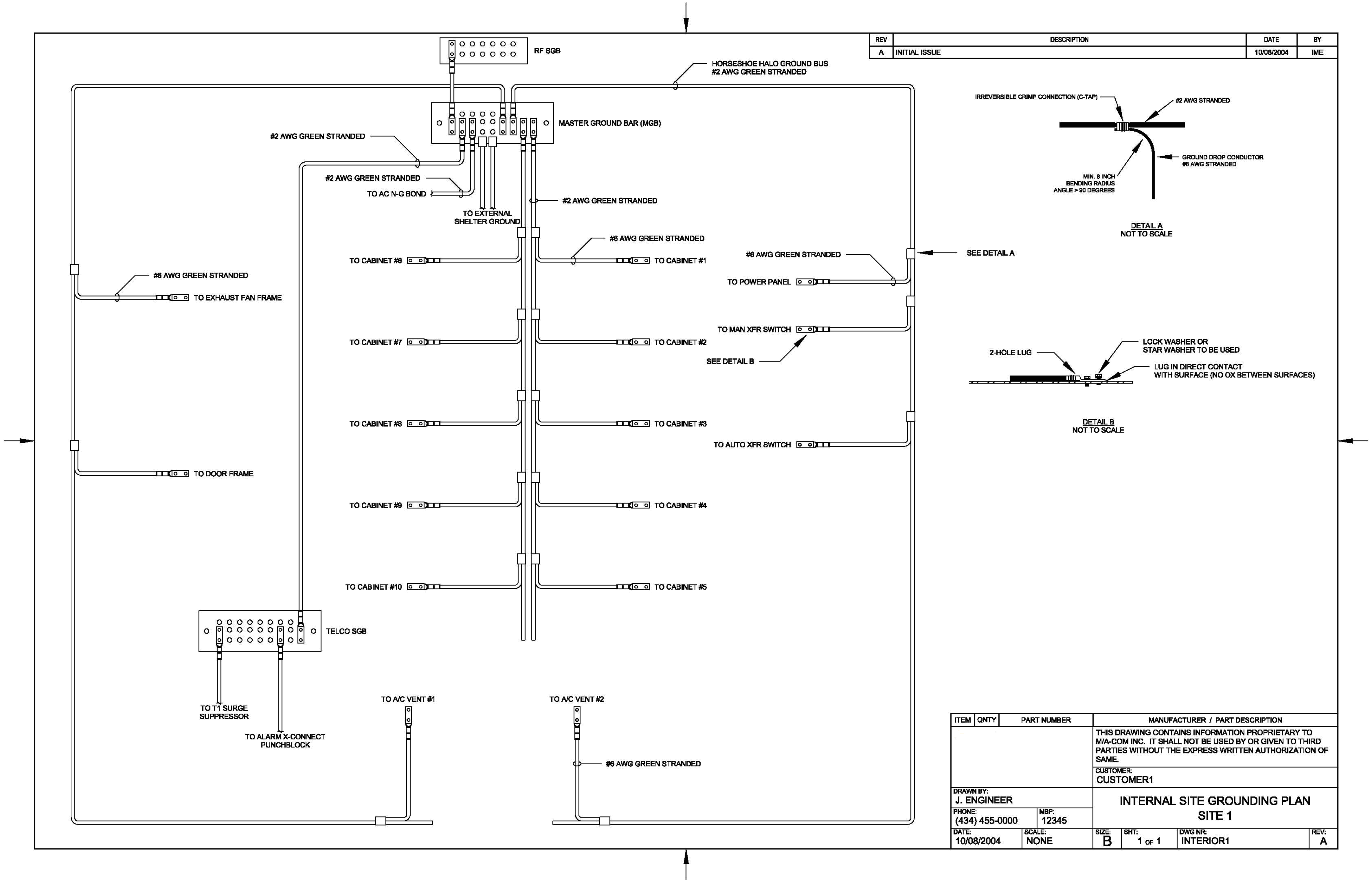
CUSTOMER:
ACUSTOMER
DRAWN BY:
IM ENGINEER
PHONE:
(434) 455-0000
MBP:
12345
EXTERIOR SITE GROUNDING PLAN
SITE 1
DATE:
10/08/2004
SCALE:
NONE
SIZE:
B
SHT:
3 OF 5
DWG NR:
EXTERIOR1
REV:
A


REV
DESCRIPTION
DATE
BY
RF ENTRY PORT
INTERIOR MASTER GROUND BAR
PVC NIPPLE CAULKED TO PREVENT WATER ENTRY
PVC CONDUIT
16" MINIMUM
#2 AWG SOLID CONNECT TO SHELTER GROUND RING
RF ENTRY PORT
6" COPPER STRAP
PVC CONDUIT
DETAIL A
1
1
NOTES:
1. ALL METALLIC OBJECTS ON THE SHELTER EXTERIOR TO BE BONDED TO THE SHELTER GROUND RING VIA #2 AWG SOLID TINNED WIRE.
2. SEE M/A-COM AE/LZT1234618/1 REV D OR LATER FOR FURTHER DETAILS.
PVC CONDUIT
#2 AWG SOLID CONNECT TO SHELTER GROUND RING
6" COPPER STRAP
6" COPPER STRAP
EXOTHERMIC WELD
A
A
HARGER FSC6 OR EQUIVALENT
2
SHELTER GROUND RING
EXOTHERMIC WELD
DETAIL A
(NOT TO SCALE)
TO RF ENTRY PORT
6" COPPER STRAP
EXOTHERMIC WELD
TO SHELTER GROUND RING
#2 AWG BARE SOLID TINNED WIRE
HARGER FSC6 OR EQUIV
SECTION A-A
(NOT TO SCALE)
ITEM
QNTY
PART NUMBER
MANUFACTURER / PART DESCRIPTION
THIS DRAWING CONTAINS INFORMATION PROPRIETARY TO M/A-COM INC. IT SHALL NOT BE USED BY OR GIVEN TO THIRD PARTIES WITHOUT THE EXPRESS WRITTEN AUTHORIZATION OF SAME.
CUSTOMER:
ACUSTOMER
DRAWN BY:
IM ENGINEER
EXTERIOR SITE GROUNDING PLAN
SITE 1
PHONE:
(434) 455-0000
MBP:
12345
DATE:
10/08/2004
SCALE:
NONE
SIZE:
B
SHT:
4 OF 5
DWG NR:
EXTERIOR1
REV:
A


REV
DESCRIPTION
DATE
BY
RF TRANSMISSION LINE
TOWER GROUND BAR
COAX GROUND KIT
EXOTHERMIC WELD
#2 AWG SOLID TINNED
SEE DETAIL FOR TOWER LEG GROUNDING
PVC CONDUIT
16" MIN
EXOTHERMIC WELD
TOWER GROUND RING
TOWER LEG
EXOTHERMIC WELD
#2 AWG STRANDED COPPER
TO GROUND ROD LOCATED NEAREST TO TOWER LEG
TOWER LEG GROUNDING DETAIL
30 IN
EXOTHERMIC WELD
#2 AWG STRANDED COPPER
5/8" X 8 FT COPPER CLAD GROUND ROD
TOWER AND SHELTER GROUND RING DETAIL
ITEM
QNTY
PART NUMBER
MANUFACTURER / PART DESCRIPTION
THIS DRAWING CONTAINS INFORMATION PROPRIETARY TO M/A-COM INC. IT SHALL NOT BE USED BY OR GIVEN TO THIRD PARTIES WITHOUT THE EXPRESS WRITTEN AUTHORIZATION OF SAME.
CUSTOMER:
ACUSTOMER
DRAWN BY:
IM ENGINEER
PHONE:
(434) 455-0000
MBP:
12345
EXTERIOR SITE GROUNDING PLAN
SITE 1
DATE:
10/08/2004
SCALE:
NONE
SIZE:
B
SHT:
5 OF 5
DWG NR:
EXTERIOR1
REV:
A


REV
DESCRIPTION
DATE
BY
A
INITIAL ISSUE
10/08/2004
IME
RF SGB
HORSESHOE HALO GROUND BUS
#2 AWG GREEN STRANDED
MASTER GROUND BAR (MGB)
#2 AWG GREEN STRANDED
#2 AWG GREEN STRANDED
TO AC N-G BOND
TO EXTERNAL
SHELTER GROUND
#2 AWG GREEN STRANDED
#6 AWG GREEN STRANDED
#6 AWG GREEN STRANDED
SEE DETAIL A
TO CABINET #6
TO CABINET #1
TO POWER PANEL
#6 AWG GREEN STRANDED
TO EXHAUST FAN FRAME
TO MAN XFR SWITCH
SEE DETAIL B
TO CABINET #7
TO CABINET #2
TO CABINET #8
TO CABINET #3
TO AUTO XFR SWITCH
TO DOOR FRAME
TO CABINET #9
TO CABINET #4
TO CABINET #10
TO CABINET #5
TELCO SGB
TO T1 SURGE
SUPPRESSOR
TO ALARM X-CONNECT
PUNCHBLOCK
TO A/C VENT #1
TO A/C VENT #2
#6 AWG GREEN STRANDED
IRREVERSIBLE CRIMP CONNECTION (C-TAP)
#2 AWG STRANDED
GROUND DROP CONDUCTOR
#6 AWG STRANDED
MIN. 8 INCH
BENDING RADIUS
ANGLE > 90 DEGREES
DETAIL A
NOT TO SCALE
2-HOLE LUG
LOCK WASHER OR
STAR WASHER TO BE USED
LUG IN DIRECT CONTACT
WITH SURFACE (NO OX BETWEEN SURFACES)
DETAIL B
NOT TO SCALE
ITEM
QNTY
PART NUMBER
MANUFACTURER / PART DESCRIPTION
THIS DRAWING CONTAINS INFORMATION PROPRIETARY TO
M/A-COM INC. IT SHALL NOT BE USED BY OR GIVEN TO THIRD
PARTIES WITHOUT THE EXPRESS WRITTEN AUTHORIZATION OF
SAME.
CUSTOMER:
CUSTOMER1
DRAWN BY:
J. ENGINEER
PHONE:
(434) 455-0000
MBP:
12345
INTERNAL SITE GROUNDING PLAN
SITE 1
DATE:
10/08/2004
SCALE:
NONE
SIZE:
B
SHT:
1 OF 1
DWG NR:
INTERIOR1
REV:
A

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