

EXTERNAL GROUNDING (EARTHING)

This chapter provides requirements and guidelines for designing and installing the external grounding (earthing) electrode system at a communications site.

This chapter provides information on the following topics:

- “Lightning Activity and Exposure” on page 4-3
- “Common Grounding (Earthing)” on page 4-5
- “Grounding (Earthing) Electrode System Component and Installation Requirements” on page 4-7
- “Dissimilar Metals and Corrosion Control” on page 4-34
- “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40
- “Minimum Site Grounding (Earthing) Requirements” on page 4-44
- “Grounding (Earthing) Roof-Mounted Antenna Masts and Metal Support Structures” on page 4-74
- “Grounding (Earthing) Rooftop Mounted Tower Structures” on page 4-79
- “Special Grounding (Earthing) Applications” on page 4-81
- “Special Grounding (Earthing) Situations” on page 4-88

NOTE: Throughout this chapter the terms *grounding* and *earthing* are used synonymously.

4.1 INTRODUCTION

The requirements and guidelines in this chapter are derived from a compilation of local and national codes, widely accepted industry codes and standards, and good engineering practices. Such codes and standards are from, but not limited to, the following standards organizations:

- Alliance for Telecommunications Industry Solutions (ATIS)
- American National Standards Institute (ANSI)
- Australian Standards® (AS)
- British Standards Institution (BS)
- International Association of Electrical Inspectors (IAEI)
- International Electrotechnical Commission (IEC)
- Institute of Electrical and Electronics Engineers (IEEE)
- National Fire Protection Association (NFPA)
- Telecommunications Industry Association (TIA)
- Underwriters Laboratories (UL)
- United States Department of Defence (DoD)
- United States Federal Aviation Administration (FAA)
- United States National Weather Service

References to the specific industry codes and standards on which this chapter is based are provided throughout. The requirements and guidelines in this chapter are provided to enhance personnel safety and equipment reliability.

Safety of personnel and protection of sensitive electronic equipment from ground faults, lightning, ground potential rise, electrical surges, and power quality anomalies is of utmost importance at any communications site. Though unexpected electrical events like lightning strikes and power surges cannot be prevented, this chapter provides design and installation information on communications site grounding electrode systems that may help minimize damage caused by these events.

**CAUTION**

Grounding (earthing) and bonding alone are not enough to adequately protect a communications site. Transient voltage surge suppression (TVSS) techniques, using appropriate surge protection devices (SPD), shall be incorporated at a communications site in order to provide an adequate level of protection. See Chapter 7, “Surge Protective Devices,” for details and requirements.

A grounding electrode system **shall** have low electrical impedance, with conductors large enough to withstand high fault currents. The lower the grounding electrode system impedance, the more effectively the grounding electrode system can dissipate high-energy impulses into the earth.

**WARNING**

The AC power system ground shall be sized appropriately for the electrical service and shall be approved by the local authority having jurisdiction.

All site development and equipment installation work **shall** comply with all applicable codes in use by the authority having jurisdiction. Grounding systems **shall** be installed in a neat and workmanlike manner (NFPA 70-2005, Article 110.12 and NFPA 780-2004, section 1.4). Where conflicting, the more stringent standard should be followed. Government and local codes **shall** take precedence over the requirements of this manual.

Unusual site conditions may require additional effort to achieve an effectively bonded and grounded (earthed) site. See “Special Grounding (Earthing) Situations” on page 4-88 in these instances. Consultation with Motorola Engineering or an engineering firm specializing in grounding electrode system design is recommended.

Some of the benefits of a properly designed and installed low-impedance grounding electrode system are described below (See ANSI T1.333-2001, section 4; ANSI T1.334-2002, section 5.1; BS 7430:1998; IEC 60364-1; IEEE STD 142-1991, section 1.3; IEEE STD 1100-1999, section 3.3.1; and NFPA 70-2005, Article 250.4 for additional information):

- To help limit the voltage caused by accidental contact of the site AC supply conductors with conductors of higher voltage.
- To help dissipate electrical surges and faults, to minimize the chances of injury from grounding system potential differences.
- To help limit the voltages caused by lightning.
- To help maintain a low potential difference between exposed metallic objects.

- To stabilize the AC voltage relative to the earth under normal conditions.
- To contribute to reliable equipment operation.
- To provide a common signal reference ground.

4.2 LIGHTNING ACTIVITY AND EXPOSURE

Communications facilities **shall** be defined as exposed to lightning unless thunderstorm activity in the area is an average of five thunderstorm-days per year or fewer and soil resistivity at the site is less than 10,000 ohm-centimeters (Ω -cm). The soil resistivity **shall** be measured as described in ANSI/IEEE STD 81. (ANSI T1.313-2003, section 5.1.1) See Appendix B for soil resistivity measurement methods.

Figure 4-1 and Figure 4-2 are maps representing typical lightning activity throughout the world. These figures are for general informational and educational purposes only and are not indicative of current or future lightning activity. The average amount of lightning that occurs in any given area varies significantly from year to year.

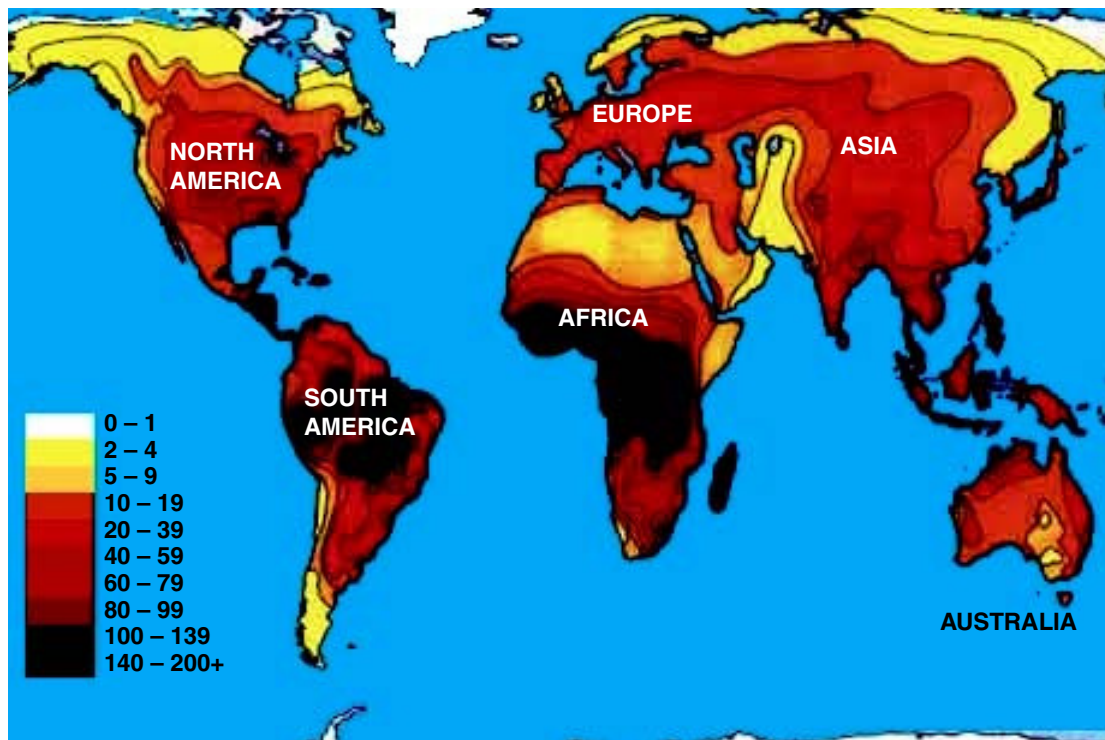


FIGURE 4-1 LIGHTNING ACTIVITY, THUNDERSTORM DAYS PER YEAR

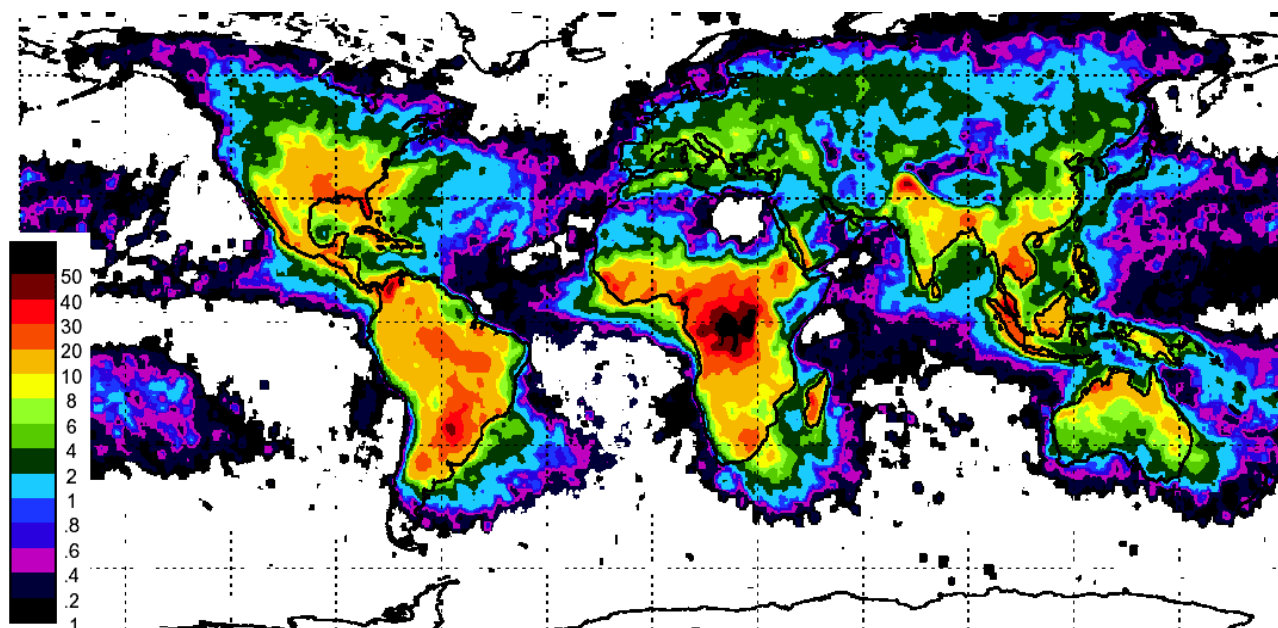


FIGURE 4-2 LIGHTNING ACTIVITY, FLASH DENSITY (FLASHES PER SQUARE KILOMETER PER YEAR)

Table 4-1 provides a relationship between thunderstorm days per year and lightning flashes per square kilometer per year (BS 6651:1999, table 6).

TABLE 4-1 RELATIONSHIP BETWEEN THUNDERSTORM DAYS PER YEAR AND LIGHTNING FLASHES PER SQUARE KILOMETER PER YEAR

Thunderstorm days per year	Flashes per square kilometer per year		Flashes per square mile per year	
	Mean	Limits	Mean	Limits
5	0.2	0.1 to 0.5	0.5	0.25 to 1.35
10	0.5	0.15 to 1	1.29	0.38 to 2.59
20	1.1	0.3 to 3	2.84	0.77 to 7.77
30	1.9	0.6 to 5	4.92	1.55 to 13
40	2.8	0.8 to 8	7.25	2 to 20.7
50	3.7	1.2 to 10	9.58	3.1 to 25.9
60	4.7	1.8 to 12	12.17	4.66 to 31
80	6.9	3 to 17	17.87	7.8 to 44
100	9.2	4 to 20	23.82	10.36 to 51.8

NOTE: Information obtained from BS 6651:1999, Table 6.

Communications facilities located at elevations significantly above the average elevation of the surrounding terrain (such as hilltops, fire towers, airport control towers, and high-rise buildings) **shall** be considered exposed to lightning regardless of thunderstorm activity and soil resistivity. (ANSI T1.313-2003, section 5.1.1.)

Communications facilities with a tower **shall** be considered as exposed, regardless of thunderstorm activity and soil resistivity. By their very construction, radio antennas/towers are considered exposed to the possible damaging effects of lightning. Tall structures, such as towers, buildings and antenna masts, provide a favorable discharge point for lightning strokes. (ANSI T1.313-2003, section 5.2.3.)

Some communications facilities may be classified as unexposed if the building and tower are within the zone of protection of a higher structure. Only a qualified engineer should determine if the communications facility is unexposed. The following standards can be used by the engineer to help determine if the communications facility is unexposed: BS 6651:1999, IEC 61024-1-2, NFPA 780-2004, or other applicable standard in effect and recognized by the local authority having jurisdiction.

4.3 COMMON GROUNDING (EARTHING)

At a communications site, there **shall** be only one grounding (earthing) electrode system. For example, the AC power system ground, communications tower ground, lightning protection system ground, telephone system ground, exposed structural building steel, underground metallic piping that enters the facility, and any other existing grounding electrode system **shall** be bonded together to form a single grounding electrode system (ANSI T1.313-2003; ANSI T1.333-2001; ANSI T1.334-2002; IEC 61024-1-2, section 2.4.4; IEEE STD 1100-1999; NFPA 70-2005, Articles 250.58, 250.104, 250.106, 800.100, 810.21, and 820.100; and NFPA 780-2004, Section 4.14).

All grounding media in or on a structure **shall** be interconnected to provide a common ground potential. This **shall** include, but is not limited to, the AC power system ground, communications tower ground, lightning protection system ground, telephone system ground, exposed structural building steel, and underground metallic piping systems. Underground metallic piping systems typically include water service, well castings located within 7.6 m (25 ft.) of the structure, gas piping, underground conduits, underground liquefied petroleum gas piping systems, and so on. Interconnection to a gas line **shall** be made on the customer's side of the meter (NFPA 780-2004, Section 4.14.1.3).

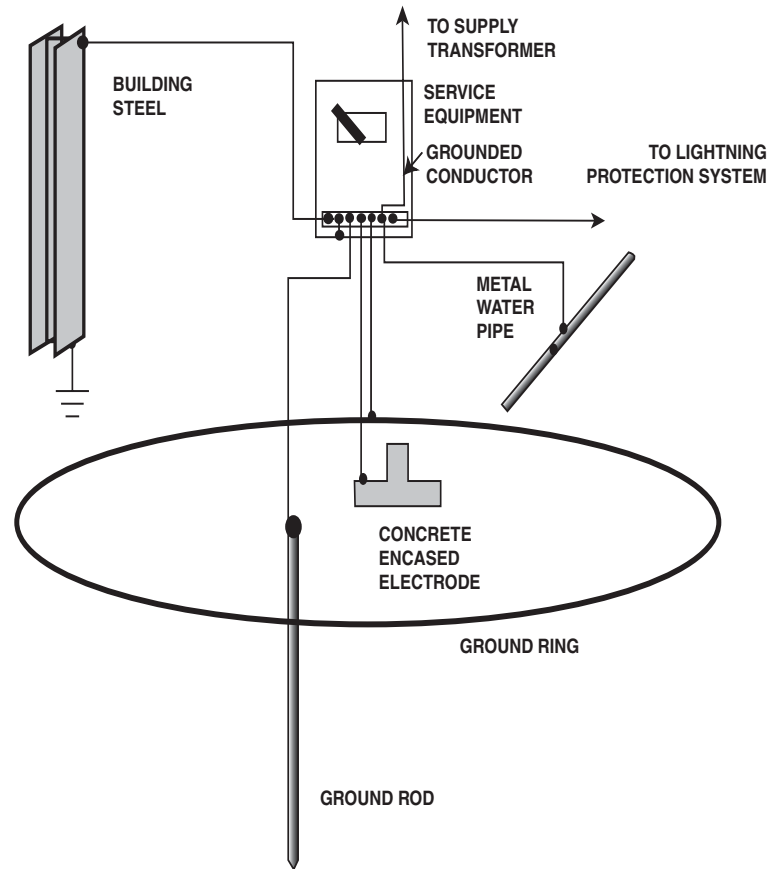


FIGURE 4-3 COMMON GROUNDING EXAMPLE

4.4 GROUNDING (EARTHING) ELECTRODE SYSTEM COMPONENT AND INSTALLATION REQUIREMENTS

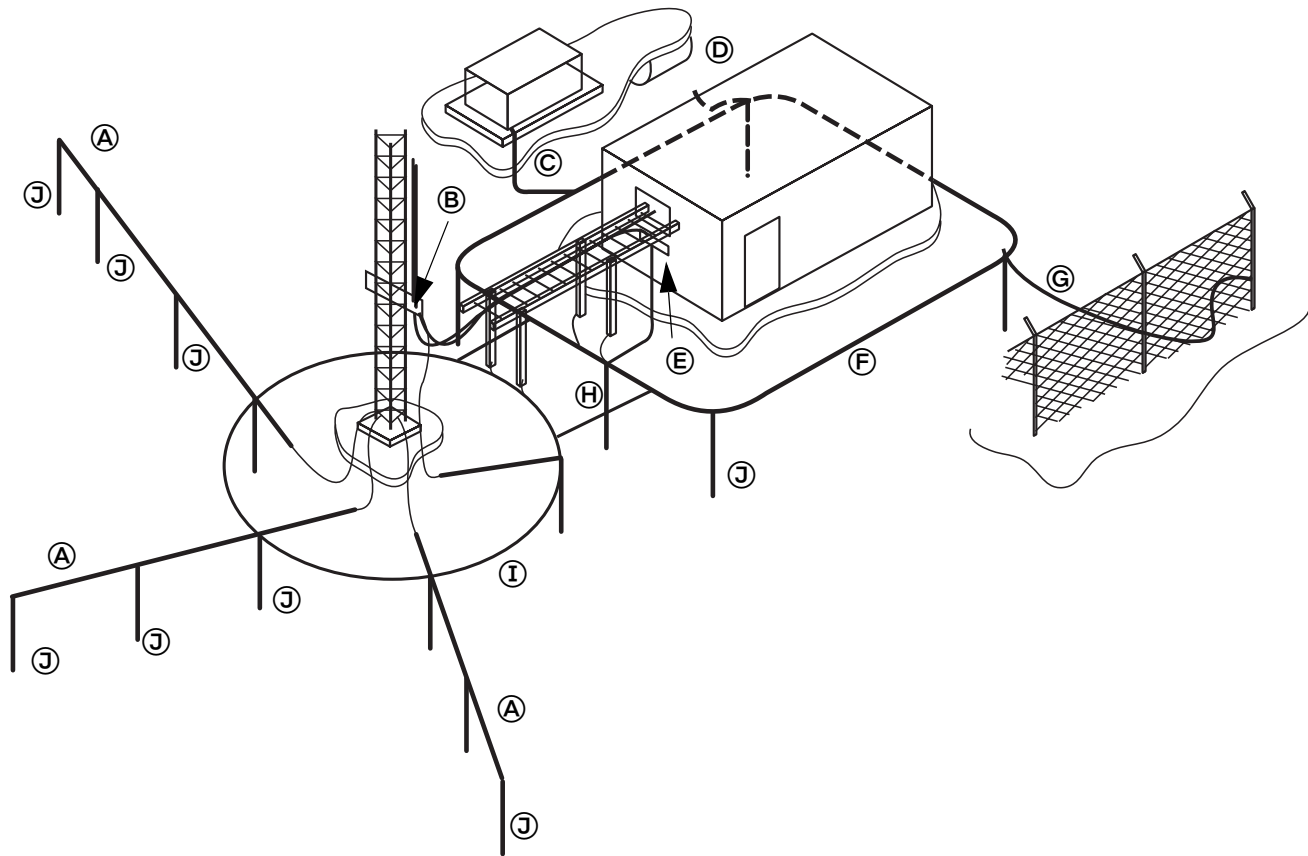


WARNING

To prevent accidental damage to underground utilities, always have the local utility company or utility locator service locate the underground utilities before excavating or digging at a site.

The external grounding (earthing) electrode system may consist of, but is not limited to, the following components, shown in Figure 4-4:

- Ground rods or other grounding electrodes
- Concrete encased electrode
- Building or shelter ground ring
- Tower ground ring
- Grounding conductors
- Radial grounding conductors
- Guy wire grounding conductors (guyed towers only)
- Tower ground bus bar
- External ground bus bar
- Fence grounding conductors



- A: Grounding Radials**
- B. Tower Ground Bus Bar and Down Conductor**
- C. Generator Grounding Conductor**
- D. Buried Fuel Tank Grounding Conductor**
- E. External Ground Bus Bar**
- F. Shelter Ground Ring**
- G. Fence Grounding Conductor**
- H. Ground Ring Bonding Conductors (2 minimum)**
- I. Tower Ground Ring**
- J. Earthing Electrodes (Ground Rods)**

FIGURE 4-4 TYPICAL EXTERNAL GROUNDING ELECTRODE SYSTEM

4.4.1 GROUNDING (EARTHING) ELECTRODES

Grounding (earthing) electrodes are the conducting elements used to connect electrical systems and/or equipment to the earth. The grounding electrodes are placed into the earth to maintain electrical equipment at the potential of the earth. Grounding electrodes may be ground rods, metal plates, concrete encased electrodes, ground rings, electrolytic ground rods, the metal frame of building or structure, and metal underground water pipes (NFPA 70-2005, Article 250 (III)).

NOTE: Metallic underground gas piping **shall not** be used as a grounding electrode (NFPA 70-2005, Article 250.52), but **shall** be bonded upstream from the equipment shutoff valve to the grounding electrode system as required by NFPA 70-2005, Article 250.104 and NFPA 780-2004, section 4.14.1.3.

4.4.1.1 GROUNDING (EARTHING) ELECTRODE RESISTANCE CHARACTERISTICS AND SPHERE OF INFLUENCE

Around a grounding (earthing) electrode, such as a driven ground rod, the resistance of the soil is the sum of the series resistances of virtual concentric shells of earth, located progressively outward from the rod. The shell nearest the ground rod has the smallest circumferential area, or cross section, so it has the highest resistance. Successive outward shells have progressively larger areas, therefore, progressively lower resistances. (IEEE STD 142-1991, section 4.11 and MIL-HDBK-419A).

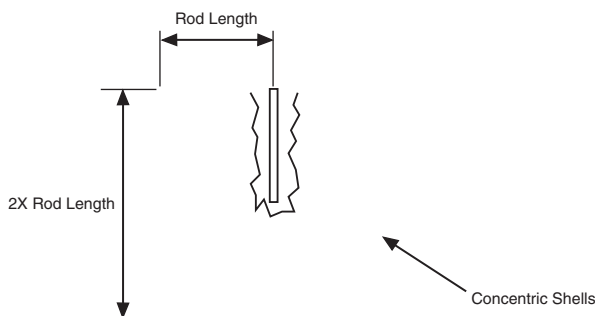


FIGURE 4-5 GROUNDING ELECTRODE SPHERE OF INFLUENCE

The effect of the concentric shells is that it takes a finite amount of earth for a ground rod to fully realize its resistance value. This finite amount of earth is commonly known as the ground rod's sphere of influence. The sphere of influence for a ground rod is commonly thought of to be a radius around the ground rod equal to its length; the ground rod achieves approximately 94% of its resistance value at this radius (100% is achieved at approximately 2.5 times the rod length) (IEEE STD 142-1991, section 4.1). See Figure 4-5.

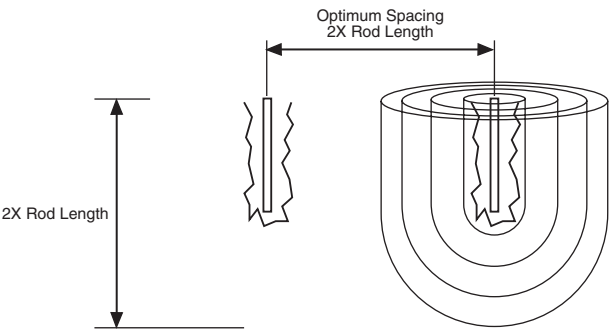


FIGURE 4-6 MINIMUM GROUNDING ELECTRODE SPACING FOR MAXIMUM EFFECTIVITY

Table 4-2 provides the relationship between percentage of total ground rod resistance and the radial distance from the ground rod (IEEE STD 142-1991, Table 9).

TABLE 4-2 TOTAL GROUND ROD RESISTANCE VS. DISTANCE FROM GROUND ROD

Distance from Electrode Surface (r)**		Approximate Percentage of Total Resistance
ft	Meters	
0.1	0.03	25%
0.2	0.06	38%
0.3	0.09	46%
0.5	0.15	52%
1.0	0.3	68%
5.0	1.5	86%
10.0*	3.0*	94%
15.0	4.6	97%
20.0	6.1	99%
25.0	7.6	100%

* 94% of the resistance to remote earth occurs within a radius equal to the length of the ground rod. This radius is commonly used as the ground rod's sphere of influence.

** Ground rod resistance at a radius (r) from a 3 m × 16 mm (10 ft. × 0.625 in.) ground rod (From IEEE STD 142-1991, Table 9)

The following observations can be made from the above table (IEEE STD 142-1991, chapter 4):

- Within the first 2.5 cm (1 in.) from the ground rod, 25% of the total resistance to earth is achieved.

- Within the first 152 mm (6 in.) from the ground rod, 52% of the total resistance to earth is achieved.
- The area immediately around a ground rod is the most important for reducing its resistance to earth. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27 for information on reducing resistance.
- In high resistivity soil areas, decreasing the soil resistance in this area is useful in improving the effectiveness of the grounding electrode system.
- In porous soil areas, decreasing the contact resistance with the ground rod in this area is useful in improving the effectiveness of the grounding electrode system.

Unless specified elsewhere in this chapter, ground rods should be installed apart from one another by the sum of their respective lengths, so their spheres of influence do not overlap (See Figure 4-6). This is especially important when only a small number of ground rods are installed, such as around tower ground rings.

NOTE: In a given area, more ground rods installed closer together (such as one length apart from one another) will achieve a lower resistance to earth than fewer rods installed further apart (such as twice the length apart from one another). For example, five 3 m (10 ft.) ground rods installed 6.1 m (20 ft.) apart in an 24.4 m (80 ft.) straight line will achieve a resistance to earth of 7.8 ohms (assuming 10,000 ohm-cm soil). Nine 3 m (10 ft.) ground rods installed 3 m (10 ft.) apart in the same 24.4 m (80 ft.) straight line will achieve a resistance to earth of 5.7 ohms.

4.4.1.2 GROUND RODS

Typical ground rods are shown in Figure 4-7. Requirements for ground rods are listed below. See IEEE STD 142-1991, section 4.3.1 and UL 467-2004 for additional information.

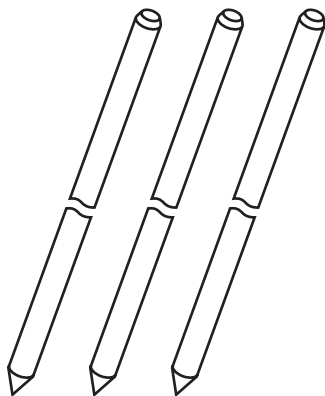


FIGURE 4-7 TYPICAL GROUND RODS

4.4.1.2.1 GROUND ROD SPECIFICATIONS

- Ground rods **shall** be UL listed (or equivalent).
- Ground rods **shall** be constructed of copper-clad steel, solid copper, hot-dipped galvanized steel, or stainless steel (ANSI-J-STD-607-A-2002, section C.4.3, and ANSI T1.334-2002, section 5.3.2). See NFPA 70-2005, Article 250.52 and UL 467-2004, section 9.2.1 for additional information.

NOTE: Stainless steel ground rods **shall** be formed of an austenitic stainless steel of the 18 percent chromium, 8 percent nickel type (UL 467-2004, section 9.2.6).

- Ground rods **shall** have a minimum length of 2.4 m (8 ft.) (ANSI T1.313-2003, section 10.3.1, ANSI T1.334-2002, section 5.3.2, NFPA 70-2005, Article 250.52, and UL 467-2004). For areas highly prone to lightning, and/or military installations, longer rods, such as 3 m (10 ft.), should be considered for the minimum length (MIL-HDBK-419A and MIL-STD-188-124B).
- Ground rods **shall** have a minimum diameter of 15.9 mm (0.625 in.) (ANSI T1.313-2003, section 10.3.1 and ANSI T1.334-2002, section 5.3.2), unless otherwise allowed by the UL listing of the ground rod (UL 467). See NFPA 70-2005, Article 250.52 for additional information.
- Ground rods **shall** be free of paint or other nonconductive coatings (NFPA 70-2005, Article 250.53 and NFPA 780-2004, section 4.13.2).

4.4.1.2.2 GROUND ROD INSTALLATION

- Where practical, ground rods **shall** be buried below permanent moisture level (MIL-HDBK-419A and NFPA 70-2005, Article 250.53).
- Where practical, ground rods **shall** penetrate below the frost line (MIL-HDBK-419A).
- Ground rods longer than the minimum required 2.4 m (8 ft.) may be required to maintain contact with permanently moist, unfrozen soil (MIL-HDBK-419A).
- When part of a ground ring system, the upper end of the ground rods **shall** be buried to the depth of the ground ring, typically 762 mm (30 in.) minimum below finished grade. The upper end of the ground rods should be buried to the same depth as the ground ring to allow for easy bonding to the ground ring. (See “External Building and Tower Ground Ring” on page 4-22.)
- When not part of a ground ring system, such as in a Type A site, the entire length of the rod **shall** be in contact with soil (NFPA 70-2005, Article 250.53). It is recommended to install the ground rods so the upper end of the rod is buried to a minimum depth of 610 mm (24 in.) below the surface of the earth (NFPA 780-2004, section 4.13.2.3). See Figure 4-8 for typical single ground rod installations.

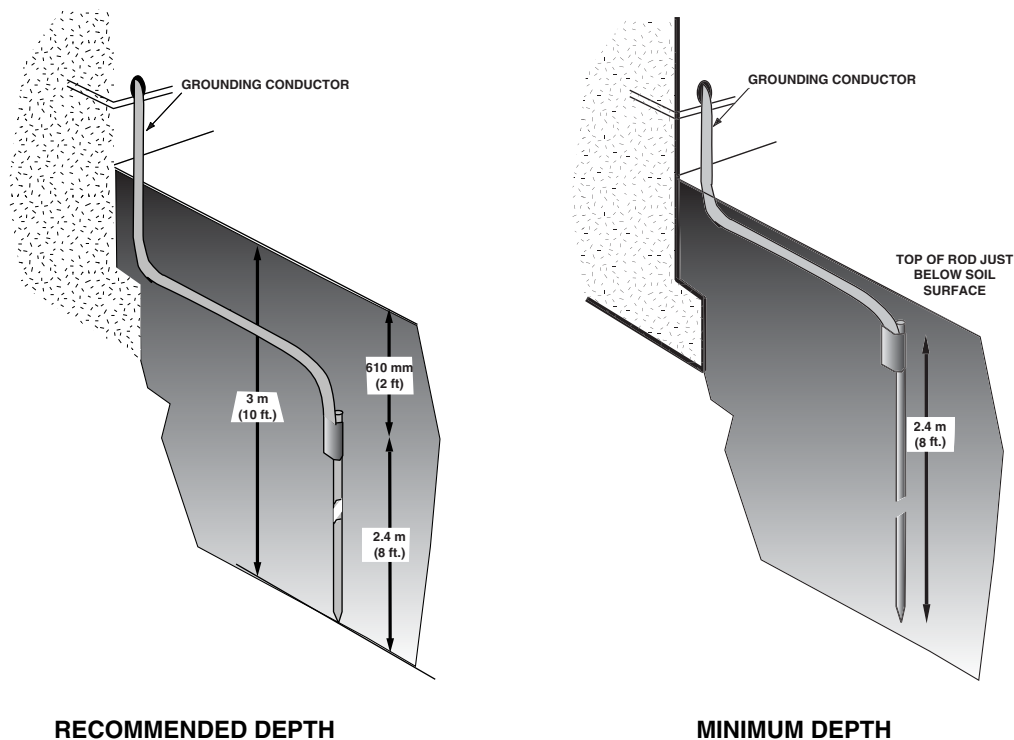


FIGURE 4-8 TYPICAL SINGLE GROUND ROD INSTALLATION

- Ground rods **shall not** be installed closer than 1.8 m (6 ft.) from other ground rods and grounding electrodes (NFPA 70-2005, Article 250.56). See Figure 4-31 on page 4-49 for an example.
- Unless otherwise stated in this chapter, ground rods **shall not** be installed closer to one another than the sum of their respective lengths, when possible. This is especially important for the ground rods associated with tower ground rings. See “Grounding (Earthing) Electrode Resistance Characteristics and Sphere of Influence” on page 4-9
- See “External Building and Tower Ground Ring” on page 4-22 for ground rod installation requirements on ground rings.
- The method of bonding grounding conductors to ground rods **shall** be compatible with the types of metals being bonded (See “Dissimilar Metals and Corrosion Control” on page 4-34).
- Ground rods that cannot be driven straight down, due to contact with rock formations, may be driven at an oblique angle of not greater than 45 degrees from the vertical, or may be buried horizontally and perpendicular to the building, in a trench at least 762 mm (30 in.) deep, as shown in Figure 4-9 (NFPA 70-2005, Article 250.53).

IMPORTANT: The top of a ground rod **shall not** be cut off if contact with rocks prevents driving of the rod. Alternate driving techniques, as describe above, **shall** be used in these cases.

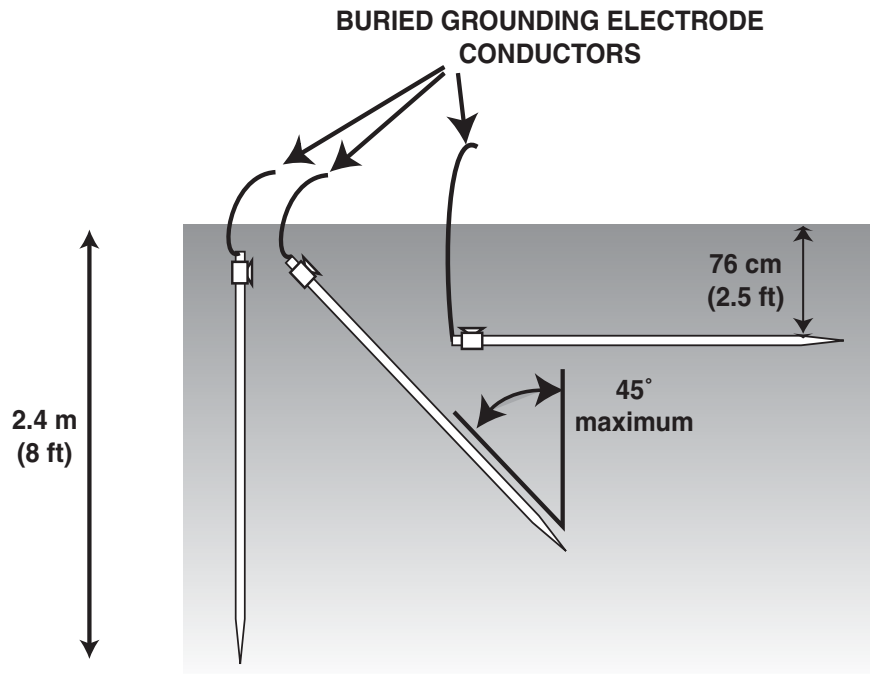


FIGURE 4-9 ANGLED GROUND ROD INSTALLATION



WARNING

When operating any kind of power tool, always wear appropriate safety glasses and other protective gear to prevent injury.

- Hammer drills or electric jackhammers may be used to drive in the ground rods. Do not deform the head of the ground rod. See IEEE STD 142-1991, section 4.3.2. for additional information.
- If rock formations prevent ground rods from being driven to the specified depth, an alternate method of achieving an acceptable grounding electrode system **shall** be engineered and implemented. See “Special Grounding (Earthing) Situations” on page 4-88 for additional information.
- When the grounding electrode system design requires deeper ground rods (in order to lower the grounding electrode system resistance, penetrate down to permanent moisture level, or to penetrate below the frost line) two or more ground rods may be joined together by use of a coupling (threaded, compression sleeve, or exothermic weld). Threaded rods or compression sleeves **shall** be UL listed. (IEEE STD 142-1991, section 4.3.1). See Figure 4-10 for an example of splicing ground rods together.

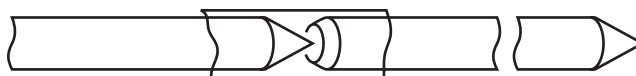


FIGURE 4-10 SPLICING TWO GROUND RODS

4.4.1.2.3 EFFECT OF GROUND ROD SIZE ON RESISTANCE TO EARTH

Increasing the diameter of a ground rod does not significantly reduce its resistance to earth. Doubling the diameter of a rod reduces its resistance to earth by approximately 10%. See Figure 4-11.

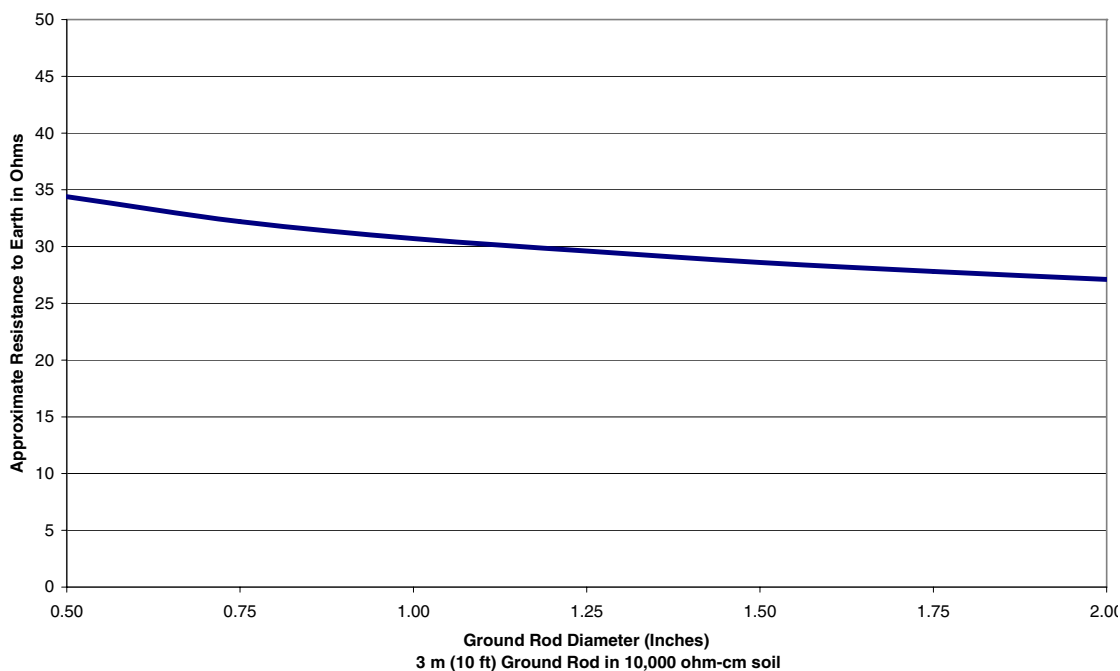


FIGURE 4-11 RESISTANCE TO EARTH DUE TO GROUND ROD DIAMETER

As the length of a ground rod is increased, its resistance to earth is substantially reduced. In general, doubling the length of a ground rod reduces the resistance to earth by 40%. See Figure 4-12.

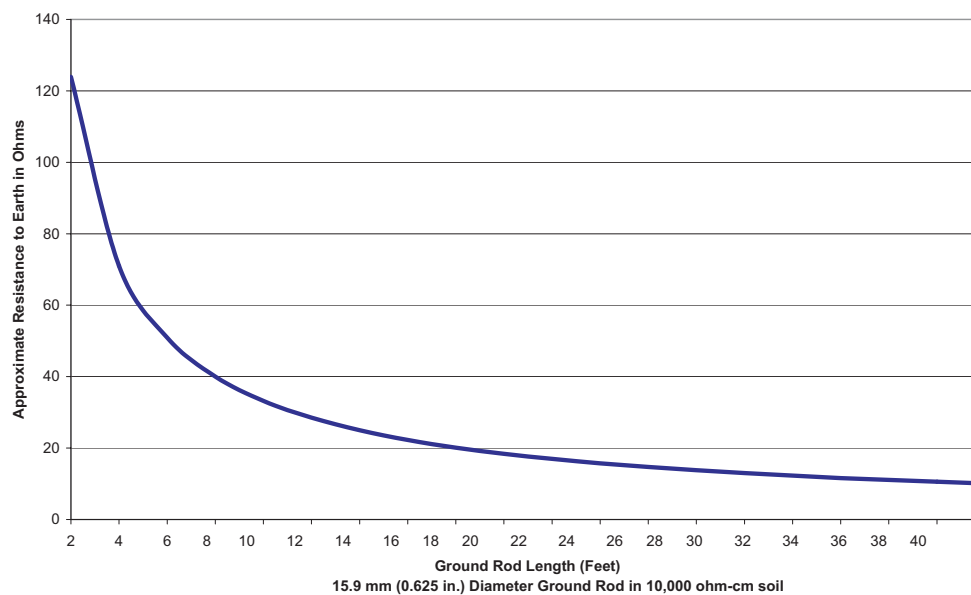


FIGURE 4-12 RESISTANCE TO EARTH DUE TO GROUND ROD LENGTH

4.4.1.2.4 EFFECT OF PARALLEL GROUND RODS

Figure 4-13 below shows the effects of adding additional ground rods (15.9 mm (0.625 in.) diameter by 3 m (10 ft.) long) together in parallel. As seen in the figure, the addition of one ground rod to the first ground rod (for a total of two rods) significantly reduces the resistance to earth of the ground rod system. Each subsequent ground rod added in parallel has less of an effect on the resistance to earth of the ground rod system.

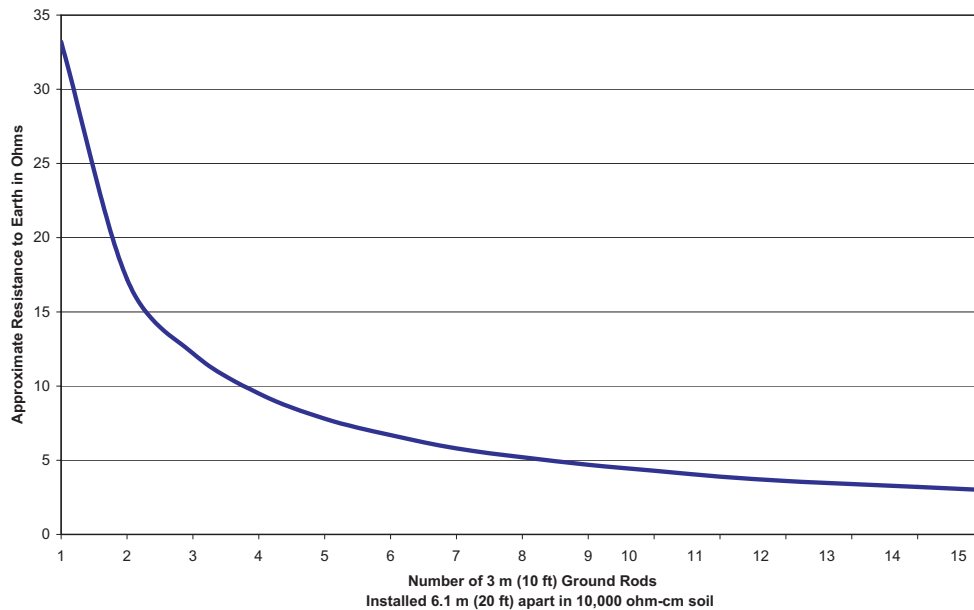


FIGURE 4-13 RESISTANCE TO EARTH DUE TO PARALLEL GROUND RODS

4.4.1.3 ELECTROLYTIC GROUND RODS

At sites where, due to poor soil conductivity (high resistivity) and/or limited space, an acceptable grounding (earthing) electrode system resistance cannot be achieved using standard ground rods, commercially available electrolytic ground rods should be considered. See MIL-HDBK-419A Volume I, section 2.9.5, and UL 467-2004, section 9.2.7 for additional information. Electrolytic ground rods (Figure 4-14) are available in straight or L-shaped versions and in various lengths from 3 m (10 ft.) to 6.1 m (20 ft.), or longer as a special order. Electrolytic ground rods are generally constructed of 54 mm (2.125 in.) diameter hollow copper pipe. This copper pipe is filled with a mixture of non-hazardous natural earth salts. Holes at various locations on the pipe allow moisture to be hygroscopically extracted from the air into the salt within the pipe, therefore forming conductive electrolytes. These electrolytes then leach out of the pipe into the soil, improving soil conductivity. Electrolytic ground rods are inserted into a pre-drilled hole, or in the case of L-shaped rods, placed into a trench at least 762 mm (30 in.) deep, and encased in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.

Electrolytic ground rods should be considered for use in grounding electrode systems covered by concrete or pavement, such as parking lots. By allowing moisture to enter, the design of the electrolytic ground rod improves the resistance of the grounding electrode system.

NOTE: Unless prohibited by local environmental authorities, condensation from the site's HVAC system may be routed to the ground rod area to keep the soil moist, improving conductivity.

Electrolytic ground rods may provide significant improvement over standard ground rods of the same length and may last several years longer than standard ground rods. The resistance to earth of electrolytic ground rods is generally more stable in environments with variations in temperature and moisture.

Requirements for the use of electrolytic ground rods are listed below:

- Electrolytic rods **shall** be UL listed (or equivalent).
- Electrolytic rods **shall** be installed per the manufacturers' recommendation.
- Electrolytic rods **shall** be free of paint or other nonconductive coatings (NFPA 70-2005, Article 250.53 and NFPA 780-2004, section 4.13.2.2).
- Electrolytes within the rod **shall** be environmentally safe and approved by the environmental authority having jurisdiction.
- L-shaped electrolytic rods **shall** be installed perpendicular to the building or shelter.
- L-shaped electrolytic rods (horizontal portion) **shall** be installed at least 762 mm (30 in.) below the earth's surface.
- Grounding electrode encasement materials (also known as backfill) **shall** be environmentally safe and approved by the environmental authority having jurisdiction. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.
- Electrolytic rods should be maintenance free.

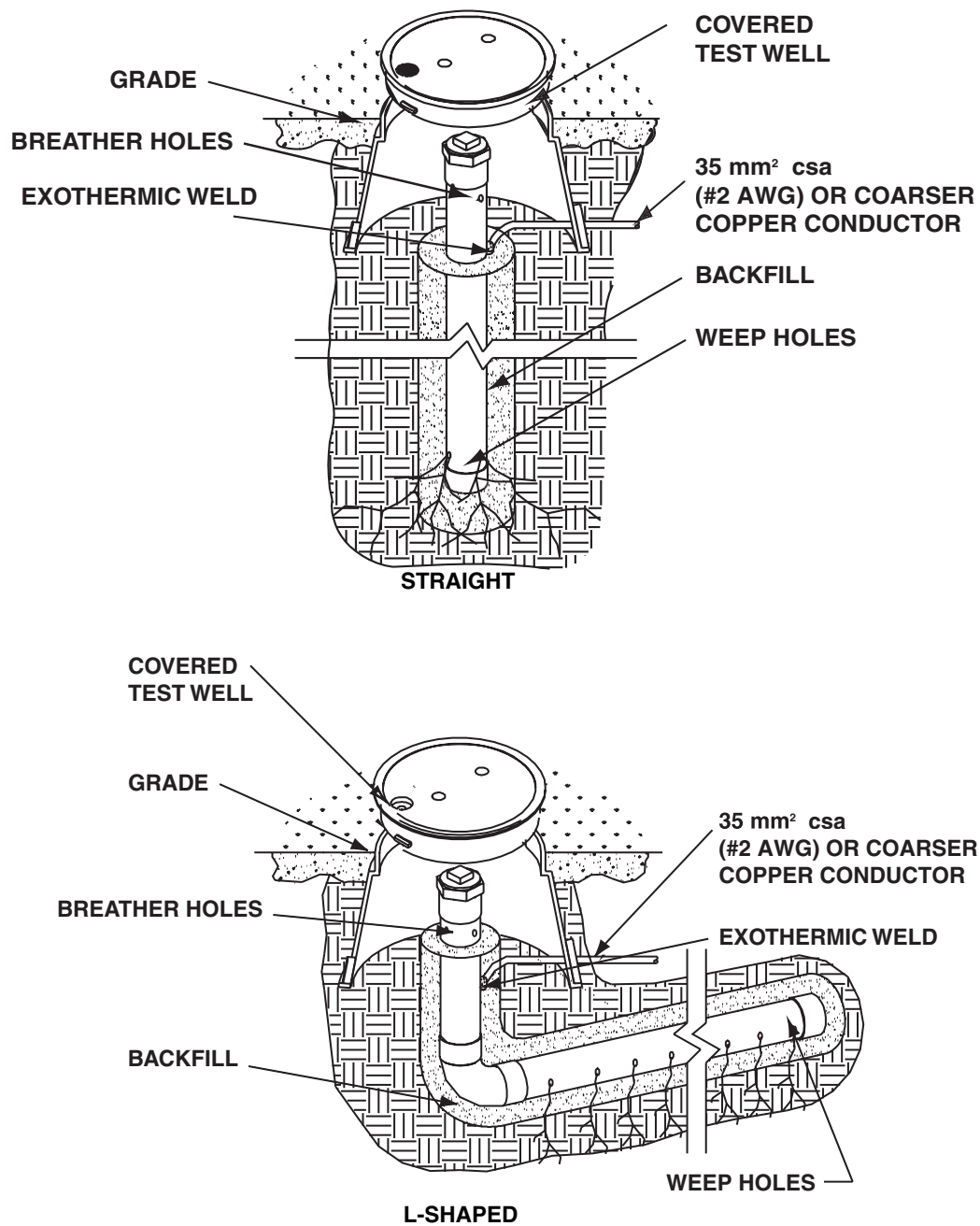
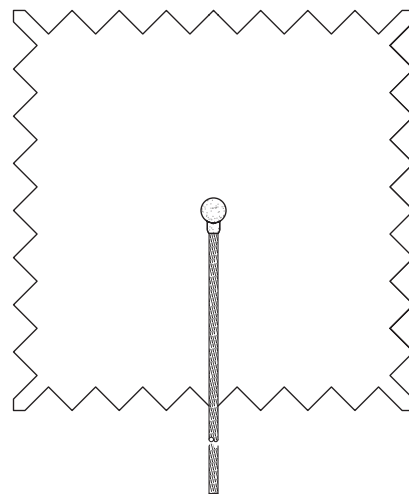


FIGURE 4-14 ELECTROLYTIC GROUND RODS

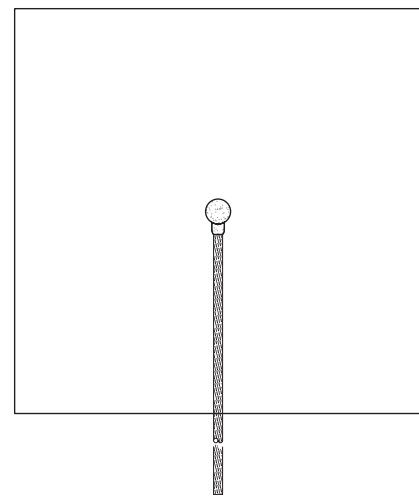
4.4.1.4 GROUND PLATE ELECTRODES

Ground plates (Figure 4-15) may be used in special cases, or if specifically engineered into the design of the grounding (earthing) electrode system. Requirements for the use of ground plate electrodes are listed below:

- Ground plates should only be used if soil conditions prohibit the use of standard ground rods, or if specifically engineered into the grounding electrode system.
- Ground plates should be UL listed (or equivalent).
- Ground plates **shall** be constructed of copper or copper-clad steel.
- Ground plates **shall** expose not less than 0.37 m^2 (2 ft.^2) of surface to exterior soil (MIL-HDBK-419A, section 2.5.5; NFPA 70-2005, Article 250.52; and NFPA 780-2004, section 4.13.6.1).
- Ground plates **shall** have a minimum thickness of 1.5 mm (0.06 in.) (MIL-HDBK-419A, section 2.5.5 and NFPA 70-2005, Article 250.52).
- Ground plates **shall** be free of paint or other nonconductive coatings (NFPA 70-2005, Article 250.53 and NFPA 780-2004, section 4.13.2.2).
- Ground plates **shall** be buried not less than 762 mm (30 in.) below the surface of the earth (NFPA 70-2005, Article 250.53). If soil conditions do not allow the ground plate to be buried at this depth, see “Shallow Topsoil Environments” on page 4-97 for additional information.
- Where practical, a ground plate **shall** be embedded below permanent moisture level (BS 7430:1998, clause 10 and NFPA 70-2005, Article 250.53).
- Ground plates should be installed vertically to allow for minimum excavation and better contact with the soil when backfilling (BS 7430:1998, clause 10 and IEEE STD 142-1991, section 4.2.4). See Figure 4-16.



SERRATED EDGES PROVIDE MORE
EDGE SURFACE



STRAIGHT EDGES

FIGURE 4-15 TYPICAL GROUND PLATES

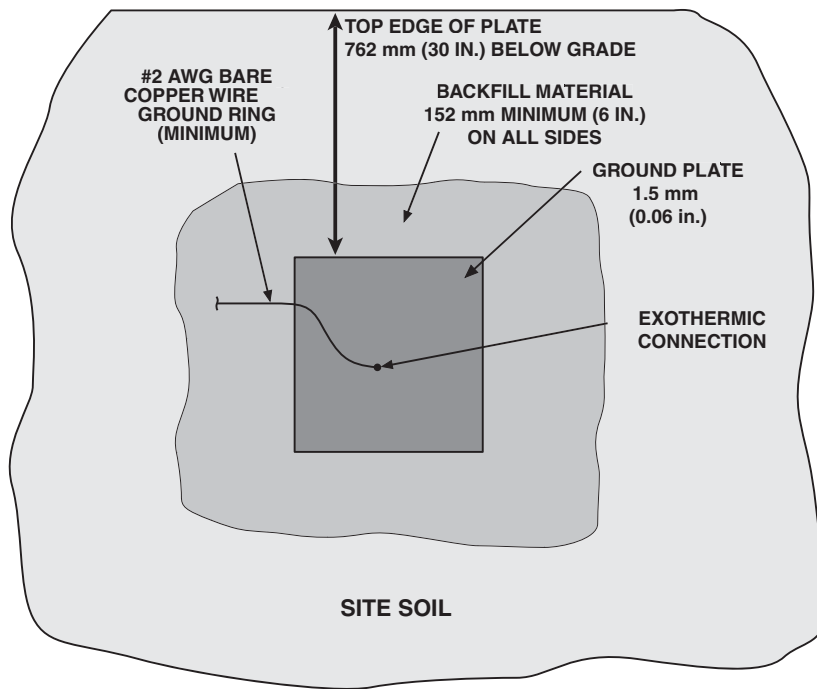


FIGURE 4-16 TYPICAL GROUND PLATE INSTALLATION

- A grounding electrode encasement material should be used to backfill around the ground plate to help insure effective contact with the earth (BS 7430:1998, clause 10). See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.

4.4.1.5 CONCRETE-ENCASED ELECTRODES

Though concrete-encased electrodes (also known as Ufer electrodes, named after Herbert G. Ufer, or foundation earth electrodes) are not required by this standard, they should be used in new construction as a method of supplementing the grounding (earthing) electrode system (IEC 61024-1-2, section 3.3.5). Concrete-encased electrodes (Figure 4-17) enhance the effectiveness of the grounding electrode system in two ways: the concrete absorbs and retains moisture from the surrounding soil, and the concrete provides a much larger surface area in direct contact with the surrounding soil. This is especially helpful at sites with high soil resistivity and/or limited area for installing a grounding electrode system. See IEEE STD 142-1991 section 4.2.3, and the International Association of Electrical Inspectors publication, *Soares Book on Grounding and Bonding*, 9th Edition, Appendix A for additional information. Requirements for a concrete-encased electrode, if used, are listed below (IEC 61024-1-2; NFPA 70-2005, Article 250.52; and NFPA 780-2004, section 4.13.3).

- Concrete-encased electrodes **shall** be encased by at least 51 mm (2 in.) of concrete, located within and near the bottom of a concrete foundation or footing that is in direct contact with the earth.
- Concrete-encased electrodes **shall** be at least 6.1 m (20 ft.) of bare copper conductor not smaller than 25 mm² csa (#4 AWG) or at least 6.1 m (20 ft.) of one or more bare or zinc galvanized or other conductive coated steel reinforcing bars or rods at least 12.7 mm (0.5 in.) in diameter.
- Concrete-encased electrodes **shall** be bonded to any other grounding electrode system at the site. See “Common Grounding (Earthing)” on page 4-5.

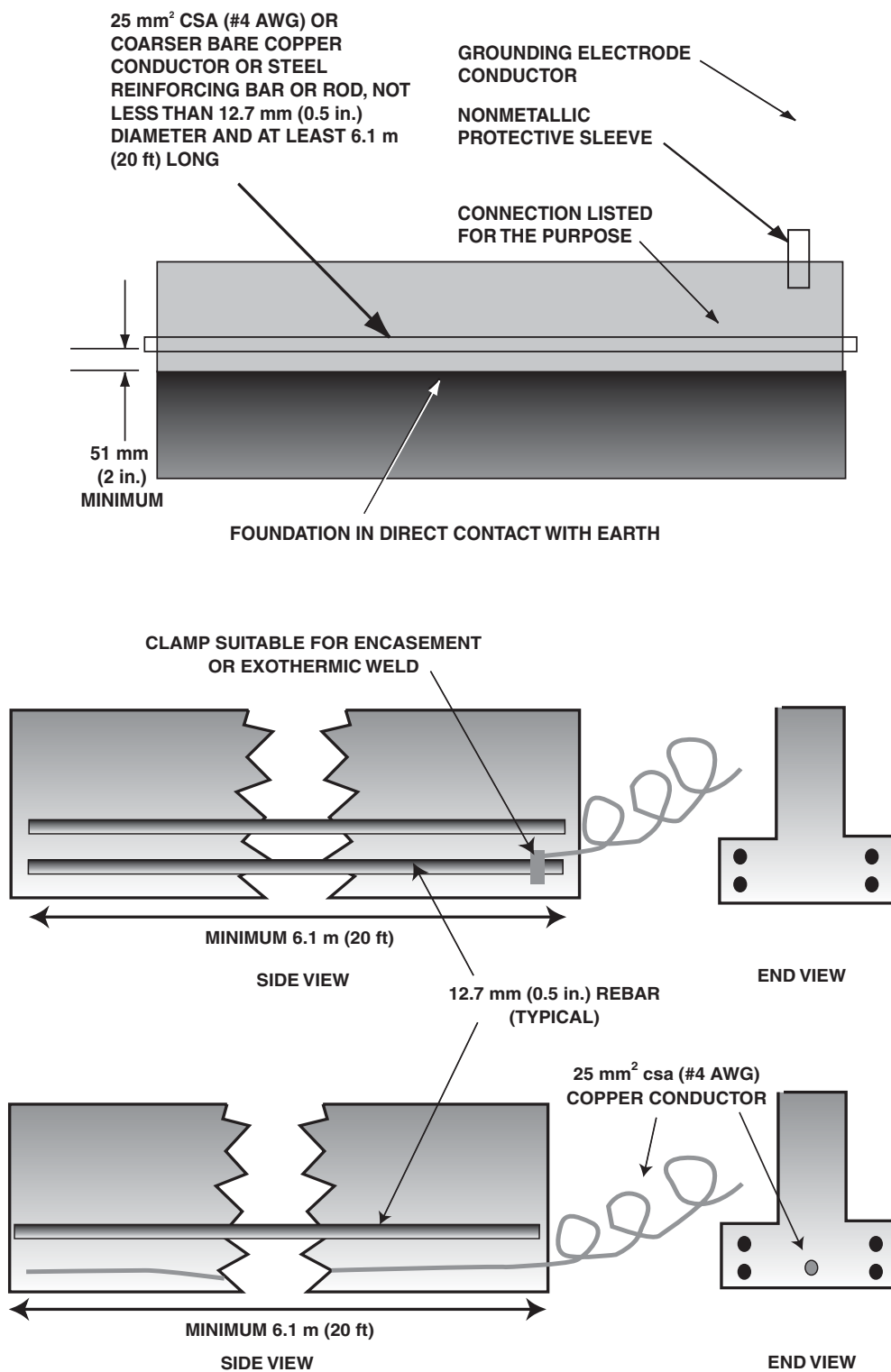


FIGURE 4-17 TYPICAL CONCRETE-ENCASED ELECTRODES

4.4.1.6 EXTERNAL BUILDING AND TOWER GROUND RING

The buried external ground rings (building and tower) provide a means of bonding ground rods together and bonding other grounding (earthing) electrode system components together, improving the overall grounding electrode system. The ground rings also help to equalize potential in the earth surrounding the tower and building structures, regardless of earth resistivity, by insuring that a low impedance current path exists throughout the area (ANSI T1.334-2002, section 5.3).

Requirement for external ground rings are listed below (see Figure 4-18):

- Unless otherwise stated, ground ring conductors **shall** be 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper (ANSI T1.313-2003 and ANSI T1.334-2002, section 5.3.1). See “Grounding (Earthing) Conductors” on page 4-28 for grounding conductor specifications.
- Solid, bare, tinned, copper conductor should be used to minimize galvanic corrosion between tower legs and other parts of the grounding electrode system (ANSI T1.313-2003, section 10.7).
- For areas highly prone to lightning, and/or military installations, larger conductors, such as 50 mm² csa (#1/0 AWG) or coarser, should be considered (MIL-HDBK-419A and MIL-STD-188-124B); stranded conductors may be used in this application.
- Building ground rings **shall** encircle the building or shelter whenever possible (ANSI T1.313-2003, ANSI T1.334-2002, MIL-HDBK-419A, and MIL-STD-188-124B).
- Tower ground rings **shall** encircle the tower structure whenever possible (ANSI T1.334-2002, section 5.3 and MIL-HDBK-419A).
- The ends of the conductor **shall** be joined together to form a ring using an exothermic weld or listed irreversible high-compression connector (ANSI T1.334-2002, section 5.3.1 and MIL-STD-188-124B). This may be easily completed at a ground rod.
- Building ground rings and tower ground rings **shall** be bonded together in at least two points using a 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductor (ANSI-J-STD-607-A-2002, section C.4.7, ANSI T1.334-2002, figure 1, and MIL-STD-188-124B). The conductors should be physically separated as much as practical. See “Common Grounding (Earthing)” on page 4-5.

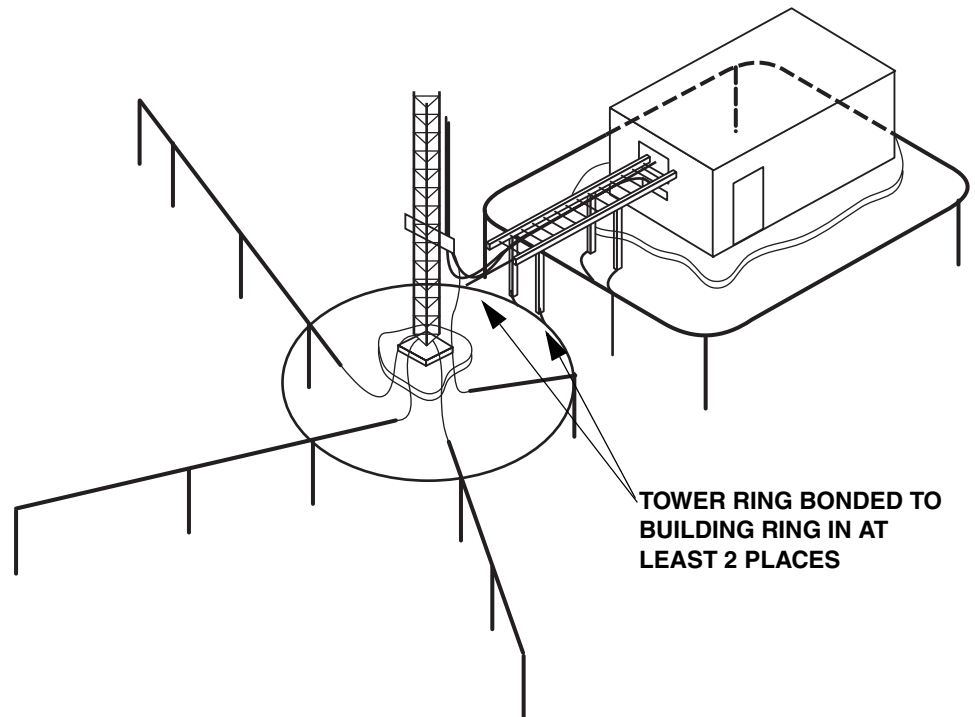


FIGURE 4-18 BONDING BUILDING AND TOWER GROUND RING SYSTEMS

- Ground rings **shall** be installed in direct contact with the earth at a depth of 762 mm (30 in.) below the earth's surface whenever possible, or below the frost line, whichever is deeper (ANSI T1.334-2002, section 5.3.1 and NFPA 70-2005, Article 250.53).
- Building ground rings **shall** be installed at least 914 mm (3 ft.) from the building foundation and should be installed beyond the drip line of the roof. It is recommended that the building ground ring and ground rods be positioned 610 mm to 1.8 m (2 ft. to 6 ft.) outside the drip line of the building or structure to ensure that precipitation wets the earth around the ground ring and rods (MIL-HDBK-419A and MIL-STD-188-124B).
- Tower ground rings **shall** be installed at least 610 mm (2 ft.) from the tower foundation (ANSI T1.334-2002, section 5.3.1).
- If 2.4 m (8 ft.) ground rods are installed along the ground rings, they **shall** be connected to the ground ring conductor at 3 m to 4.6 m (10 ft. to 15 ft.) intervals (ANSI T1.334-2002), unless otherwise specified.
 - If longer ground rods are used, a larger separation proportional to the increase in rod length may be used.
 - Ground rods **shall** be placed a minimum of one rod length apart from one another along the ground rings (ANSI T1.313-2003, figure 3(a)).
 - Ground rods **shall not** be separated from an adjacent ground rod along the ground ring by more than the sum of their respective lengths. (MIL-HDBK-419A).

4.4.1.7 RADIAL (COUNTERPOISE) GROUNDING CONDUCTORS

For high lightning prone geographical areas, sites normally occupied (such as 911 dispatch centers), sites with high soil resistivity, or when bedrock prohibits the driving of ground rods, radial (counterpoise) grounding (earthing) conductors should be employed to improve equalization of the grounding electrode system (ANSI T1.334-2002, section 5.4), and to help meet the site's grounding electrode system resistance requirements (see “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-46). Radial grounding conductors are conductors installed horizontally in the ground and radiating away from the tower and building.

In typical soil resistivity conditions of 10,000 ohm-cm, the addition of five radial conductors 7.6 m (25 ft) in length may reduce the tower grounding electrode system resistance by a factor of two or three. More importantly, adding radial conductors divides lightning strike current into segments that allow for more effective dissipation of energy into the earth, and away from the equipment building.

When used, radial conductors **shall** meet the following specifications:

- The conductors **shall** radiate away from the building and tower (ANSI T1.334-2002, section 5.4).
- The conductors **shall** be installed at the tower or tower ground ring whenever possible. If the conductors cannot be installed at the tower, installation at the building is acceptable, but should be installed near the RF transmission line entry point.

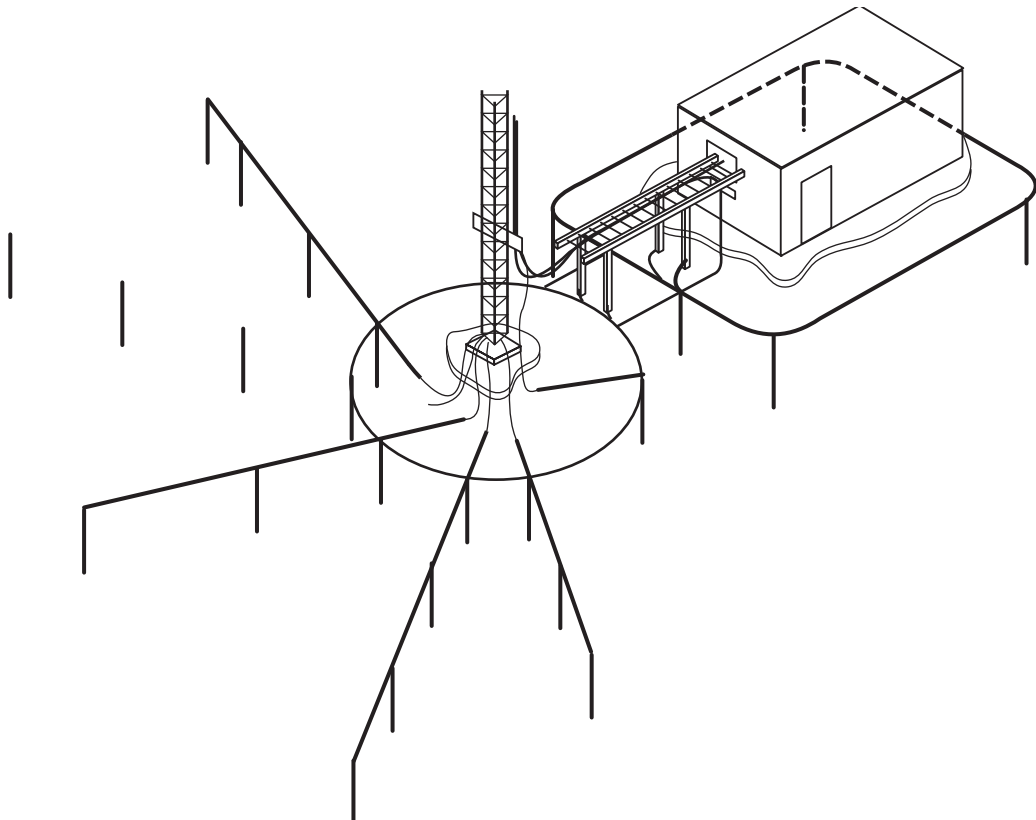


FIGURE 4-19 INSTALLATION OF RADIAL CONDUCTORS

- When radial conductors are used, a minimum of three to five conductors should be used.
- The conductors **shall** be installed equally spaced from one another, as much as practical.

- The conductors **shall** be bonded directly to the tower and tower ground ring (ANSI T1.334-2002, section 5.4). If it is not practical to bond all conductors to the tower, the tower **shall** have additional grounding conductors bonding it to the tower ground ring; 70 mm² (#2/0 AWG) or coarser conductor is recommended in this case.
- Conductor bonding **shall** comply with “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40
- The conductors **shall** be constructed of 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper. See “Grounding (Earthing) Conductors” on page 4-28 for conductor specifications and installation requirements. (ANSI T1.334-2002, section 5.4)
- The conductors **shall** be buried at least 457 mm (18 in.) below ground (ANSI T1.334-2002, section 5.4). When topsoil conditions allow, it is recommended to bury the conductors to a depth of at least 762 mm (30 in.) (ANSI-J-STD-607-A-2002, section C.9.2); this is especially important in areas where the frost line may reach 457 mm (18 in.).
- The minimum length of each conductor **shall** be 7.6 m (25 ft.). If the desired resistance to earth is not achieved at 7.6 m (25 ft.), the radial conductor may be extended to help obtain the desired resistance (ANSI T1.334-2002, section 5.4). The maximum effective length for a single radial conductor is generally considered to be approximately 24.4 m (80 ft.). Adding additional conductors is generally more effective than extending the length of a single conductor.

NOTE: When multiple radial conductors are used, the conductors should be of different lengths to help prevent resonant “ringing” of the tower from a lightning strike.

NOTE: Low resistance in radial (counterpoise) grounding configurations is desirable, but not critical. Low resistance in the dissipating path of strike currents into the earth is of secondary importance when compared to the primary objective of controlling voltage gradients and voltage differences between structures and equipment close to the tower (ANSI T1.334-2002, section 5.4).

- When soil conditions allow, the effectiveness of the radial grounding conductor may be increased by including a ground rod every 4.9 m (16 ft.) (or twice the length of the ground rods) installed as described in “Ground Rods” on page 4-11. See Figure 4-19 on page 4-24 for an example of ground radials.

Figure 4-20 on page 4-26 shows the resistance characteristics of a radial grounding conductor. The resistance to earth of a straight horizontal electrode (radial grounding conductor) may be calculated as follows:

$$R = \frac{\rho}{\pi L} \left[\ln \left[\frac{2L}{(2aD)^{1/2}} \right] \right]^{-1}$$

Where:

$D \ll L$

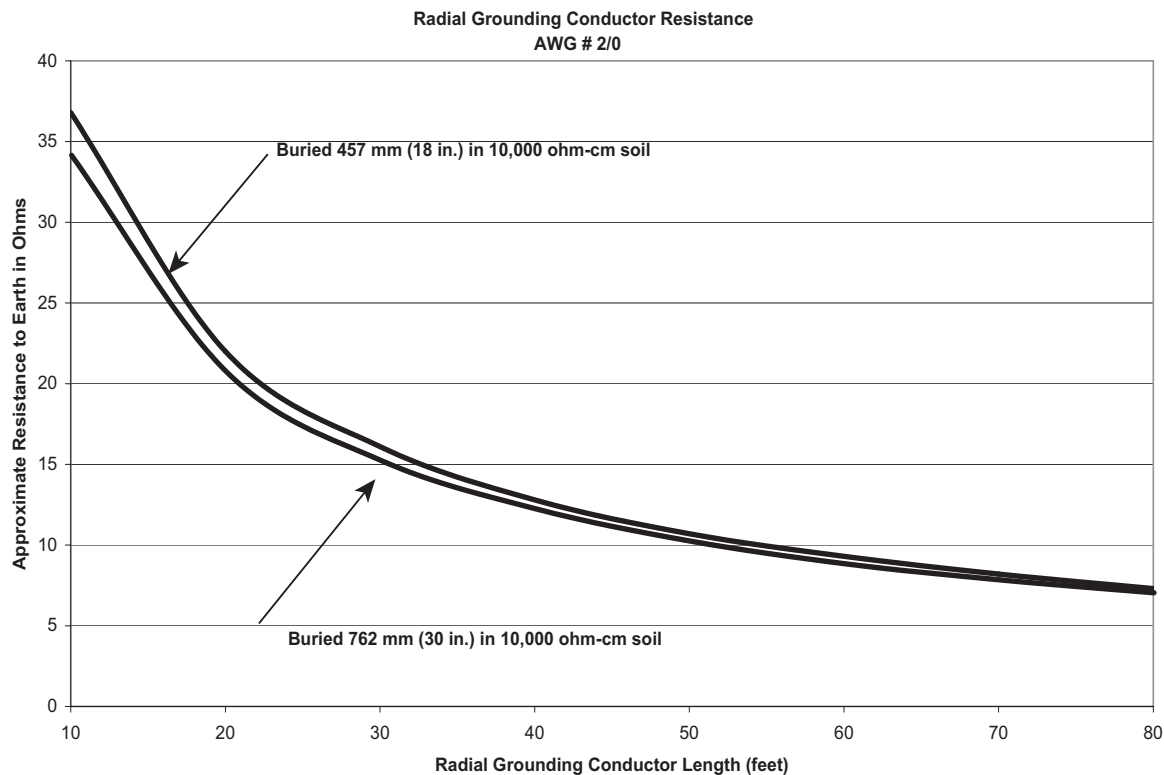
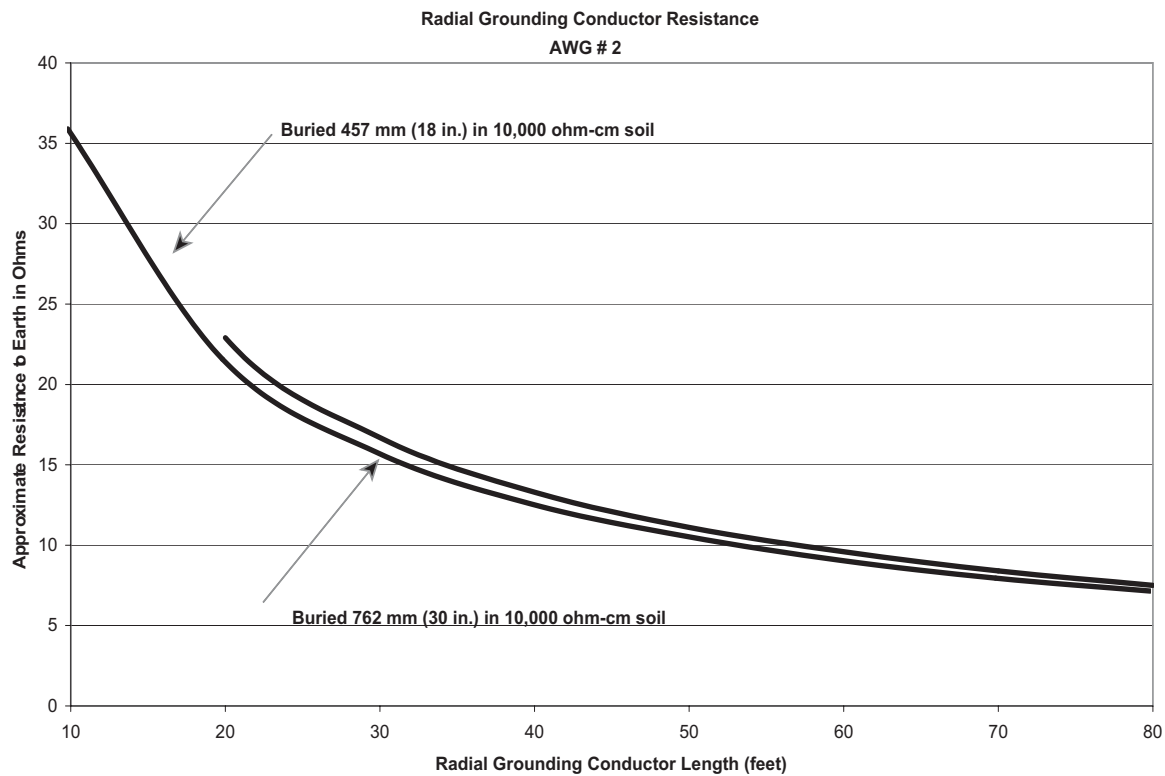
R: The resistance of the electrode in ohms

ρ : The soil resistivity in meter-ohms

L: The length of the electrode in metres

a: The electrode radius in meters

D: The electrode depth in meters

**FIGURE 4-20** RESISTANCE CHARACTERISTICS OF A RADIAL GROUNDING CONDUCTOR

4.4.1.8 GROUND TEST WELLS

Ground test wells are not required, but may be desired for troubleshooting and/or inspecting the grounding (earthing) electrode system components. Ground test wells are typically constructed of PVC tubing 203 mm (8 in.) or more in diameter and have a detachable cover to keep debris out. A typical PVC ground test well is shown in Figure 4-21.

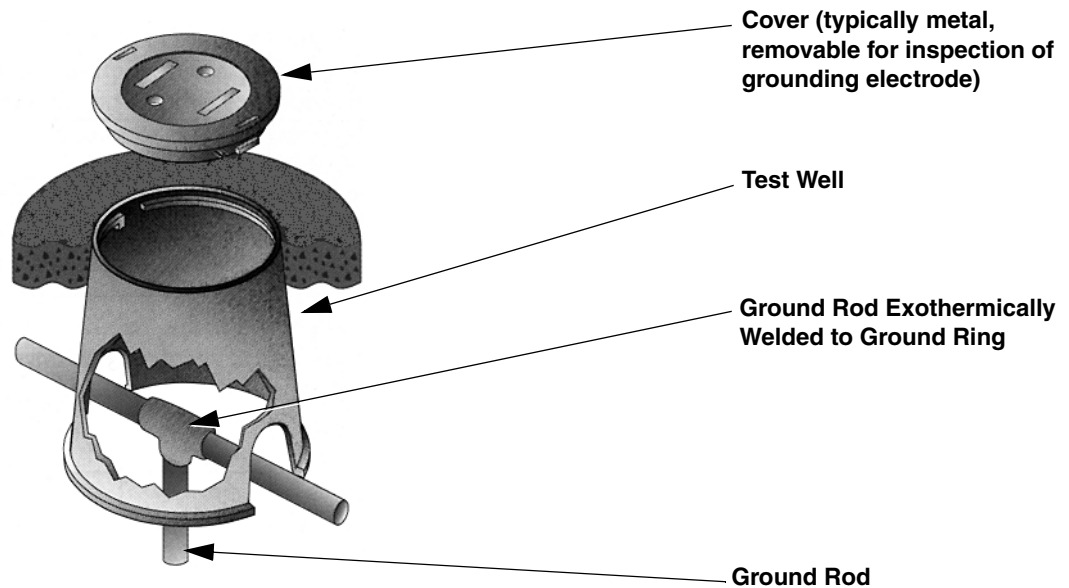


FIGURE 4-21 TYPICAL GROUND TEST WELL

4.4.1.9 GROUNDING (EARTHING) ELECTRODE ENCASEMENT MATERIALS

The resistance to earth of a grounding (earthing) electrode is directly proportional to soil resistivity and inversely proportional to the total area in contact with the soil. Grounding electrode encasement materials (also known as backfill or ground enhancing material) may consist of the following: bentonite or bentonite containing material, concrete, or conductive concrete or cement made with graded granular carbonaceous aggregate in place of the conventional sand or gravel. Grounding electrode encasement materials can absorb water from surrounding soil and have hydration and water retention properties. When placed around grounding electrodes and their interconnecting cable, grounding electrode encasement materials greatly increase the effective area in contact with soil, which in turn reduces the resistance of the grounding electrode system. See MIL-HDBK-419A Volume I, section 2.9 and BS 7430:1998, section 8.5 for more details.

Grounding electrode encasement material may be used as needed to improve the grounding electrode system resistance and/or to protect the grounding electrode system components from corrosive soil (BS 7430:1998, section 19.6.1). Grounding electrode encasement material is generally used with electrolytic ground rods, but may also be used on grounding conductors, standard ground rods, and ground plates as a way to improve the resistance to earth of a grounding electrode system. Requirements for the use of grounding electrode encasement material are as follows:

- Grounding electrode encasement material **shall** be packaged for the purpose of grounding electrode encasement.
- Grounding electrode encasement material **shall** be environmentally safe and approved by the environmental authority having jurisdiction.
- Grounding electrode encasement material **shall** be used in accordance with the manufacturers' instructions.
- Grounding electrode encasement material **shall not** have a corrosive effect on the grounding electrode system components.
- The use of charcoal or petroleum based coke breeze is not recommended as it may result in rapid corrosion of copper electrodes and copper conductors (BS 7430:1998, clause 8.5; BS 6651:1999, clause 18.4.2; and FAA STD 019d-2002, section 3.8.3.5). Charcoal and petroleum based coke typically contains high levels of sulfur, which in the presence of moisture will accelerate corrosion. Coke breeze derived from coal in coke ovens is generally considered acceptable; all the corrosives and volatiles have been cooked off at extremely high temperatures (FAA STD 019d-2002, section 3.8.3.5).

Per MIL-HDBK-419A, the suggested grounding electrode encasement (backfill) material is a mixture of 75 percent gypsum, 20 percent bentonite clay, and 5 percent sodium sulfate. The gypsum, which is calcium sulfate, absorbs and retains moisture and adds reactivity and conductivity to the mixture. Since it contracts very little when moisture is lost, it will not pull away from the ground rod or surrounding earth. The bentonite ensures good contact between the ground rod and earth by its expansion, while the sodium sulfate prevents polarization of the ground rod by removing the gases formed by current entering the earth through the ground rod. This mixture is readily available from cathodic protection distributors as standard galvanic anode backfill. The backfill mixture should be covered with 305 mm (12 in.) of excavated soil. See MIL-HDBK-419A Volume I, section 2.9 for additional information.

4.4.2 GROUNDING (EARTHING) CONDUCTORS

Grounding (earthing) conductors are the conductors used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or grounding electrode system. These conductors may connect grounding electrodes together, form buried ground rings, and connect objects to the grounding electrode system. See BS 7430:1998, clause 3.17 and NFPA 70-2005, Article 100 for additional information.

4.4.2.1 GENERAL SPECIFICATIONS

General specifications for grounding (earthing) conductors are listed below.

- Unless otherwise stated, all below-ground, or partially below-ground, external grounding electrode system conductors **shall** be 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductors (ANSI T1.313-2003 and ANSI T1.334-2002, section 5.3). For areas highly prone to lightning, and/or military installations, larger conductors, such as 50 mm² csa (#1/0 AWG) or coarser, should be considered (MIL-HDBK-419A); stranded conductors may be used in this application. Tinned conductors are recommended for stranded conductors.
- Solid, bare, tinned, copper conductors should be used to help minimize galvanic corrosion between tower legs and other parts of the grounding electrode system (ANSI T1.313-2003, section 10.7). See "Dissimilar Metals and Corrosion Control" on page 4-34.

- Grounding electrode conductors **shall** be installed in one continuous length without a splice or joint, unless spliced using irreversible compression-type connectors listed for the purpose or by exothermic welding (NFPA 70-2005, Article 250.64). See “Bonding Methods” on page 4-41 for additional information.
- Above-ground conductors used for bonding individual metallic objects **shall** be 16 mm² csa (#6 AWG) or coarser, tinned or un-tinned, copper conductors (ANSI T1.334, section 5.3.3). See “Metallic Objects Requiring Bonding” on page 4-67 for additional information.
- Above-ground conductors used for bonding multiple metallic objects (used as a ground bus conductor) **shall** be 35 mm² csa (#2 AWG) or coarser, tinned or un-tinned, copper conductors. See “Metallic Objects Requiring Bonding” on page 4-67.
- Above-ground bonding conductors should be jacketed, whenever practical (ANSI T1.334-2002, section 5.1).
- Solid straps or bars may be used as long as the cross-sectional area equals or exceeds that of the specified grounding conductor.

**WARNING**

The AC power system grounding conductors shall be sized appropriately for the electrical service and shall be approved by the authority having jurisdiction.

4.4.2.2 BENDING AND ROUTING GROUNDING (EARTHING) CONDUCTORS

Grounding (earthing) conductors **shall** be run in a direct manner with no sharp bends or narrow loops (ANSI T1.313-2003, section 11.3, and ANSI T1.334-2002, section 13.4). Sharp bends and/or narrow loops increase the impedance and may produce flash points (also see NFPA 780-2004, section 4.9.5). The following requirements apply when installing grounding system conductors:

- Sharp bends **shall** be avoided (ANSI T1.334-2002, section 13.4).
- Grounding conductors **shall** be run as short, straight, and smoothly as possible, with the fewest possible number of bends and curves (ANSI T1.313-2003, section 11.3; ANSI T1.334-2002, section 13.4; and NFPA 70-2005, Articles 800.100, 810.21, and 820.100).
- A minimum bending radius of 203 mm (8 in.) **shall** be maintained, applicable to grounding conductors of all sizes (ANSI T1.313-2003, section 11.3; MIL-STD-188-124B; and NFPA 780-2004, section 4.9.5). A diagonal run is preferable to a bend even though it does not follow the contour or run parallel to the supporting structure. See Figure 4-22.
- All bends and curves **shall** be made toward the ground location (grounding electrode system or ground bar).

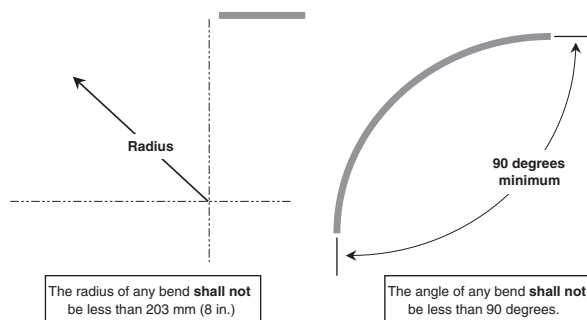


FIGURE 4-22 MINIMUM BENDING RADIUS FOR GROUNDING CONDUCTORS

4.4.2.3 PROTECTING AND SECURING GROUNDING (EARTHING) CONDUCTORS

Above ground external grounding (earthing) conductors, including straps, are exposed to movement by wind and other physical forces that can lead to damage or breakage over time. The following requirements **shall** apply when installing grounding conductors:

- Grounding conductors **shall** be protected where exposed to physical damage (NFPA 70-2005, Articles 250.64, 800.100, 810.20, 820.100; and NFPA 780-2004, section 4.9.11).
- Grounding conductors exposed to physical damage **shall** be protected for a minimum distance of 1.8 m (6 ft.) above grade level (NFPA 780-2004, section 4.9.11.2). Such areas may include, but are not limited to, runways, driveways, school playgrounds, cattle yards, public walks (NFPA 780-2004, section 4.9.11).
- Metallic guards and/or conduits used to protect grounding conductors **shall** be bonded to the grounding conductor at both ends (NFPA 70-2005, Article 250.64 and NFPA 780-2004, section 4.9.11.1).
- The grounding conductor or its enclosure **shall** be securely fastened to the surface on which it is carried (NFPA 70-2005, Articles 250.64 and 810.21; and NFPA 780-2004, section 4.10).
- Grounding conductors **shall** be secured using appropriate hardware intended for the purpose.
- When metallic fasteners are used on bare grounding conductors, fasteners of the same material **shall** be used, or approved bonding techniques **shall** be observed for the connection of dissimilar metals. See “Dissimilar Metals and Corrosion Control” on page 4-34. See NFPA 780-2004, section 4.10.2 for additional information.
- Above ground grounding conductors **shall** be securely fastened at intervals not exceeding 91 cm (3 ft.) where practical. (ANSI T1.334-2002, section 8.3 and NFPA 780-2004, Section 4.10)

4.4.3 EXTERNAL GROUND BUS BAR

The purpose of the external ground bus bar (EGB) is to provide a convenient grounding (earthing) termination point for antenna transmission lines (coaxial cables) and other cables prior to their entry into a building or shelter (ANSI T1.313-2003). Antenna transmission lines and other communications cables with metallic sheaths **shall** be grounded as close as practical to their point of entry into the building or shelter (NFPA 70-2005, articles 770.93, 800.100, 810.20, 820.93, and 820.100).

Requirements for external ground bus bars, when used, are listed below:

- The EGB **shall** be constructed and minimally sized in accordance with Table 4-3 on page 4-32, ensuring the ground bus bar is large enough to accommodate all transmission lines and other grounding connections.
- The EGB **shall** be designed for the purpose of grounding and should be UL listed,
- The EGB **shall** be installed at the point where the antenna transmission lines and other communications cables enter the building or shelter.
- The EGB **shall** be connected directly to the grounding electrode system using a downward run of 35 mm² csa (#2 AWG) or coarser, bare, solid or stranded, tinned or un-tinned, copper conductor; it is recommended to use a larger conductor, such as 120 mm² (#4/0 AWG) (United States National Weather Service Manual 30-4106-2004, “Lightning Protection, Grounding, Bonding, Shielding, and Surge Protection Requirements”). See Figure 4-23. The grounding conductor **shall** be installed in a direct manner with no sharp bends or narrow loops. (See “Bending And Routing Grounding (Earthing) Conductors” on page 4-29.)

- Connection of the grounding electrode conductor to the EGB **shall** use exothermic weld or listed irreversible compression connections (ANSI T1.313-2003).

For reduced impedance to the grounding electrode system, the EGB can be connected to the grounding electrode system using solid copper strap. Relatively small copper strap has significantly less inductance (impedance to lightning) than large wire conductors. For example, 38.1 mm (1.5 in.) copper strap has less inductance than 70 mm² csa (#2/0 AWG) wire. To further reduce the inductance to ground, several copper straps can be installed across the entire length of the external ground bus bar and routed down to the external grounding ring. See Figure 4-23.

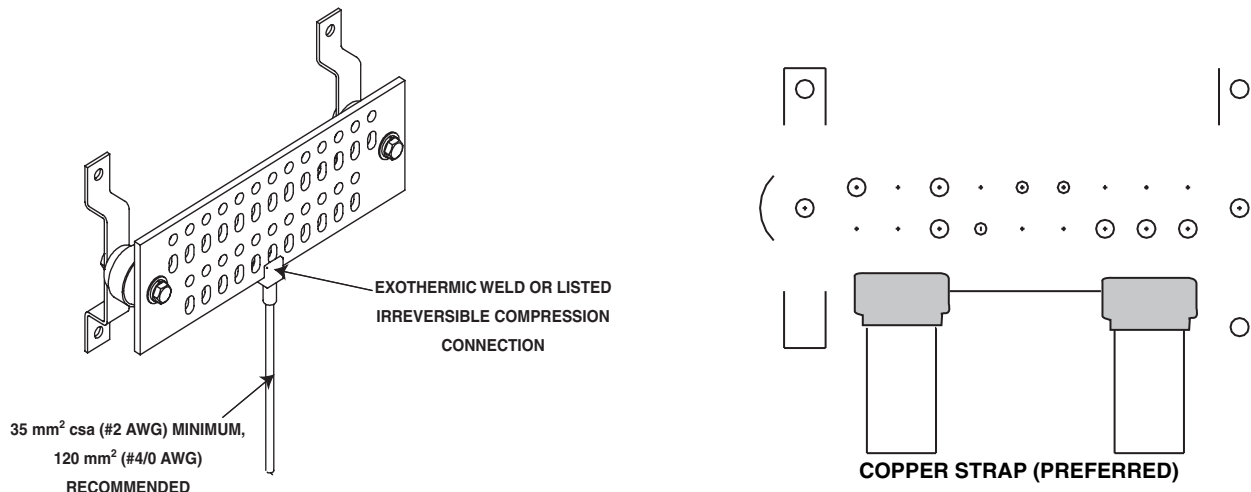


FIGURE 4-23 TYPICAL EXTERNAL GROUND BUS BARS

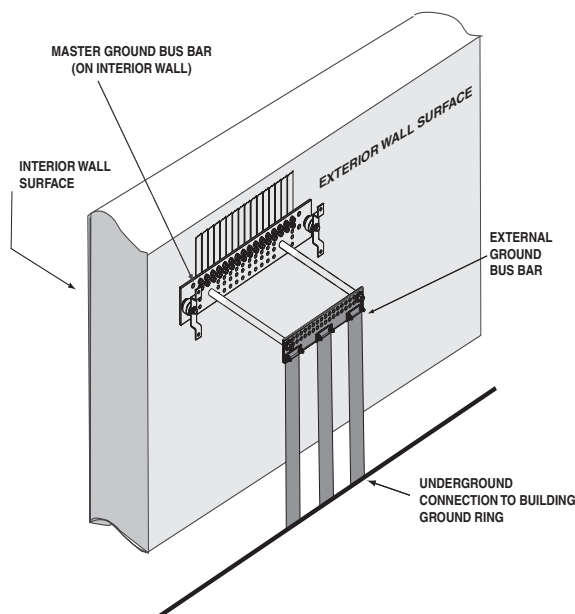


FIGURE 4-24 INTEGRATED CABLE ENTRY PORT WITH GROUND STRAPS

TABLE 4-3 EXTERNAL GROUND BUS BAR SPECIFICATIONS (WHEN REQUIRED)

Item	Specification
Material	Bare, solid Alloy 110 (99.9%) copper bus bar or plate of one piece construction. May be tin-plated.
Minimum Dimensions (ANSI-J-STD-607-A-2002 and NFPA 70-2005, Article 250.64)	Height: 51 mm (2 in.) Thickness: 6.35 mm (0.25 in.) Length: Variable to meet the application requirements and allow for future growth. 305 mm (12 in.) is recommended as the minimum length.
Mounting brackets	Stainless steel
Insulators	Polyester fiberglass 15 kV minimum dielectric strength flame resistant per UL 94 VO classification
Conductor mounting holes	Number dependent on number of conductors to be attached Holes to be 11 mm (0.4375 in.) minimum on 19 mm (0.75 in.) centers to permit the convenient use of two-hole lugs.
Method of attachment of grounding electrode conductor	Exothermic welding Irreversible crimp connection

IMPORTANT: For improved lightning protection at the site, the RF transmission line entry point and EGB should be installed as low to the ground as practical; 610 mm (2 ft.) is the recommended maximum height for the RF transmission line entry point. (United States National Weather Service Manual 30-4106-2004, “Lighting Protection, Grounding, Bonding, Shielding, and Surge Protection Requirements”.) See “Design Considerations to Help Reduce Effects of Lightning” on page 2-19.

4.4.3.1 TOWER GROUND BUS BAR

The purpose of the tower ground bus bar (TGB) is to provide a convenient termination point on the tower for multiple transmission line (coaxial) grounding (earthing) conductors. The tower ground bus bar should be an integral part of the tower construction. If the tower ground bus bar is not part of the tower construction, it **shall** be constructed and minimally sized in accordance with Table 4-4 on page 4-34, ensuring the ground bus bar is large enough to accommodate all coaxial cable connections and connection to the grounding electrode system.

The requirements for installing tower ground bus bars are as follows:

- Where a galvanized tower is not protected against precipitation run-off from copper and copper alloys, the tower ground bus bar (TGB) **shall** be constructed of tinned copper. See “Methods To Help Reduce Corrosion” on page 4-38.
- The tower ground bus bar **shall** be installed below the transmission line ground kits, near the area of the tower at the point where the antenna transmission lines transition from the tower to the shelter.
- The tower ground bus bar **shall** be connected to the tower grounding electrode system with a 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned, copper conductor.

- For reduced impedance to earth, the tower ground bus bar may be directly bonded to the tower, using hardware of materials suitable for preventing dissimilar metal reactions, if possible and allowed by the tower manufacturer. This is in addition to the required grounding conductor as described above.
- The grounding conductors **shall** be run as short, straight, and smoothly as possible. See “Bending And Routing Grounding (Earthing) Conductors” on page 4-29.
- The grounding conductor may be sleeved in PVC for protection if desired (ANSI T1.313-2003, section 11.4). This may be required in order to keep the grounding conductor from making incidental contact with the tower.

For reduced impedance to the grounding electrode system, the TGB can be connected to the external grounding electrode system using solid copper strap. Relatively small copper strap has significantly less inductance (impedance to lightning) than large wire conductors. For example, 38.1 mm (1.5 in.) copper strap has less inductance than 70 mm² csa (#2/0 AWG) wire. To further reduce the inductance to ground, several copper straps can be installed across the entire length of the tower ground bus bar and routed down to the external grounding ring.

Additional ground bus bars may be installed at different heights along the vertical length of the tower for bonding multiple transmission line ground kits to the tower, if not already included as part of the tower structure. The additional ground bus bars **shall** be bonded directly to the tower using tower manufacturer approved methods. Bonding to the tower may include the following options:

- Bolting a tin-plated bus bar directly to the tower structure using stainless steel hardware. In this case, a grounding conductor is not required.
- Securing a bus bar to the tower using appropriate mechanical hardware. Electrically bonding the bus bar to the tower using a grounding conductor. The grounding conductor should bond to the tower using appropriate hardware, such as stainless steel beam clamps, or stainless steel band/strap type clamp. The grounding conductor **shall** bond to the bus bar using exothermic weld, irreversible compression connectors, or listed compression two-hole lugs.

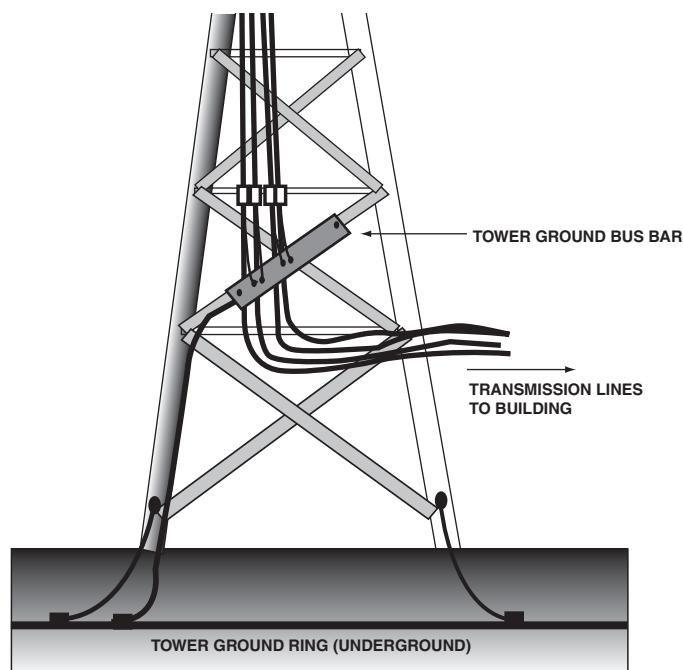


FIGURE 4-25 TYPICAL TOWER GROUND BUS BARS

TABLE 4-4 TOWER GROUND BUS BAR SPECIFICATIONS

Item	Specification
Material	Bare, solid Alloy 110 (99.9%) copper bus bar or plate of one piece construction. Should be tin-plated if installing on a galvanized tower. (See “Dissimilar Metals and Corrosion Control” on page 4-34 for information regarding tower corrosion related to copper bus bars.)
Minimum Dimensions (ANSI-J-STD-607-A-2002 and NFPA 70-2005, Article 250.64)	Height: 51 mm (2 in.) Thickness: 6.35 mm (0.25 in.) Length: Variable to meet the application requirements and allow for future growth. 305 mm (12 in.) is recommended as the minimum length.
Mounting brackets	Stainless steel
Conductor mounting holes	Number dependent on number of conductors to be attached Holes to be 11 mm (0.4375 in.) minimum on 19 mm (0.75 in.) centers to permit the convenient use of two-hole lugs.
Method of attachment of grounding electrode conductor	Exothermic welding Irreversible crimp connection

4.5 DISSIMILAR METALS AND CORROSION CONTROL

Although the type of metals used in a grounding (earthing) electrode system do not affect the resistance to earth of the grounding electrode system, consideration should be given to select a metal that is resistance to corrosion in the type of soil in which it will be installed. The two areas that should be considered regarding the corrosion resistance of a metal are the compatibility with the soil itself and possible galvanic corrosion effects when it is electrically connected to neighboring metals at the site. (BS 7430:1998)

4.5.1 CORROSION RELATED TO SOIL TYPE

The compatibility of a metal with soil is determined by the chemical composition of the soil. The chemical composition factors associated with the corrosion of metals in contact with the soil are as follows: acidity or alkalinity (pH), salt content, soil porosity (aeration), and the presence of anaerobic bacteria. (BS 7430:1998 and TIA/EIA-222-F-R2003)

The following list gives a general representation of the aggressiveness of soils, listed in order of increasing aggressiveness (BS 7430:1998):

- Gravelly soils (Least Aggressive)
- Sandy soils
- Silty soils (loam)
- Clays
- Peat and other organic soils
- Made up soils containing cinders (Most Aggressive)

The least aggressive soils tend to be those having a high resistivity. The resistivity of soil can be measured, which provides an indication of corrosiveness under aerated conditions (BS 7430:1998). See “Performing Soil Resistivity Test” on page B-6 for measurement details. Soil with a resistivity below 2,000 ohm centimeters ($\Omega\text{-cm}$) is generally considered to be highly corrosive (TIA/EIA-222-F-R2003).

More details about the aggressiveness of soils can be obtained by measuring the redox (from the words reduction and oxidation) potential of the soil, which indicates the risk of corrosion due to the presence of anaerobic bacteria (BS 7430:1998). Test equipment required to measure redox potential is commercially available. The procedure required to test the redox potential can be found in ISO 11271:2002(E). A geotechnical firm may be required to measure the redox potential of the soil.

General guidance on the corrosiveness of some grounding electrode system metals in relation to soil composition is given below in Table 4-5 (BS 7430:1998). A geotechnical firm may be required to determine all of the listed soil parameters.

TABLE 4-5 CORROSION RESISTANCE PROPERTIES OF COMMON GROUNDING ELECTRODE SYSTEM METALS AS RELATED TO SOIL COMPOSITION

Soil Parameter		Grounding Electrode Metal		
		Copper	Galvanized Steel	Austenitic Stainless Steel*
Resistivity ($\Omega\text{-cm}$)	< 700	Slightly Reduced	Moderately Reduced	Slightly Reduced
	700 to 4000	Slightly Reduced	Moderately Reduced	Generally Unaffected
	> 4000	Generally Unaffected	Generally Unaffected	Generally Unaffected
Redox Potential (mV)	< 200	Moderately Reduced	Considerably Reduced	Moderately Reduced
	200 to 400	Slightly Reduced	Slightly Reduced	Generally Unaffected
	> 400	Generally Unaffected	Generally Unaffected	Generally Unaffected
Moisture Content (%)	< 10	Generally Unaffected	Generally Unaffected	Generally Unaffected
	10 to 80	Slightly Reduced	Moderately Reduced	Slightly Reduced
	> 80	Slightly Reduced	Slightly Reduced	Slightly Reduced
Dissolved				
Salts		Moderately Reduced	Moderately Reduced	Slightly Reduced
Chlorides		Moderately Reduced	Moderately Reduced	Moderately Reduced
pH				
Acidic	< 6	Moderately Reduced	Considerably Reduced	Slightly Reduced
Neutral	6 to 8	Generally Unaffected	Generally Unaffected	Generally Unaffected
Alkaline	> 8	Slightly Reduced	Moderately Reduced	Generally Unaffected
Organic Acids	> 8	Considerably Reduced	Moderately Reduced	Slightly Reduced
* Austenitic stainless steel shall be formed from 18% chromium and 8% nickel (18/8 stainless steel), per UL 467-2004, section 9.2.6. Table based on information from BS 7430:1998.				

The following general observations can be made from Table 4-5:

- Copper-clad steel or solid copper ground rods are one of the better and commonly used materials for grounding electrodes. However, the adverse effect of dissolved salts, organic acids and acid soils generally should be noted (BS 7430:1998, clause 11).
- Copper or copper-clad ground rods should not be used in soils where organic acids are present, unless protective measures are taken, such as encasing the ground rods in a grounding electrode encasement material. Organic acids are commonly found in poorly drained and poorly aerated soils. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.
- Galvanized ground rods should not be used in soils with a redox potential below 200 mV, unless protective measures are taken, such as encasing the ground rods in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.
- Galvanized ground rods should not be used in acidic soils with a pH below 6.

4.5.2 GALVANIC CORROSION

Galvanic corrosion (also called dissimilar metals corrosion) refers to corrosion damage induced when two dissimilar metals are electrically connected and coupled through an electrolyte (such as soil). When a metal is electrically connected to a dissimilar metal, a difference of potential exists between the two metals. If the dissimilar metals are also in contact with a low resistivity soil, a complete circuit will exist. Current will flow from one metal to the other due to the electrical connection and return path through the soil. This naturally occurring phenomenon is why current is obtained from a battery when its terminals are electrically connected to a load (TIA/EIA-222-F-R2003). See Figure 4-26 for an example of installations with and without galvanic corrosion.

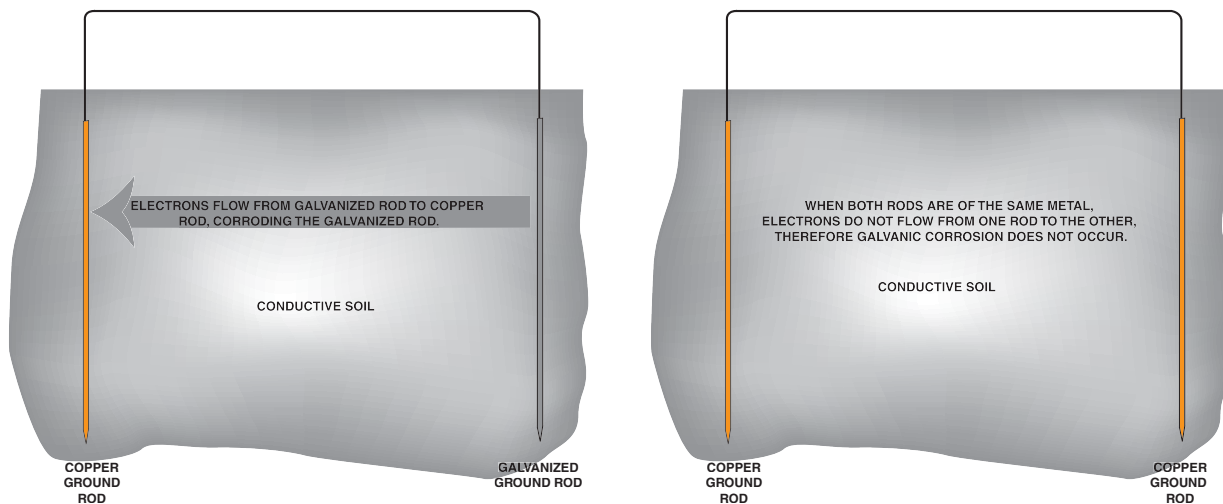


FIGURE 4-26 INSTALLATIONS WITH AND WITHOUT GALVANIC CORROSION

Metals may be listed in order of their respective potentials; such a list is called a galvanic series. A galvanic series of commonly used grounding (earthing) electrode system metals and alloys is given in Table 4-6 (from TIA/EIA-222-F-R2003 and MIL-HDBK-419A). When a complete circuit exists, corrosion occurs on the metal listed higher in the galvanic series. The metal listed higher in the galvanic series (anode) is where current exits and travels through the soil toward the metal listed lower on the galvanic series (cathode). The galvanic series of commonly used metals and alloys is as follows:

TABLE 4-6 GALVANIC SERIES OF COMMON METALS

Anodic (Active) End
Magnesium
Zinc (material used to galvanize steel)
Aluminum
Steel, Iron
Lead, Tin
Brass, Copper, Bronze
Silver
Graphite
Cathodic (Most Noble) End

The rate of corrosion mainly depends on the conductivity of the soil and the relative position of the metals in the galvanic series. The higher the soil conductivity (low resistivity), and the further apart the metals are in the galvanic series, the faster the rate of corrosion (TIA/EIA-222-F-R2003). To some extent, the rate of corrosion also depends on the relative surface areas of the metals (BS 7430:1998 and IEEE STD 142-1991). A small anode (such as a galvanized steel guy anchor point) and large cathode (such as a copper grounding electrode system) should not be installed; in this case, the total current is confined to a small space and the current density is large, therefore, corroding the galvanized steel (IEEE STD 142-1991).

General guidance on the suitability of metals for bonding together with neighboring metals is given below in Table 4-7 (BS 7430:1998); both metals are assumed to be located in the earth. The bond between the neighboring metals could be located above or below ground.

TABLE 4-7 SUITABILITY OF METALS FOR BONDING

Metal assumed to have the Larger Surface Area	Electrode metal or item assumed to have the Smaller Surface Area			
	Steel	Galvanized Steel	Copper	Tinned Copper
Galvanized Steel	Suitable	Suitable	Suitable	Suitable
Steel in Concrete	Not Suitable	Not Suitable	Suitable	Suitable
Galvanized Steel in Concrete	Suitable	*	Suitable	Suitable
Lead	Suitable	*	Suitable	Suitable
Key: Suitable = Materials suitable for bonding. Not Suitable = Materials not suitable for bonding. * = Materials suitable for bonding, but the galvanizing on the smaller surface may suffer. This table is based on Table 8 of BS 7430:1998.				

4.5.3 MISCELLANEOUS GENERAL INFORMATION

- Galvanized steel is strongly electronegative to copper and steel encased in concrete, therefore, careful consideration must be given before galvanized ground rods are used at a site that contains a concreted encased electrode. (See BS 7430:1998, clause 11.2 for additional information.) See “Concrete-Encased Electrodes” on page 4-20.
- Steel encased in concrete has a potential similar to that of copper; therefore, may be bonded to copper or copper-clad ground rods. (See BS 7430:1998 and IEEE STD 142-1991 for additional information.)

4.5.4 METHODS TO HELP REDUCE CORROSION

Listed below are some general requirements and guidelines to help prevent corrosion of the grounding (earthing) electrode system and other metallic items at the communications site:

- The same metal **shall** be used throughout the grounding electrode system whenever possible.
- Aluminum or copper-clad aluminum grounding conductors **shall not** be used (NFPA 70-2005, Article 250.64).
- Copper **shall not** come into incidental contact with galvanized steel.
- Copper **shall not** come into incidental contact with aluminum.
- Precipitation run-off from copper and copper alloys can attack galvanized parts (BS 6651:1999 and IEC 61024-1-2, section 5.2); therefore, bare copper conductors or copper bus bars **shall not** be installed above galvanized steel, such as a tower, unless the steel is protected against the precipitation run-off (IEC 61024-1-2, section 5.2).

**CAUTION**

Extremely fine particles are shed by copper parts, which result in severe corrosive damage to galvanized parts, even where the copper and galvanized parts are not in direct contact (IEC 61024-1-2, section 5.2).

- Where a galvanized tower is not protected against precipitation run-off from copper and copper alloys, the tower ground bus bar (TGB) **shall** be constructed of tinned copper or other suitable material.
- Where tinned conductors or galvanized ground rods are used, care **shall** be exercised during installation so that surfaces are not damaged. If surfaces of these ground elements are damaged, the potential for deterioration from galvanic action increases (ANSI T1.313-2003, section 11.5 and ANSI T1.334-2002, section 13.6).
- Exothermically welded joints on galvanized material **shall** be coated with a zinc-enriched paint to prevent corrosion.
- Copper/aluminum joints **shall** be avoided wherever possible. In cases where they cannot be avoided, the connections **shall** be exothermically welded or made using an AL/CU listed bimetallic transition connector (IEC 61024-1-2, section 5.2). Use a listed conductive anti-oxidant compound on all mechanical connections (ANSI T1.334-2002, section 9).
- Solid, bare, tinned copper conductor should be used to minimize galvanic corrosion between tower legs and other parts of the grounding electrode system (ANSI T1.313-2003, section 10.7).
- Grounding connections to galvanized towers **shall** be exothermally welded whenever possible. When exothermic welding is not possible, the tower grounding conductor **shall** be constructed of tinned-copper (IEC 61024-1-2, section 5.2).
- Select appropriate grounding electrode system components using Table 4-5.
- When soil conditions are not favorable, such as highly acidic or alkaline, grounding electrode system component corrosion may be reduced by encasing the components in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27, and BS 7430:1998, section 19.6.1, for additional information.
- When soil conditions are not favorable, such as highly acidic or alkaline, grounding electrode system component corrosion may be reduced by installing electrolytic ground rods encased in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27 and “Electrolytic Ground Rods” on page 4-16.
- When soil conditions are not favorable, such as highly acidic or alkaline, the useful life of a copper ground rod can be extended by using solid copper ground rods instead of copper-clad rods, if soil conditions allow driving of the solid copper rod.
- When soil conditions are not favorable, such as highly acidic or alkaline, the useful life of buried grounding conductors can be extended by using larger conductors, such as 70 mm² csa (#2/0 AWG) instead of 35 mm² (#2 AWG).
- Use a listed conductive anti-oxidant compound on all mechanical connections (ANSI T1.334-2002, section 9). The anti-oxidant compound **shall** be liberally installed between the two metals (see Figure 4-27 on page 4-40).
- See “Guy Anchor Points” on page 4-54 for information regarding proper grounding techniques to help minimize galvanic corrosion of the guy anchor.

4.6 BONDING TO THE EXTERNAL GROUNDING (EARTHING) ELECTRODE SYSTEM

4.6.1 REQUIREMENTS

All below-grade grounding (earthing) electrode system connections **shall** be joined using exothermic welding or listed irreversible high-compression fittings compressed to a minimum of 13.3 tonnes (12 tons) of pressure, or as otherwise required by the specific component manufacturer (ANSI T1.313-2003, figure 3(a)). Manufacturer requirements **shall** be followed for all connections. Connectors and fitting used **shall** be listed for the purpose, for the type of conductor, and for the size and number of conductors used.

All above grade grounding electrode system connections (such as grounding electrode conductor connection to ground bus bars and tower legs) **shall** be joined using exothermic welding, or listed irreversible high-compression fittings compressed to a minimum of 13.3 tonnes (12 tons) of pressure, or as otherwise required by the specific component manufacturer (ANSI T1.313-2003, figure 3(a)).

All above grade bonding connections (such as bonding to ancillary equipment, or bonding coaxial ground kits to bus bars) **shall** be joined using exothermic welding, listed lugs, listed pressure connectors, listed clamps, or other listed means required by the specific component manufacturer. Connecting hardware **shall** be designed for the purpose, for the type of conductor, and for the size and number of conductors used. All mechanical connections **shall** be coated with a listed conductive anti-oxidant compound. The anti-oxidant compound **shall** be liberally applied between the two metals (see Figure 4-27)(NFPA 70-2005, Article 250.70).

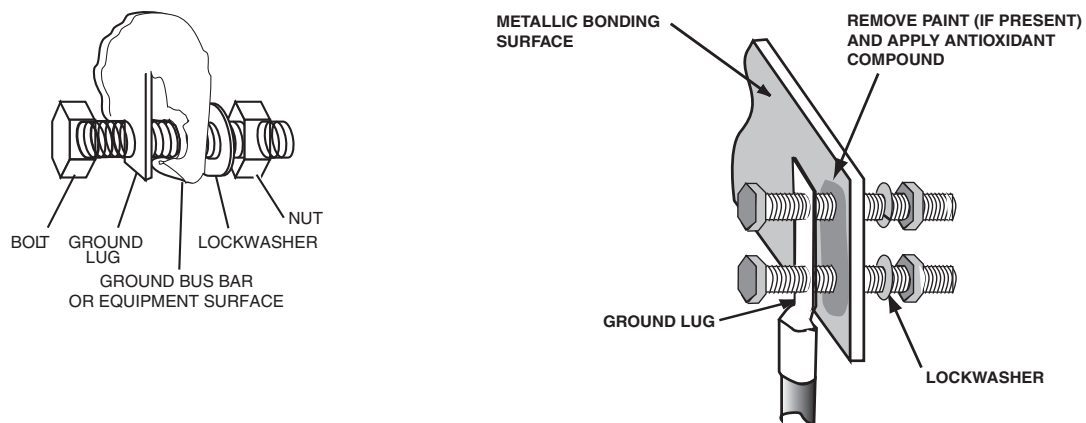


FIGURE 4-27 PROPER LOCATION OF WASHER WHEN CONNECTING GROUNDING LUG

NOTE: In some instances, exothermic welding may not be possible or may be prohibited by the specific component manufacturer (such as towers or fences); in these cases, other suitable means for bonding is allowed.

Connecting hardware **shall** be listed for the purpose, for the type of conductor, and for the size and number of conductors used. All mechanical connections **shall** be coated with a listed conductive anti-oxidant compound (NFPA 70-2005, Article 250.70).

All exothermic and irreversible compression connections for use on external grounding applications **shall** be UL 467 listed. Copper connectors **shall** maintain minimum 88% conductivity rating. Compression systems **shall** include crimped die index and company logo for purposes of inspection. Aluminum **shall not** be used for connection purposes.

Bonding **shall** be performed so that a suitable and reliable connection exists. The following requirements **shall** be observed when bonding grounding connections:

- Paint, enamel, lacquer and other nonconductive coatings **shall** be removed from threads and surface areas where connections are made to ensure good electrical continuity (NFPA 70-2005, Article 250.12). Use of a star washer does not alleviate the requirement to remove nonconductive coatings from attachment surfaces. See Figure 4-27 for proper star/lock washer location. Star washers should only be used as a lock washer.
- After bonding to a painted or galvanized structure, the area **shall** be painted with a zinc-enriched paint.
- Exothermic welding is the preferred method for bonding connections to the external grounding electrode system.
- Two-hole lugs secured with fasteners in both holes are preferred over single-hole lugs. Two-hole lugs prevent movement of the lug.
- When connecting ground lugs or compression terminals to ancillary equipment, such as air conditioners and vent hoods, a lock washer **shall** be placed on the nut side. See Figure 4-27. Sheet metal screws and/or self-tapping screws **shall not** be used.
- All mechanical connections **shall** be coated with a listed conductive anti-oxidant compound (NFPA 70-2005, Article 250.70, ANSI T1.334-2002, section 9). The anti-oxidant compound **shall** be liberally installed between the two metals (see Figure 4-27 on page 4-40).

4.6.2 BONDING METHODS

The following paragraphs describe acceptable methods for bonding to the external grounding (earthing) electrode system. Exothermic welding and the use of listed irreversible high-compression fittings are the only acceptable methods for below-grade bonding. Other mechanical connection methods **shall not** be used below-grade.

4.6.2.1 EXOTHERMIC WELDING

Exothermic welding is a method of welding electrical connections without an external heat source, such as electricity or gas. The process is based on the reaction of granular metals which when combined, produce a molten metal. This reaction, which is completed in seconds, takes place in a crucible. The liquid metal flows from the crucible into a mold where it meets the ends of the conductors to be welded. The temperature of the molten metal is sufficient to fuse the metal of the conductors, resulting in a welded molecular bond. Exothermic welding alloys are available for aluminum, copper, and copper to steel connections.

**WARNING**

To help prevent injury from molten metal or sparks and to reduce the risk of fire, follow the exothermic welding manufacturer's safety warnings and requirements.

- Heavy clothing, work shoes or boots, gloves, and safety glasses **shall** be worn when performing exothermic welding,
- Exothermic welding **shall not** be performed unless another person capable of rendering first aid is present. A suitable fire extinguisher **shall** be close by with an attendant during the process.
- Observe the following prerequisites for exothermic welding:
 - Follow the manufacturer's recommendations.
 - Use the proper molds for the conductors being welded.
 - Use the proper weld material for the metals being welded.
 - Properly clean all metal parts prior to welding.
 - Properly dry all metal parts and molds prior to welding.

The exothermic welding process is shown in Figure 4-28.

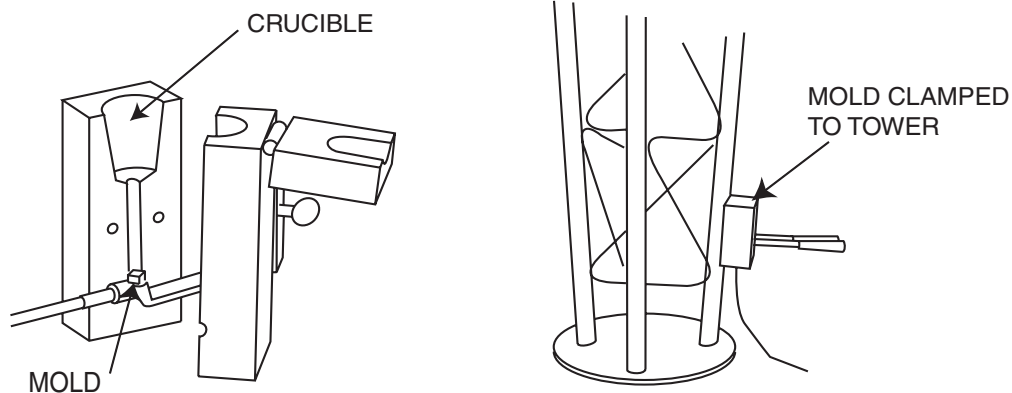


FIGURE 4-28 EXOTHERMIC WELDING MOLD (LEFT) AND PROCESS (RIGHT)

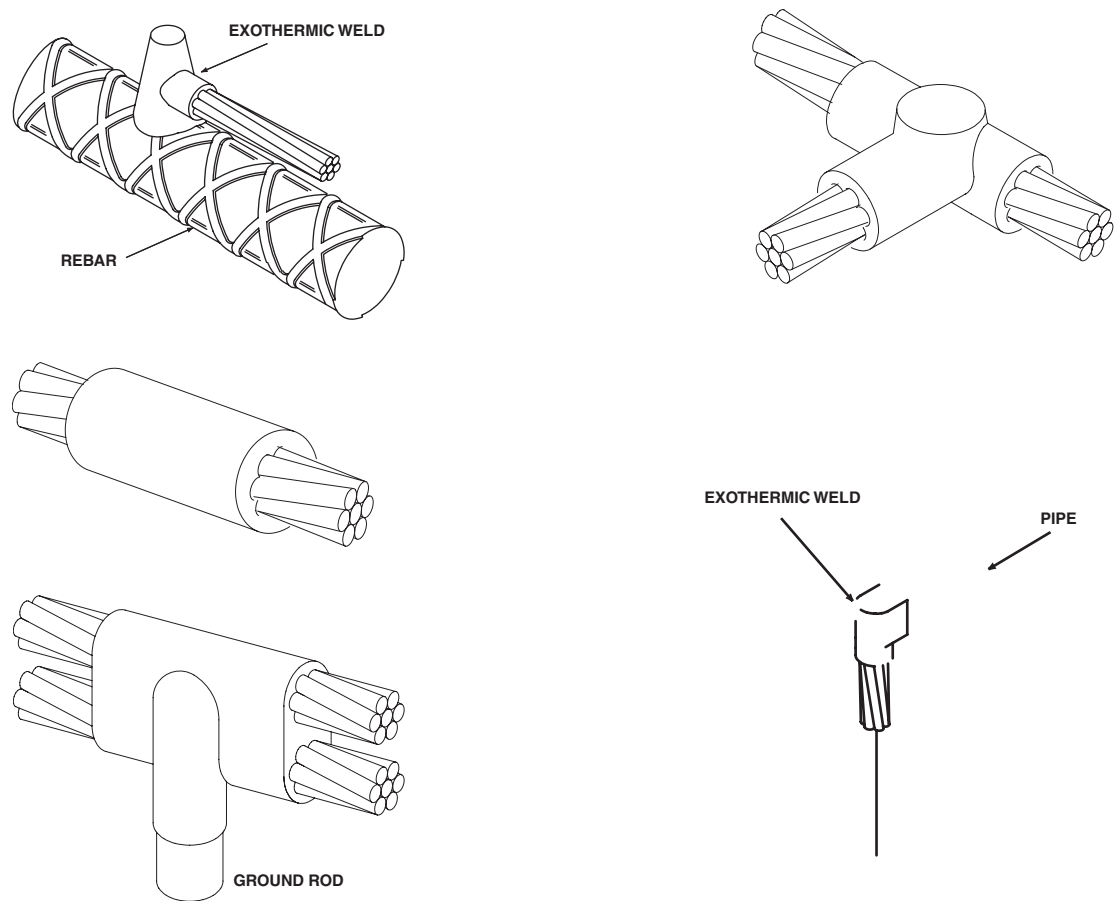


FIGURE 4-29 EXAMPLES OF COMPLETED EXOTHERMIC WELDS

4.6.2.2 IRREVERSIBLE HIGH COMPRESSION FITTINGS



WARNING

Wear safety glasses, hard hat, and steel-toes shoes when working with high-compression fittings.

When using irreversible high-compression fittings, always use the compression tool recommended by the manufacturer in accordance with the instructions provided by the manufacturer. Use fittings made of the same material as the materials being bonded to avoid dissimilar metal reactions. See Figure 4-30 for examples of high-compression fittings.

- Use fittings properly sized for the conductors being bonded.
- Use fittings and compression tools rated at 13.3 tonnes (12 tons) of force.
- Use only UL-listed connectors.
- To ensure good contact, clean conductors using a wire brush before crimping.
- Coat all crimped connections with a listed conductive antioxidant compound before crimping.

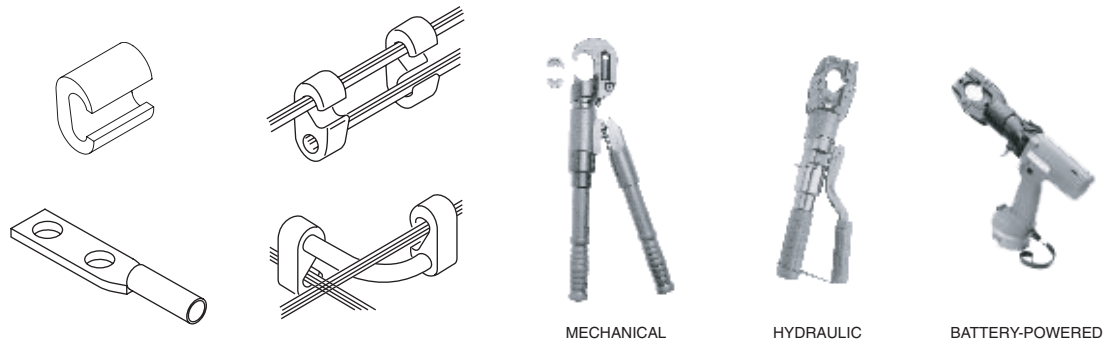


FIGURE 4-30 HIGH-COMPRESSION CONNECTORS AND TYPICAL CRIMPING TOOLS

4.7 MINIMUM SITE GROUNDING (EARTHING) REQUIREMENTS

This section provides the minimum grounding (earthing) requirements for installing a grounding electrode system at a communications site and for bonding site equipment to the grounding electrode system. Reasonable attempts **shall** be made to achieve the grounding electrode system resistance design goal, as defined in “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-46

The requirements for installing a typical grounding electrode system are as follows:

- Perform a soil resistivity test at the site as described in Appendix B, “Soil Resistivity Measurements”
- Calculate the resistance of a single ground rod as described in “Interpreting Test Results” on page B-10.
- Determine the resistance requirement of the grounding electrode system, based on the site type (“Light Duty” or “Standard Duty” site). See “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-46.

4.7.1 TYPE “A” SITE - LIGHT DUTY

- Determine if the single ground rod will meet the minimum 25 ohm requirement. If the single ground rod does not meet the 25 ohm requirement, an additional ground rod, or other grounding (earthing) electrode, will be required. See “Type “A” Site Grounding (Earthing)” on page 4-48 for additional information.
- Install the ground rod(s) as described in “Type “A” Site Grounding (Earthing)” on page 4-48 and elsewhere throughout this chapter.

NOTE: It is recommended to use two grounding electrodes as the minimum installation, even if 25 ohms is achieved with a single grounding electrode.

4.7.2 TYPE “B” SITE - STANDARD DUTY

- Using a site drawing, determine where to install the minimum required ground rods, while maintaining equal separation between rods. See “External Building and Tower Ground Ring” on page 4-22 for additional information regarding ground rod placement requirements along ground rings.
- Determine if radial grounding (earthing) conductors should be installed at the site, such as when the site is located in a high lightning prone geographic area or when the site is normally occupied, such as a dispatch center. See “Radial (Counterpoise) Grounding Conductors” on page 4-24.
- Calculate the resistance of the grounding electrode system using “Calculating Resistance of Complex Ground Rod Systems” on page B-30.
- If the required resistance cannot be met, recalculate using one or more of the follow techniques:
 - Recalculate using longer ground rods.
 - Recalculate using radial grounding conductors if not already included. See “Radial (Counterpoise) Grounding Conductors” on page 4-24.
 - Recalculate using closer spaced ground rods, resulting in more ground rods at the site (do not install ground rods closer than one ground rod length apart from other ground rods).
- If the resistance requirement still cannot be met, see “Special Grounding (Earthing) Situations” on page 4-88.
- Develop a detailed site grounding electrode system drawing based on the previous steps.
- Install the grounding electrode system using components and techniques as specified throughout this chapter.
- Test the grounding electrode system resistance to earth as described in Appendix D.
- Bond all external metal objects to the grounding electrode system as required throughout this chapter.

4.7.3 SPECIAL GROUNDING (EARTHING) SITUATIONS

- See “Calculating Multiple Grounding Electrode System Resistance (Electrodes In Straight Line)” on page B-19 for the information required to calculate the resistance to earth of multiple ground rods installed in a straight line.
- See “Multiple Grounding Electrode System Resistance Calculation (Electrodes In Ring Configuration)” on page B-24 for the information required to calculate the resistance to earth of multiple ground rods installed in a ring configuration.
- See “Calculating Multiple Grounding Electrode System Resistance (Ground Rod Grid Configuration)” on page B-24 for the information required to calculate the resistance to earth of multiple ground rods installed in a ground rod grid configuration.

4.7.4 GROUNDING (EARTHING) ELECTRODE SYSTEM RESISTANCE REQUIREMENTS

In order to disperse lightning energy into the earth without causing dangerous over-voltage, the shape and dimensions of the grounding (earthing) electrode system are more important than a specific resistance value of the grounding electrode system. However, a low resistance grounding electrode system is generally recommended (IEC 61024-1-2). Attempts should be made to reduce the grounding electrode system resistance to the lowest practical value (MIL-HDBK-419A, section 2.2.3).

NOTE: Although grounding electrode system resistance is important and should be met whenever possible, it alone does not determine the suitability of the grounding electrode system to properly dissipate and control lightning energy. The resistance of the grounding electrode system is only a general measure of merit. Proper design and installation of the grounding electrode system, installation of ground rings, ground rods, radial grounding conductors, and the bonding of systems and equipment, is as important as the resistance to earth.

Effective grounding electrode system shape and dimensions are achieved through the proper installation of the required and recommended grounding electrode system components listed throughout this chapter. The required and recommended grounding electrode system components are, but not limited to, the following:

- **Building ground ring.** See “External Building and Tower Ground Ring” on page 4-22.
- **Tower ground ring.** See “External Building and Tower Ground Ring” on page 4-22.
- **Ground rods** properly installed and spaced around the building and tower ground rings. See “Ground Rods” on page 4-11.
- **Radial grounding conductors** for high lightning prone geographical areas, sites that are normally occupied (such as 911 dispatch centers), sites with high soil resistivity, or when bedrock prohibits the driving of ground rods. See “Radial (Counterpoise) Grounding Conductors” on page 4-24.
- **Proper bonding of all grounding electrode system components.** See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.
- **Proper bonding of all ancillary equipment.** See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

The grounding electrode system resistance requirement is determined based on the classification of the site. Communications sites are classified by this standard into two categories:

- **Type A:** See “Type “A” Sites - Light Duty” on page 4-46.
- **Type B:** See “Type “B” Sites - Standard Duty” on page 4-47.

4.7.4.1 TYPE “A” SITES - LIGHT DUTY

Type “A” sites **shall** have a grounding (earthing) electrode system resistance design goal of 25 ohms or less for a single grounding electrode (NFPA 70-2005, Article 250.56; MIL-HDBK-419A, section 2.2.2.1). If the design goal of 25 ohms cannot be achieved throughout the year with a single grounding electrode, then the grounding electrode **shall** be augmented by at least one additional grounding electrode (NFPA 70-2005, Article 250.56). See “Soil Resistivity Variability and Factors Affecting Soil Resistivity” on page B-1 for information regarding the seasonal variations in grounding electrode resistance.

NOTE: It is recommended to use two grounding electrodes as the minimum installation, even if 25 ohms is achieved with a single grounding electrode.

Type “A” sites typically have the following characteristics:

- No tower associated with the site
- Non-critical installation
- Not part of a larger system infrastructure
- Single control station
- RF alarm/reporting site
- Small telemetry cabinet utilizing an existing utility pole to support the antenna
- Single voting receiver site
- May be located in a commercial office or residence

4.7.4.2 TYPE “B” SITES - STANDARD DUTY

Type “B” sites **shall** have a grounding (earthing) electrode system resistance design goal as low as practical and not over 10 ohms (AS 3516.2-1998, BS 6651:1999, FAA STD 019d-2002, MIL-HDBK-419A, and MIL-STD-188-124A); Motorola recommends a design goal of 5 ohms or less (also see the International Association of Electrical Inspectors publication, “Soares Book on Grounding and Bonding” - 9th Edition, Appendix B and the United States National Weather Service Manual 30-4106-2004, “Lightning Protection, Grounding, Bonding, Shielding, and Surge Protection Requirements”). If the design goal of 10 ohms (or recommended 5 ohms) cannot be achieved with the minimum accepted grounding electrode system, reasonable efforts **shall** be made to achieve the design goal using supplemental grounding techniques. The supplemental grounding techniques are described in “Supplemental Grounding (Earthing)” on page 4-48.

Type “B” sites typically have the following characteristics:

- A tower is associated with the site
- 911 dispatch center
- Communications dispatch center
- Base station and/or repeater site
- Telecommunication repeater equipment is installed, such as cellular, PCS, or wide-area repeater site
- Large installation or multiple systems, such as telephone or electronic switches, LANs/WANs, and Mobile Switching Offices (MSO) are installed
- Critical public safety or military installation

4.7.4.3 SUPPLEMENTAL GROUNDING (EARTHING)

Sites with high (poor) soil resistivity **shall** require enhancements to the grounding (earthing) electrode system if the resistance requirement of the site cannot be met. Sites in high lightning prone geographical areas, and sites normally occupied (such as dispatch centers), should also include enhancements to the grounding electrode system, regardless if the resistance requirements are met. Some techniques for enhancing the grounding electrode system are described below:

- Installation of radial grounding conductors.
- Installation of concrete encased electrodes in new construction.
- Installation of longer ground rods.

NOTE: Doubling the length of a ground rod will reduce its resistance value by approximately 40% (assuming homogeneous soil).

- Installation of electrolytic ground rods.
- Use of grounding electrode encasement materials.
- Specific design by Motorola Engineering or other engineering firm.

4.7.5 TYPE “A” SITE GROUNDING (EARTHING)

In sites defined as Type “A”, a single ground rod may be sufficient if it can achieve 25 ohms or less throughout the year. If a single ground rod cannot achieve 25 ohms or less throughout the year, then the grounding (earthing) electrode **shall** be augmented by an additional grounding electrode (NFPA 70-2005, Article 250.56 and MIL-HDBK-419A, section 2.2.2.1), or alternate methods **shall** be used. Such alternate methods may include the following:

- Installation of concrete encased electrodes as part of new construction.
- Installation of a longer rod that can achieve 25 ohms or less throughout the year. In general, doubling the length of a ground rod will reduce its resistance value by approximately 40%.
- Installation of a parallel ground rod. The ground rods **shall** maintain a minimum separation of 1.8 m (6 ft.) from one another (NFPA 70-2005, Article 250.56). For maximum parallel efficiency, the ground rods should be separated by the sum of their respective lengths. See “Grounding (Earthing) Electrode Resistance Characteristics and Sphere of Influence” on page 4-9 and Figure 4-31 for additional information.

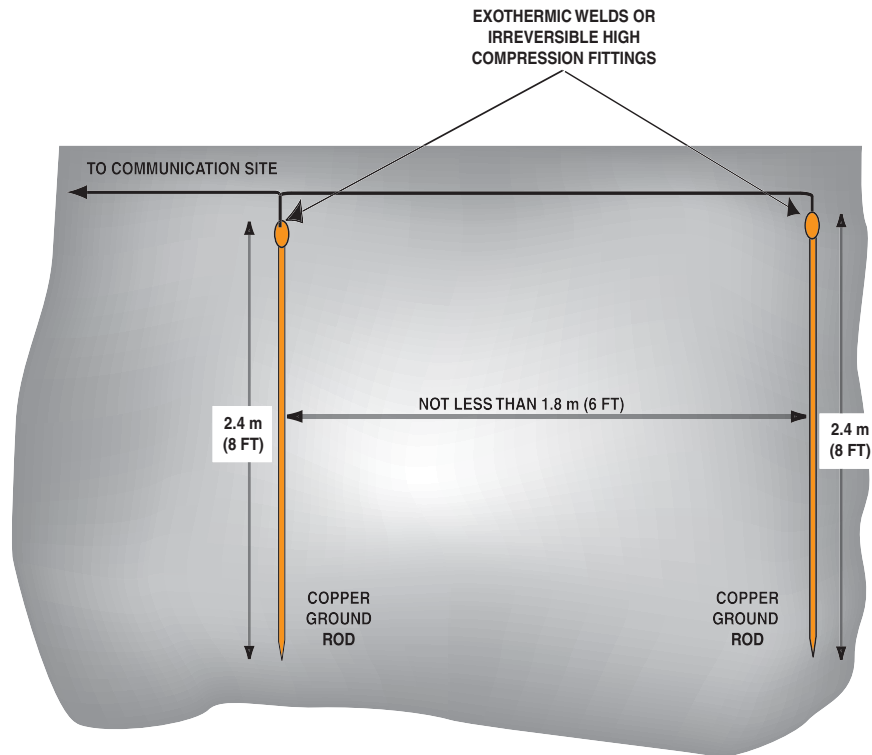


FIGURE 4-31 PARALLEL GROUND ROD INSTALLATION

NOTE: It is recommended to use two grounding electrodes as the minimum installation, even if 25 ohms is achieved with a single grounding electrode.

- Installation of a small ground ring (Figure 4-64 on page 4-89).
- Installation of an electrolytic ground rod.

At an existing building, the AC power system grounding electrode system will typically serve adequately as the communications Type “A” grounding electrode system. A supplemental Type “A” grounding electrode system may need to be installed if the site has an RF transmission line (or other communications cables) entry point at a different location than the AC power utilities entrance. If a supplemental Type “A” grounding electrode system is installed, it **shall** be bonded to any other grounding electrode system at the site. See “Common Grounding (Earthing)” on page 4-5. For an example of bonding a supplemental grounding electrode system to an existing AC power service grounding electrode system, see Figure 4-54 on page 4-77 and Figure 4-64 on page 4-89.

NOTE: A single 2.4 m × 15.9 mm (8 ft. × 0.625 in.) ground rod requires a soil resistivity of approximately 6,250 ohm-cm or less throughout the year in order to achieve a resistance value of 25 ohms; a 3 m × 15.9 mm (10 ft. × 0.625 in.) ground rod would require 7,500 ohm-cm; a 4.9 m × 15.9 mm (16 ft. × 0.625 in.) ground rod would require 11,200 ohm-cm; and a 6.1 m × 15.9 mm (20 ft. × 0.625 in.) ground rod would require 13,600 ohm-cm. See Chapter , “Soil Resistivity Measurements,” for additional information.

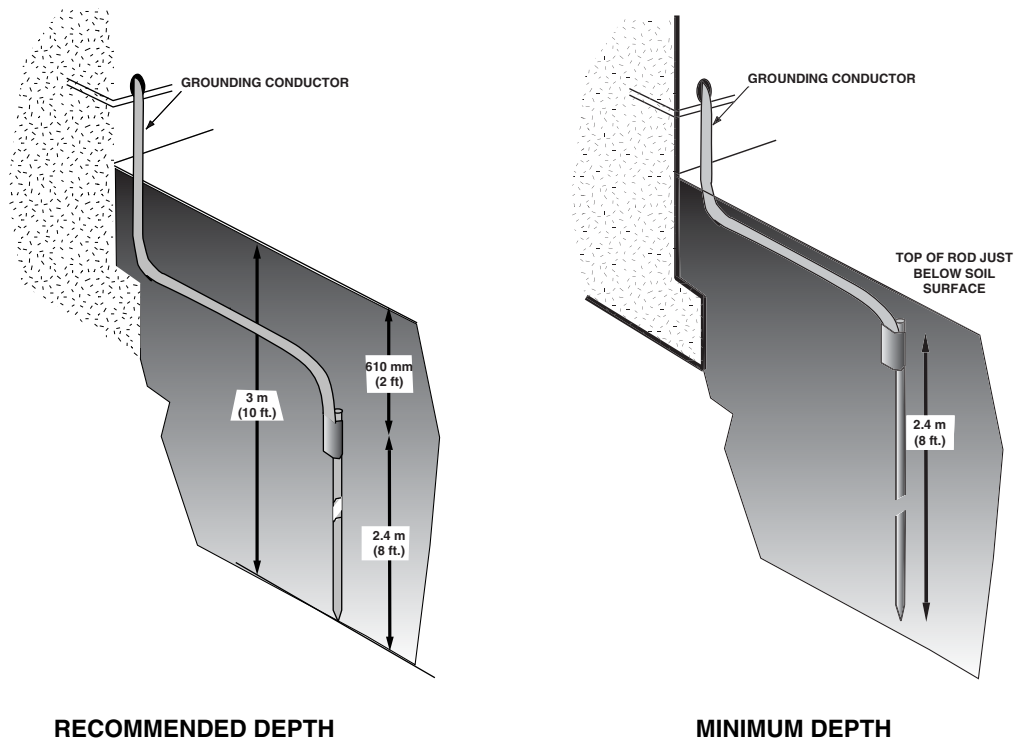


FIGURE 4-32 TYPICAL SINGLE GROUNDING ELECTRODE INSTALLATION

4.7.6 TOWER GROUNDING (EARTHING)

An external grounding (earthing) electrode system for a communications tower is required to disperse lightning energy to earth before it is able to enter the associated communications structure (or enclosure). Although it is impossible to prevent all lightning energy from entering the communications structure (or enclosure), the majority of the lightning energy can be controlled and diverted to earth (ANSI T1.313-2003 and ANSI T1.334-2002). Antenna masts and metal support structures **shall** be grounded (NFPA 70-2005, Article 810.15).

IMPORTANT: For towers installed at high lightning prone geographical areas or sites normally occupied (such as 911 dispatch centers), radial grounding conductors should be employed to improve equalization of the grounding electrode system (ANSI T1.334-2002, section 5.4). See “Radial (Counterpoise) Grounding Conductors” on page 4-24. This is recommended even if the grounding electrode system resistance requirement is met without the use of radial grounding conductors.

Towers can be classified into three basic categories (ANSI T1.334-2002, section 6.3):

- Self-Supporting Towers (including monopoles)
- Guyed Towers
- Wooden Structures (poles)

**CAUTION**

Some antenna structures, such as water storage tanks, may require special grounding and bonding techniques due to the possibility of corrosion and should be designed by a licensed engineer.

IMPORTANT: When only the minimum number of tower ground rods are used, the ground rods **shall** be separated from other ground rods by the sum of their respective lengths, whenever practical. When the tower ground ring is large enough, additional ground rods **shall** be installed as needed to limit the distance between 2.4 m (8 ft.) ground rods from 3 m to 4.6 m (10 to 15 ft.) (ANSI T1.334-2002); if longer ground rods are used, a larger separation proportional to the increase in rod length may be used. See “Grounding (Earthing) Electrode Resistance Characteristics and Sphere of Influence” on page 4-9 for additional information.

4.7.6.1 SELF-SUPPORTING TOWERS (INCLUDING MONOPOLES)

Self-supporting towers **shall** minimally be grounded (earthed) as follows:

- The tower **shall** be encircled by a ground ring (ANSI T1.334-2002, section 5 and MIL-HDBK-419A).
 - The tower ground ring **shall** be installed at least 610 mm (2 ft.) from the tower structure base or footing (ANSI T1.334-2002, section 5.3.1).
 - The tower ground ring **shall** be installed in accordance with “External Building and Tower Ground Ring” on page 4-22.
 - The tower ground ring **shall** be bonded to the building ground ring in at least two points using a 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductor (ANSI T1.334-2002, figure 1 and MIL-STD-188-124B). See “External Building and Tower Ground Ring” on page 4-22 and Figure 4-18 on page 4-23.
- For towers not exceeding 1.5 m (5 ft.) in base width (including monopoles), the tower ground ring **shall** consist of at least two ground rods installed on opposite (diametrically opposed) sides (ANSI T1.313-2003, section 10.3.1; ANSI T1.334-2002, section 5.2; and ANSI/TIA/EIA-222-F-R2003, section 12).
 - Ground rods **shall** meet the specifications and be installed in accordance with “Ground Rods” on page 4-11.
- For towers equal to or exceeding 1.5 m (5 ft.) in base width, the tower ground ring **shall** consist of at least one ground rod per tower structure leg (ANSI T1.313-2003, section 10.3.1; and ANSI/TIA/EIA-222-F-R2003, section 12).
 - Ground rods **shall** meet the specifications and be installed in accordance with “Ground Rods” on page 4-11.
- For monopole towers equal to or exceeding 1.5 m (5 ft.) in base width, the tower ground ring **shall** consist of four equally spaced ground rods.
 - Ground rods **shall** meet the specifications of and be installed in accordance with “Ground Rods” on page 4-11.
- All monopole towers **shall** be bonded to the tower ground ring using at least four equally spaced grounding conductors of 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned, copper conductor.

- Each leg of a self-supporting tower **shall** be bonded to the tower ground ring using grounding conductors of 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned, copper conductor. See Figure 4-33.
- The tower grounding conductors **shall** be exothermically bonded to the tower unless specifically directed otherwise by the tower manufacturer.
- The tower's support piers (concrete footings) should have the rebar electrically connected to the tower holding bolts (ANSI T1.313-2003, section 10.3.1).
- Install radial grounding conductors if needed. See "Radial (Counterpoise) Grounding Conductors" on page 4-24.

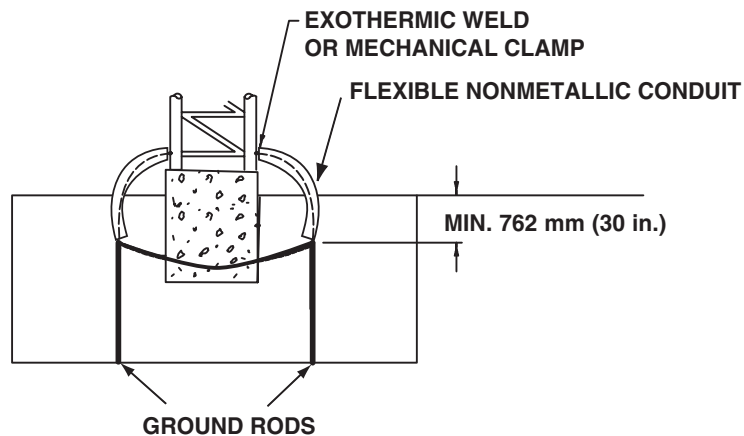


FIGURE 4-33 EXAMPLE OF SELF-SUPPORTING TOWER GROUNDING

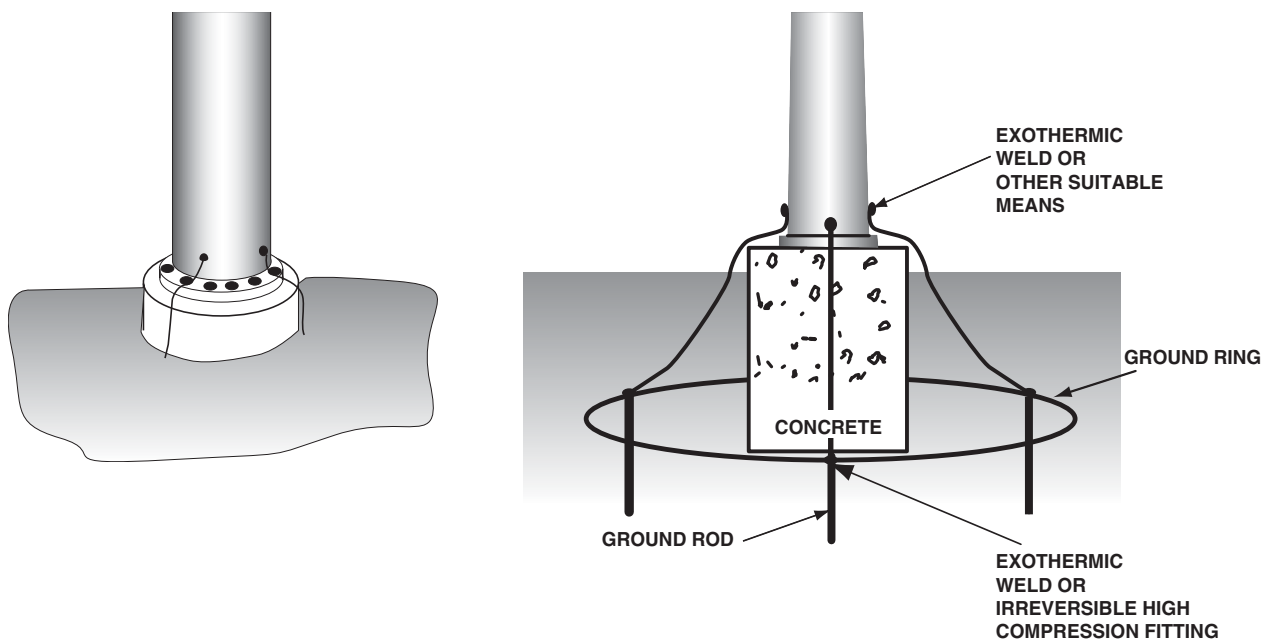


FIGURE 4-34 EXAMPLE OF MONOPOLE TOWER GROUNDING

4.7.6.2 GUYED TOWERS

Guyed towers **shall** minimally be grounded (earthed) as follows:

- The tower **shall** be encircled by a ground ring (ANSI T1.334-2002, section 5 and MIL-HDBK-419A).
 - The tower ground ring **shall** be installed at least 610 mm (2 ft.) from the tower structure base or footing (ANSI T1.334-2002, section 5.3.1).
 - The tower ground ring **shall** be installed in accordance with “External Building and Tower Ground Ring” on page 4-22.
 - The tower ground ring **shall** be bonded to the building ground ring in at least two points using a 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductor (ANSI T1.334-2002, figure 1, and MIL-STD-188-124B). See “External Building and Tower Ground Ring” on page 4-22.
- The tower ground ring **shall** consist of at least two ground rods installed on opposite (diametrically opposed) sides (ANSI T1.313-2003, section 10.3.1; ANSI T1.334-2002, section 5.2; and ANSI/TIA/EIA-222-F-R2003, section 12).
 - Ground rods **shall** meet the specifications and be installed in accordance with “Ground Rods” on page 4-11.
- The bottom plate of a guyed tower **shall** be bonded to the tower ground ring using three equally spaced grounding conductors, or each leg **shall** be bonded to the tower ground ring using grounding conductors of 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned copper conductor. See Figure 4-35.
- The tower grounding conductors **shall** be exothermically bonded to the tower unless specifically directed otherwise by the tower manufacturer.
- The tower's support piers (concrete footings) should have the rebar electrically connected to the tower holding bolts (ANSI T1.313-2003, section 10.3.1).
- Install radial grounding conductors if needed. See “Radial (Counterpoise) Grounding Conductors” on page 4-24.

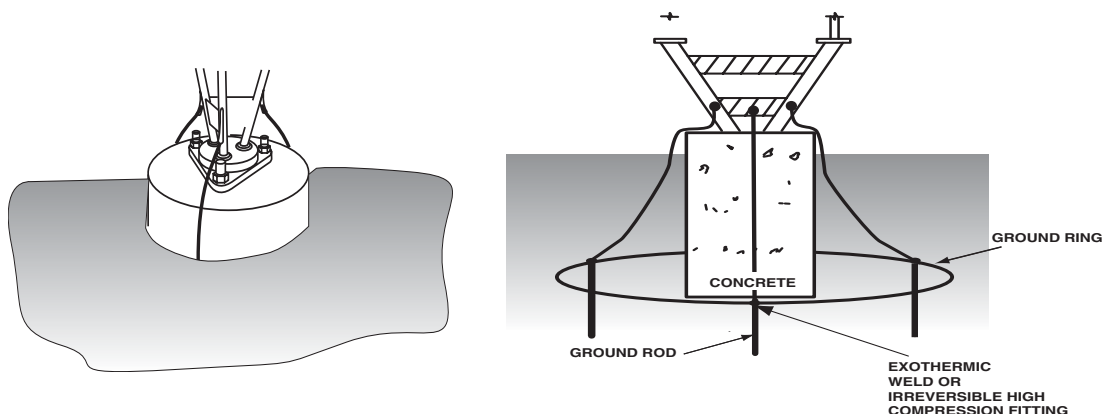


FIGURE 4-35 EXAMPLE OF GUYED TOWER GROUNDING

4.7.6.2.1 GUY ANCHOR POINTS

Grounding (earthing) guy anchor points requires special attention due to the possibility of galvanic corrosion damage to the anchor points. Although various methods for grounding guy anchor points are possible, any variation from the requirements and guidelines in this section **shall** be designed by a licensed professional engineer. Guy wire anchors **shall** minimally be grounded as outlined in the following sections.

New Construction:

- The guy anchor **shall not** be permitted to make direct contact with soil by being encased in reinforced concrete over the entire embedded length of the anchor. The concrete encasement **shall** extend a minimum of 152 mm (6 in.) above grade.

NOTE: Encasing the anchor in reinforced concrete over the entire embedded length of the anchor helps prevent galvanic corrosion from the guy anchor to copper components of the grounding electrode system. Galvanized steel encased in concrete has a similar potential to that of copper (see “Miscellaneous General Information” on page 4-38). Additionally, encasing the anchor in reinforced concrete over the entire embedded length of the anchor will help prevent the galvanic corrosion that would otherwise exist from the portion of the anchor in direct contact with soil to the portion encased in concrete.

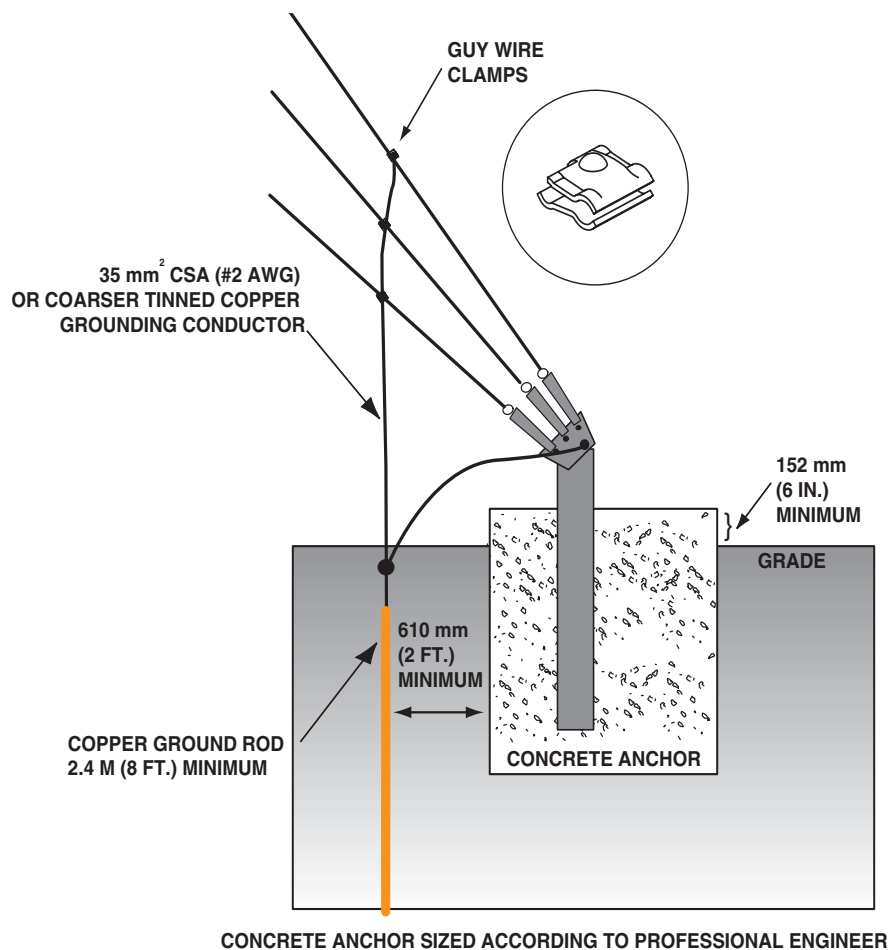


FIGURE 4-36 GUY ANCHOR POINT GROUNDING FOR NEW CONSTRUCTION

- A ground rod **shall** be installed at each guy anchor point (ANSI/TIA/EIA-222-F-R2003). Ground rods **shall** meet the specifications and be installed in accordance with “Ground Rods” on page 4-11.
- All guy wires at a guy anchor point **shall** bond to the ground rod (ANSI T1.313-2003, section 10.3.1, and ANSI/TIA/EIA-222-F-R2003) using a grounding conductor of 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned, copper conductor. Do not use un-tinned wire.
- The grounding conductor **shall** be connected to each guy wire using stainless steel or other approved clamps. Each connection **shall** be coated with a listed conductive anti-oxidant compound.

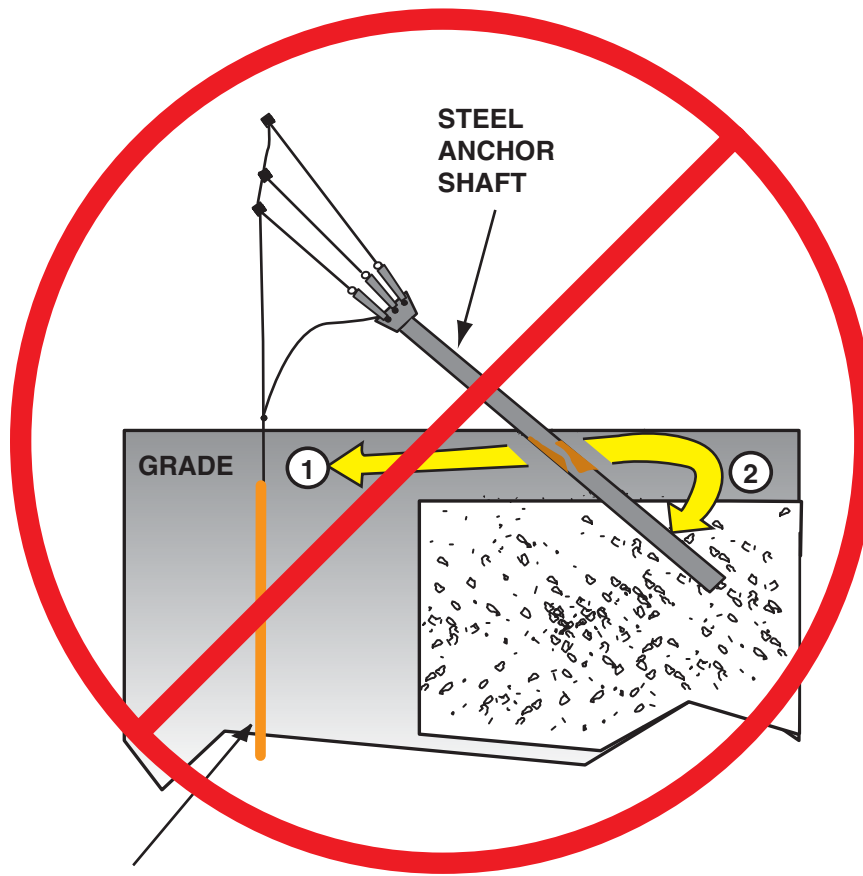
**CAUTION**

Do not attempt to exothermically weld to tower guy wires.

- The grounding conductor **shall** be connected to the guy wires above the turnbuckles.
- The grounding conductor **shall** maintain a continuous vertical drop from the guy wire attachment point to the grounding electrode.

Existing Anchor Points:

- If possible, backfill around the embedded anchor with a high resistivity soil, such as gravel. This may be beneficial in reducing the rate of corrosion between the guy anchor point and copper grounding electrode system components. (TIA/EIA-222-F-R2003)
- Isolation of anchors from the structure using guy insulators may help reduce the transmission of stray currents from outside sources, therefore, minimizing electrolytic corrosion (TIA/EIA-222-F-R2003, section 4.1). Guy isolators should only be installed under the advice of a professional engineer. Galvanic corrosion due to the presence of copper ground rods is greatly reduced if the ground wires are connected on the tower side of the isolation point (TIA/EIA-222-F-R2003, section 4.1).
- A ground rod **shall** be installed at each guy anchor point (ANSI/TIA/EIA-222-F-R2003). Ground rods **shall** meet the specifications and be installed in accordance with “Ground Rods” on page 4-11. In order to reduce galvanic corrosion from the galvanized guy anchor point to a nearby copper ground rod, this ground rod **shall** be constructed of galvanized steel, unless a guy insulator is used (TIA/EIA-222-F-R2003, section 4.1).



COPPER GROUND ROD

1. CORROSION FROM STEEL ANCHOR SHAFT TO COPPER GROUND ROD AND OTHER COPPER GROUNDING ELECTRODE SYSTEM COMPONENTS
2. CORROSION FROM STEEL ANCHOR SHAFT TO THE PORTION OF ANCHOR SHAFT ENCASED IN CONCRETE (STEEL ENCASED IN CONCRETE IS SIMILAR TO COPPER.)

FIGURE 4-37 GUY ANCHOR GALVANIC CORROSION EXAMPLE

- All guy wires at a guy anchor point **shall** bond to the ground rod (ANSI T1.313-2003, section 10.3.1, and ANSI/TIA/EIA-222-F-R2003) using a grounding conductor of 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned copper conductor. Do not use un-tinned wire.
- The grounding conductor **shall** be connected to each guy wire using stainless steel or other approved clamps. Each connection **shall** be coated with a listed conductive anti-oxidant compound.



CAUTION

Do not attempt to exothermically weld to tower guy wires.

- The grounding conductor **shall** be connected to the guy wires above the turnbuckles (see Figure 4-38).
- The grounding conductor **shall** maintain a continuous vertical drop from the guy wire attachment point to the grounding electrode.

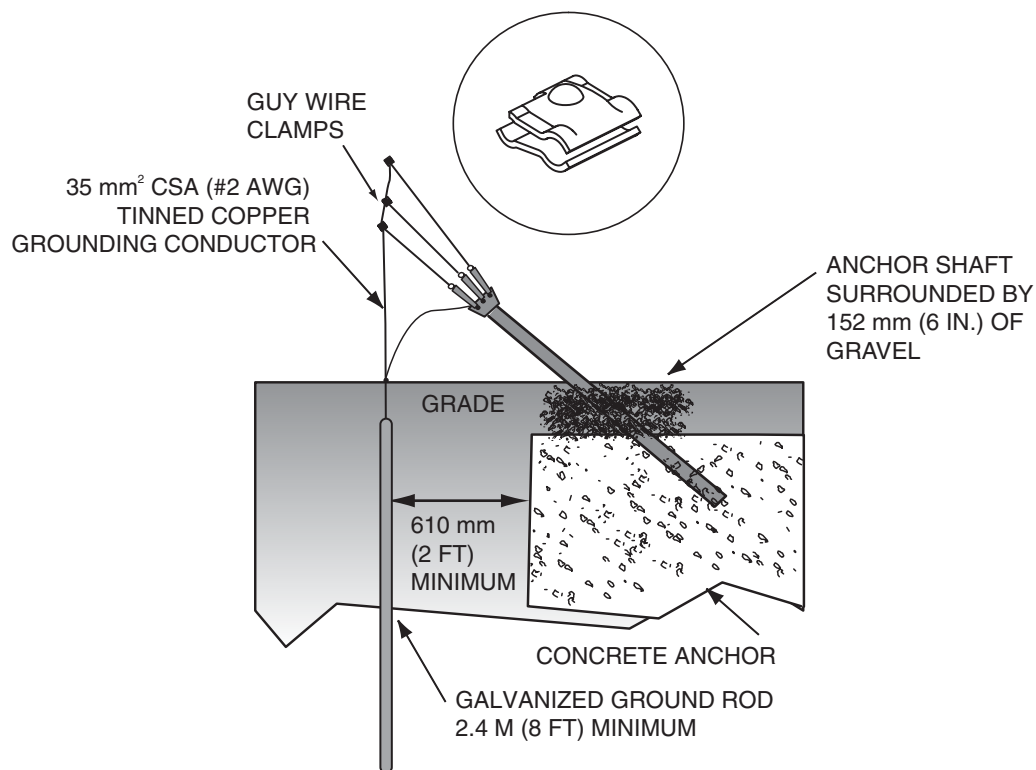


FIGURE 4-38 GUY ANCHOR POINT GROUNDING FOR EXISTING CONSTRUCTION

4.7.6.2.2 CATHODIC PROTECTION

Additional corrosion control can be obtained through the use of Cathodic Protection. See MIL-HDBK-419A Volume I, section 2.10 and TIA/EIA-222-F-R2003, section 4.4 for additional information.

Cathodic protection should only be installed under the advice of a licensed professional engineer.



WARNING

Any type of corrosion control installation techniques does not eliminate the need for proper monitoring and maintenance over the life of the structure (TIA/EIA-222-F-R2003, section 4).

4.7.6.3 WOODEN STRUCTURES (POLES)

Wooden pole structure towers (and other non-metallic towers) **shall** minimally be grounded (earthed) as follows:

- The wooden pole **shall** have a vertical grounding conductor installed over the length of the wooden pole.
- The vertical grounding conductor **shall** be constructed of 35 mm² csa (#2 AWG) or coarser solid, bare, tinned or un-tinned copper conductor (ANSI T1.334-2002, section 6.5).
- The grounding conductor **shall** be installed in accordance with “Grounding (Earthing) Conductors” on page 4-28.
- The vertical grounding conductor **shall** terminate into a radial grounding conductor or tower ground ring (with rods) (ANSI T1.334-2002, section 6.5).
 - The radial grounding conductor **shall** be installed in accordance with “Radial (Counterpoise) Grounding Conductors” on page 4-24.
 - The tower ground ring **shall** be installed in accordance with “External Building and Tower Ground Ring” on page 4-22.
 - Ground rods **shall** meet the specifications and be installed in accordance with “Ground Rods” on page 4-11.
- The wooden pole grounding electrode system **shall** be bonded to the building grounding electrode system. See “Common Grounding (Earthing)” on page 4-5.

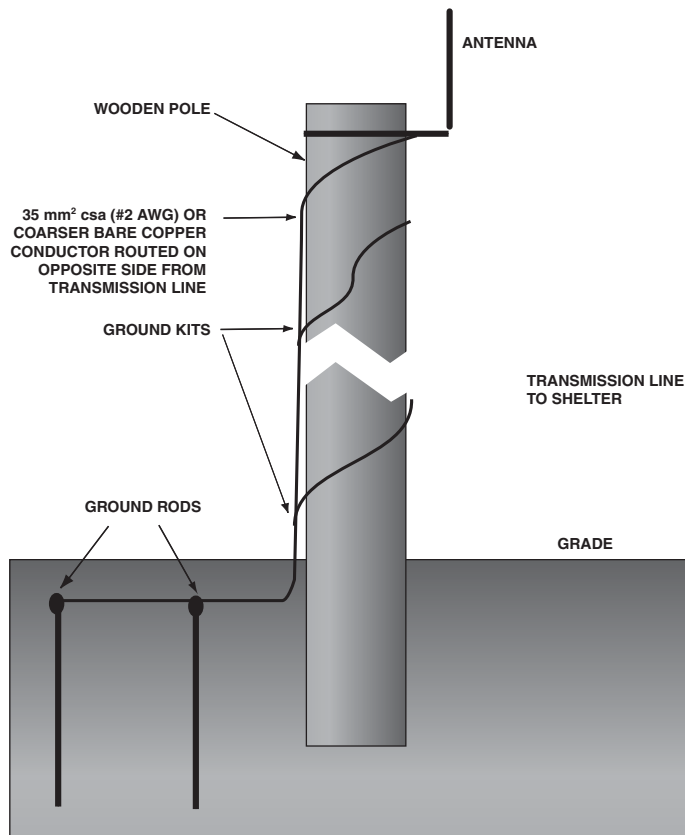


FIGURE 4-39 WOODEN POLE GROUNDING

4.7.7 DEDICATED COMMUNICATIONS BUILDING GROUNDING (EARTHING)

All dedicated communications buildings **shall** have a properly installed external grounding (earthing) electrode system. The grounding electrode system resistance **shall** meet the requirements of “Grounding (Earthing) Electrode System Resistance Requirements” on page 4-46.

A typical site grounding electrode system layout is shown in Figure 4-4 on page 4-8. The building grounding electrode system requirements are listed below and **shall** also include any additional grounding electrode system components required to achieve the resistance requirements of the site. See “Minimum Site Grounding (Earthing) Requirements” on page 4-44.

- Installation of concrete encased electrodes as part of new construction. See “Concrete-Encased Electrodes” on page 4-20.
- The building **shall** be encircled by a ground ring installed in accordance with “External Building and Tower Ground Ring” on page 4-22.
- The building ground ring **shall** have a ground rod installed near the external ground bus bar (EGB), at each corner of the shelter, and as follows:
 - If 2.4 m (8 ft.) ground rods are used, additional ground rods **shall** be installed as needed to reduce the distance between rods from 3 m to 4.6 m (10 to 15 ft.) (ANSI T1.334-2002).
 - If longer ground rods are used, a larger separation proportional to the increase in rod length may be used.
 - Ground rods **shall** be placed a minimum of one rod length apart along the ground rings (ANSI T1.313-2003, figure 3(a)).
 - Ground rods **shall not** be separated from an adjacent ground rod along the ground ring by more than the sum of their respective lengths. (MIL-HDBK-419A).
- The ground rods **shall** be installed in accordance with “Ground Rods” on page 4-11.
- The ground rods **shall** be exothermically welded to the ground ring, or as otherwise allowed in “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.
- The building ground ring **shall** be bonded to the tower ground ring using a minimum of two 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductors. See “External Building and Tower Ground Ring” on page 4-22 and Figure 4-4 on page 4-8.
- The tower **shall** be grounded in accordance with “Tower Grounding (Earthing)” on page 4-50.
- Determine if radial grounding conductors should be installed at the site, see “Radial (Counterpoise) Grounding Conductors” on page 4-24

4.7.7.1 GENERATORS EXTERNAL TO THE BUILDING

Generators installed outside of the building, within 1.8 m (6 ft.) of the building, **shall** be bonded to the nearest practical location on the grounding (earthing) electrode system as shown in Figure 4-40 on page 4-60, using a 16 mm² csa (#6 AWG) or coarser, copper conductor (ANSI T1.334-2002, section 5.3.3). Grounding conductors routed below ground, or partially below ground, **shall** be a 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductor.

External generator grounding **shall** comply with the following:

- Bonding to the generator chassis **shall** be done in accordance with the manufacturer's requirements.

- The grounding conductors **shall** meet the requirements of “Grounding (Earthing) Conductors” on page 4-28.
- Bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high compression fittings. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

Generators installed more than 1.8 m (6 ft.) away from the building **shall** be bonded to the nearest practical location on the grounding electrode system as describe above for generators within 1.8 m (6ft.) of the building. In addition, the generator **shall** have a ground rod installed nearby and bonded to the generator (ANSI T1.313-2003). See Figure 4-40. Installation of the addition generator ground rod **shall** comply with the following:

- The additional ground rod **shall** meet the requirements of “Ground Rods” on page 4-11.
- The additional ground rod **shall** be installed using methods described in “Ground Rods” on page 4-11.
- The grounding conductor between the ground rod and generator **shall** be a 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned or un-tinned, copper conductor. The grounding conductor **shall** meet the requirements of “Grounding (Earthing) Conductors” on page 4-28.
- Bonding to the ground rod **shall** be made using exothermic welding or listed irreversible high compression fittings. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

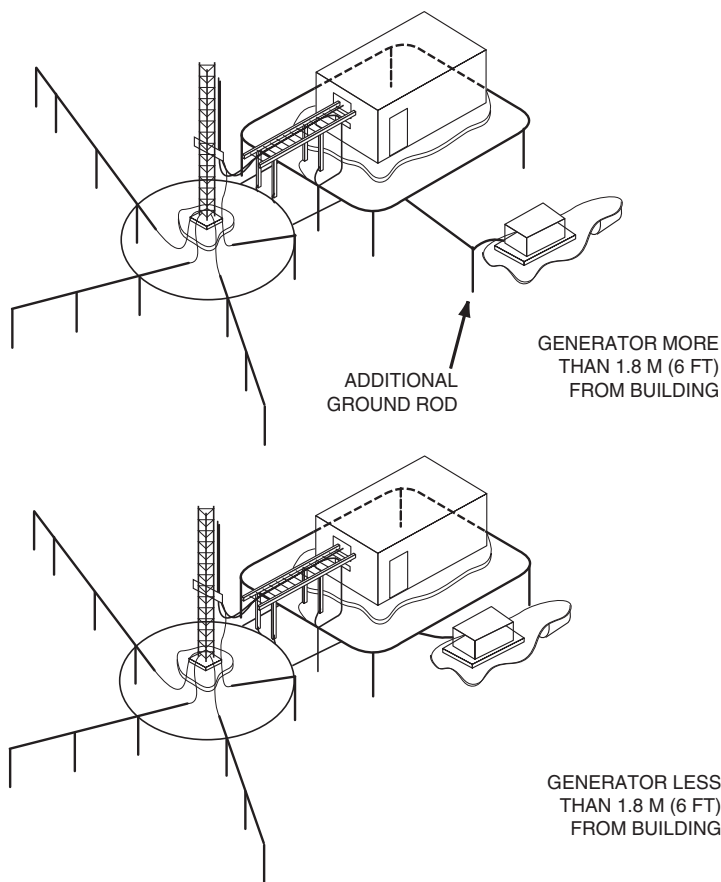


FIGURE 4-40 GENERATOR GROUNDING

4.7.8 OUTDOOR CABINET GROUNDING (EARTHING)

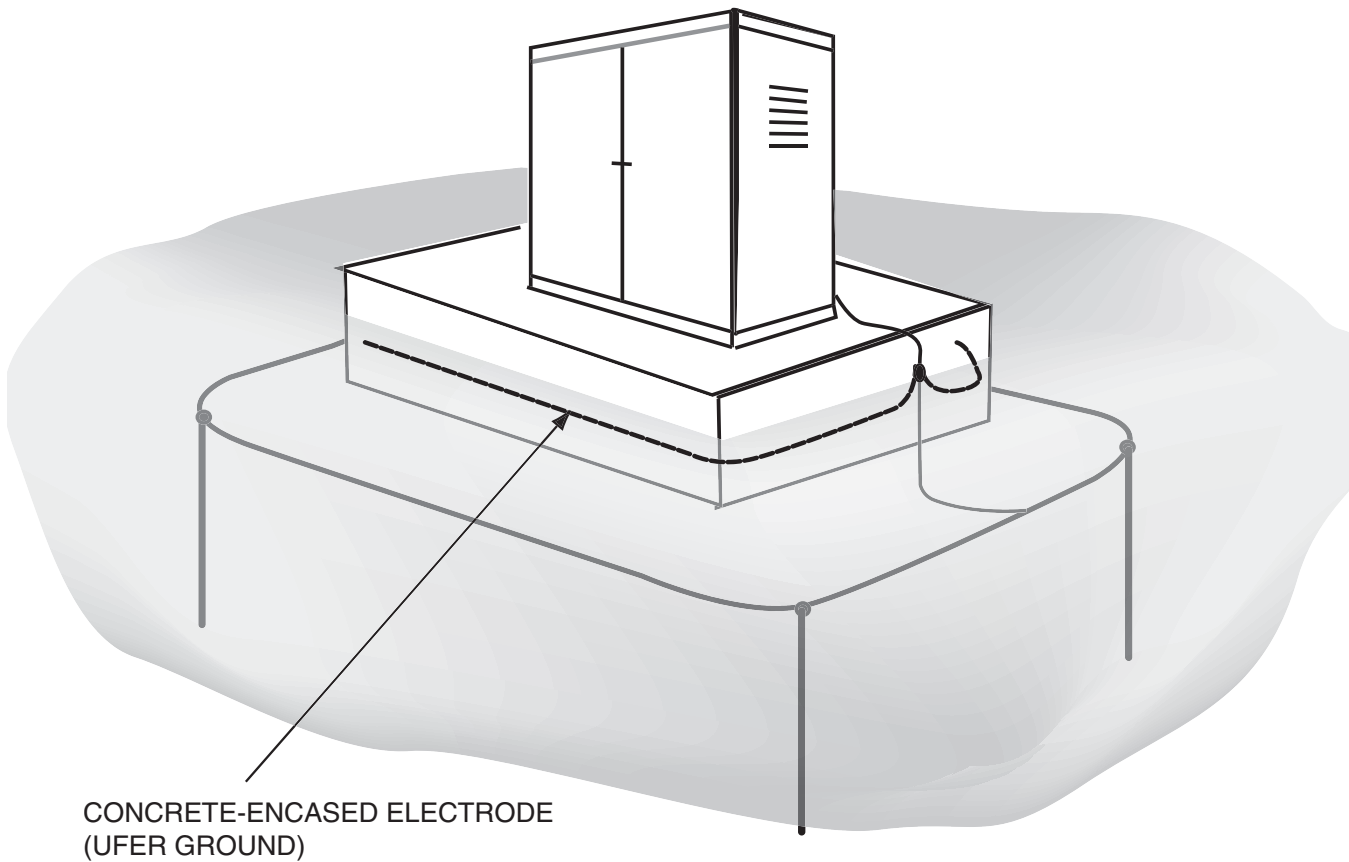
Outdoor cabinets are grounded (earthed) in a very similar manner as a dedicated communications building (ANSI T1.313-2003, section 1.1). See “Dedicated Communications Building Grounding (Earthing)” on page 4-59 for details.

Outdoor cabinets **shall** be grounded as follows:

- The cabinet **shall** be encircled with a ground ring. The ground ring **shall** meet the requirements defined in “External Building and Tower Ground Ring” on page 4-22.
- The ground ring **shall** be installed at least 610 mm (2 ft.) from the cabinet foundation/pad.
- The cabinet ground ring **shall** have a ground rod installed at each corner and as needed to limit the distance between rods from 3 m to 4.6 m (10 to 15 ft.). Ground rods **shall** have a minimum separation from other ground rods equal to its length (ANSI T1.313-2003).
- The cabinet ground ring **shall** bond to the tower ground ring as detailed in “External Building and Tower Ground Ring” on page 4-22.
- Towers associated with outdoor cabinets **shall** be grounded as detailed in “Tower Grounding (Earthing)” on page 4-50.
- RF transmission lines **shall** be grounded/bonded as detailed in “RF Transmission Line and Preamplifier Grounding (Earthing)” on page 4-62.
- Metallic objects near the cabinet **shall** be bonded to the cabinet grounding electrode system as detailed in “Metallic Objects Requiring Bonding” on page 4-67.
- The cabinet grounding electrode system **shall** bond to the cabinet's internal ground point and cabinet housing using a 35 mm² csa (#2 AWG) or coarser, tinned or un-tinned, copper conductor. The conductor **shall** be run in a direct manner with no sharp bends or narrow loops (ANSI T1.313-2003, section 11.3, and ANSI T1.334-2002, section 13.4). See “Bending And Routing Grounding (Earthing) Conductors” on page 4-29.

In addition to the above requirements, the follow recommendations should be considered:

- Cabinets installed on pads that incorporate a footing should consider the use of concrete encased electrodes, in addition to the ground ring. See “Concrete-Encased Electrodes” on page 4-20.
- Depending on the location of the cabinet's internal ground point, the grounding conductor installed between the grounding electrode system and the cabinet's internal ground point may need to be routed through the concrete footing/pad in order to allow conductor routing in a direct manner. This requires the grounding conductor to be installed before the concrete is poured.

**FIGURE 4-41** CABINET GROUNDING SYSTEM

4.7.9 RF TRANSMISSION LINE AND PREAMPLIFIER GROUNDING (EARTHING)

Tower mounted antenna preamplifiers **shall** be bonded to the tower using 16 mm² csa (#6 AWG) or coarser, solid or stranded, tinned, copper conductor. Connection to the amplifier **shall** be made in accordance with the amplifier manufacturer requirements. Connection to the tower **shall** be made using tower manufacturer-approved methods (typically a type of mechanical clamp).

Transmission lines **shall** be bonded to the tower in order to prevent lightning from creating a difference of potential between the tower and the transmission lines and to help drain lightning energy to earth. A potential difference could cause arcing between the tower and the RF transmission line cable, resulting in damage to the transmission lines. See Figure 4-43 through Figure 4-46 for examples of transmission line grounding (earthing) conductor attachment methods.

All transmission lines **shall** be bonded to the tower using ground kits as follows:

- Transmission line ground kits **shall** be installed per manufacturer specifications.
- Transmission line ground kits **shall** be sealed from the weather to prevent water and corrosion damage to the transmission line (ANSI T1.313-2003, section 10.5).

- Transmission line ground kits **shall** be attached to an effectively grounded vertical member of the tower, using tower manufacturer-approved methods (typically a type of mechanical clamp). Transmission line ground kits may attach to a tower bus bar in lieu of directly attaching to the tower structure, see “Tower Ground Bus Bar” on page 4-32. See Figure 4-42 through Figure 4-46 for examples of methods used to attach to the tower. (ANSI T1.313-2003, section 10.5)
- Transmission line ground kit grounding conductors **shall** be installed without drip loops, parallel to the transmission line, and pointed down towards the ground to provide a direct discharge path for lightning (ANSI T1.313-2003, section 10.5.1).
- Transmission line ground kits **shall** be installed at the first point of contact, near the antenna (ANSI T1.334-2002, section 6.6; ANSI T1.313-2003, section 10.5.1; and MIL-HDBK-419A).
- Transmission line ground kits **shall** be installed at the bottom of the tower near the vertical to horizontal transition point (ANSI T1.313-2003, section 10.5.1; ANSI T1.334-2002, section 6.6; and MIL-HDBK-419A). The ground kits **shall** be bonded to the tower or tower ground bus bar (TGB) if installed.
- If the tower is greater than 61 m (200 ft.) in height, an additional ground kit **shall** be installed at the tower midpoint (ANSI T1.334-2002, section 6.6 and MIL-HDBK-419A). Additional ground kits **shall** be installed as necessary to reduce the distance between ground kits to 61 m (200 ft.) or less.
- In high lightning prone geographical areas, additional ground kits should be installed at spacing between 15.2 to 22.9 m (50 to 75 ft.) (ANSI T1.313, section 10.5.1 and ANSI T1.334-2002, section 6.6). This is especially important on towers taller than 45.7 m (150 ft.).

NOTE: The use of down-conductors on metallic towers is not recommended for grounding/bonding transmission lines. The down-conductor has a much higher impedance to earth than the tower. The use of down-conductors does not provide equipotential bonding between the transmission lines and tower.

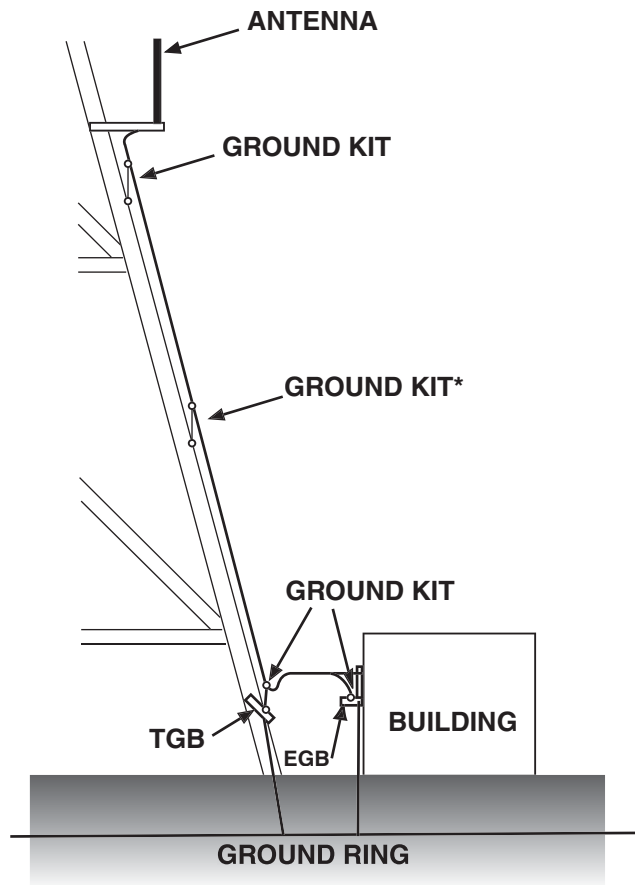
Transmission line ground kits **shall** be installed near the building, shelter, equipment housing, or cabinet entry point (ANSI T1.334-2002, section 6.6; MIL-HDBK-419A; and NFPA 70-2005, Articles 810.20 and 820.93). The ground kits **shall** bond to the external ground bus bar (EGB) if installed, or directly to the grounding electrode system, ensuring a continuous downward flow toward the grounding electrode system is maintained.

NOTE: Transmission lines installed on a wooden pole structure **shall** bond to the wooden pole vertical grounding conductor in the same manner as described above.



CAUTION

Braided grounding conductors shall not be used under any circumstances. Braided conductors corrode easily and become a point for RF interference.



* Required ground kit for towers taller than 61 m (200 ft);
optional ground kit for towers 61 m (200 ft) or less.

FIGURE 4-42 LOCATION OF TRANSMISSION LINE GROUNDING KITS

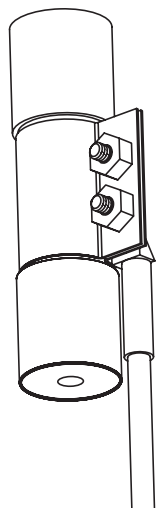


FIGURE 4-43 TRANSMISSION LINE GROUND KIT

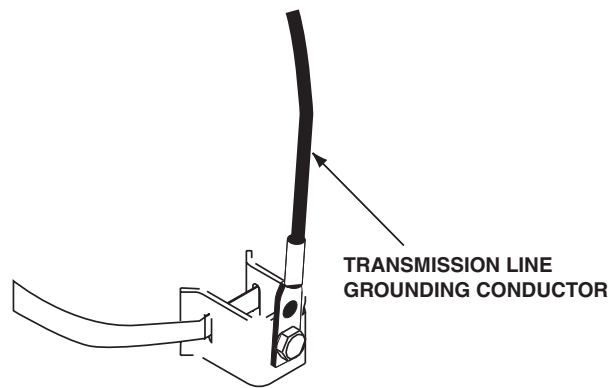


FIGURE 4-44 GROUNDING TRANSMISSION LINE TOP AND MIDDLE (TUBULAR TOWER)

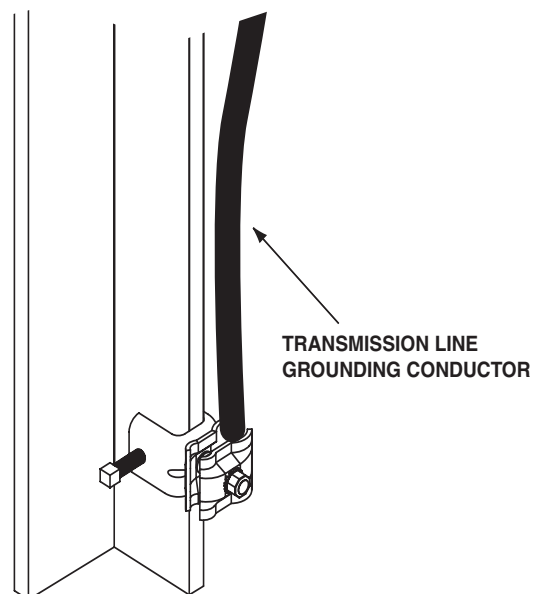


FIGURE 4-45 GROUNDING TRANSMISSION LINE TOP AND MIDDLE (ANGULAR TOWER)

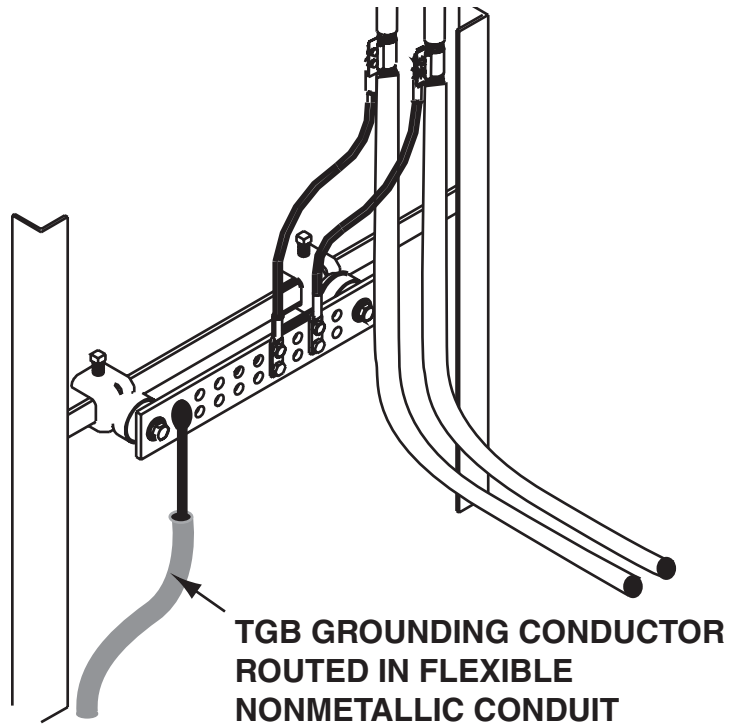


FIGURE 4-46 BUS BAR CONFIGURATION, BOTTOM GROUND KIT (ANGULAR TOWER)

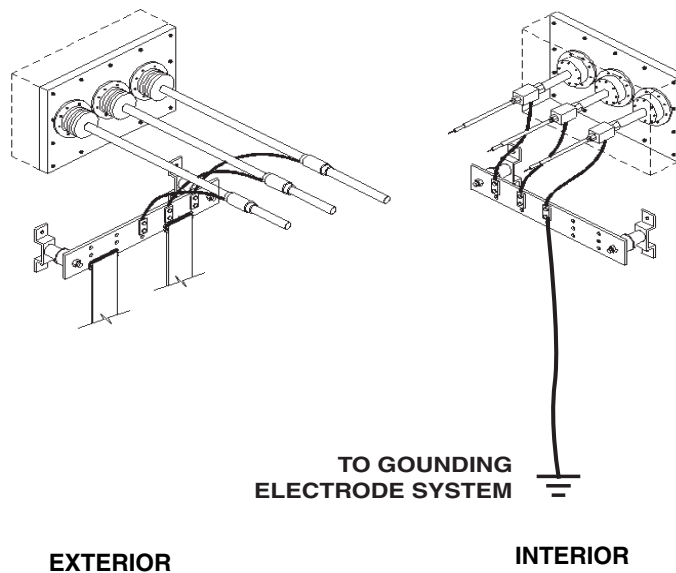


FIGURE 4-47 TRANSMISSION LINE GROUNDING AT BUILDING ENTRY POINT

4.7.10 METALLIC OBJECTS REQUIRING BONDING

The objective of bonding metallic objects is to equalize the potential between conductive parts. This is done for personnel safety and to prevent arcing between metallic components that might otherwise be at different potentials. Bonding conductors **shall** be as short and straight as possible. (ANSI T1.313-2003, section 6.3)

Metallic objects that are located within 1.8 m (6 ft.) of the external grounding (earthing) electrode system, or within 1.8 m (6 ft.) of a grounded metallic item, **shall** be bonded to the external grounding electrode system using 16 mm² csa (#6 AWG) or coarser conductors as described in “Grounding (Earthing) Conductors” on page 4-28 (ANSI T1.334-2002, section 5.3.3). Bonding to the metallic objects **shall** be made as allowed by the manufacturer. In high lightning prone geographical areas, or areas of high soil resistivity, it is recommended to bond all metallic objects that are located within 3 m (10 ft.) of the external grounding electrode system, or within 3 m (10 ft.) of a grounded metallic item (ANSI T1.313-2003, section 10.3.2). Metallic objects requiring bonding include, but are not limited to, the items listed below. (ANSI T1.313-2003, section 10.3.2; ANSI T1.334-2002, section 5.3.3.)

- Fences
- Fence posts
- Fence gates
- Cable Bridge/Ice Bridge
- Generator frame
- Skid plate or metal support frame of a prefabricated shelter
- Metallic members of all incoming telecommunications cables, including paired-conductor and optical fiber (ANSI T1.313-2003, section 8.2)
- Facility grounding electrode system
- Main telephone company ground (if external)
- Metallic entry points
- Metallic conduits, piping, and raceways
- HVAC units
- Vent covers (if not already grounded inside)
- Storage tanks (above and below grade) if allowed
- External light fixtures or support masts
- Any other grounding electrode systems at the site (see “Common Grounding (Earthing)” on page 4-5)

NOTE: Bonding conductors installed underground **shall** be constructed of 35 mm² csa (#2 AWG) or coarser conductor. See “Grounding (Earthing) Conductors” on page 4-28.

Series or daisy chain¹ connection arrangements **shall not** be used. (See Figure 5-20 on page 5-34 for an example of a “daisy-chained” ground connection.)

4.7.10.1 FENCE AND GATE GROUNDING (EARTHING)

All site fencing, including gates, within 1.8 m (6 ft.) of the grounding (earthing) electrode system (such as building or tower ground ring and radial grounding conductors), or any metallic item grounded to the grounding electrode system, **shall** be effectively bonded to the external grounding electrode system to help prevent shock hazard to personnel from lightning or other electrical anomalies (ANSI T1.334-2002, section 5.3.3). In high lightning prone geographical areas, or areas of high soil resistivity, it is recommended to effectively bond fencing that is located within 3 m (10 ft.) of the external grounding electrode system, or within 3 m (10 ft.) of a grounded metallic item (ANSI T1.313-2003, section 10.3.2).

When fences are located at an electrical power substation, the fence grounding **shall** be made as required by local code and by the electric power utility company. The fence grounding should comply with IEEE-STD 80-2000 and is beyond the scope of this document.

A fencing grounding scheme is shown below in Figure 4-48 for a typical communications site with a nearby installed perimeter fence system.

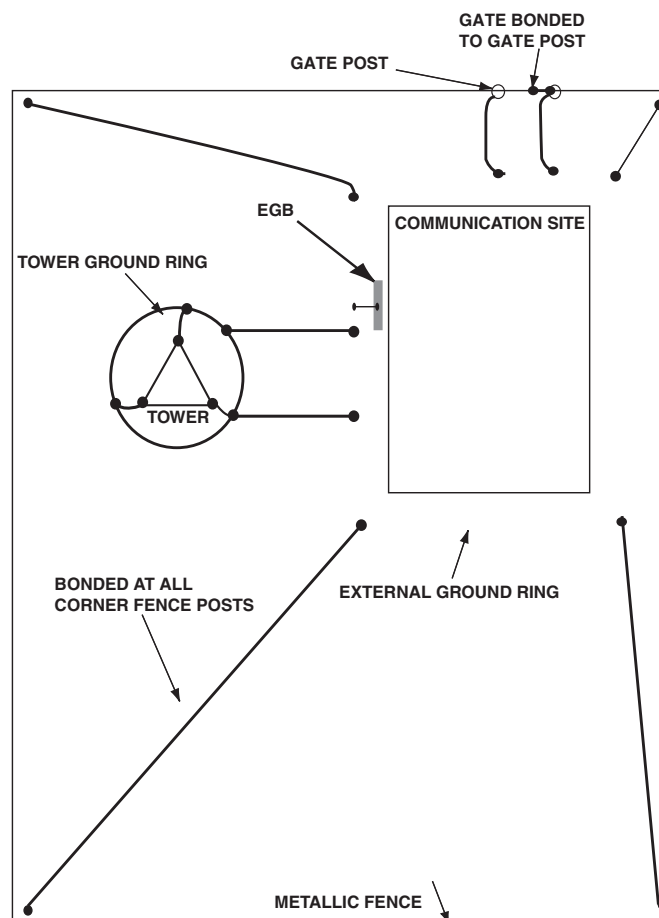


FIGURE 4-48 FENCE BONDING EXAMPLE

1. The series or daisy chain method, which refers to any method of connection whereby the conductors are connected from one peripheral device to a second and possibly on to a third device in a series arrangement whereby the removal of the second connection point interrupts the ground path from the first device, **shall not** be used.

The fencing system for a nearby installed fence at a communications site **shall** be grounded/bonded as follows:

- Each corner fence post **shall** be bonded to the nearest location of the building ground ring using 35 mm² csa (#2 AWG) or coarser, bare, solid or stranded, tinned, copper conductors. The grounding conductors **shall** be buried to the same depth as the building ground ring, wherever practical. See ANSI T1.313-2003, figure 3(a).
- The fence fabric near each corner bonding point **shall** also be bonded to the building ground ring. This bond may be made using the same grounding conductor used for the corner fence post, or by bonding directly to the fence post using approved methods described within this chapter. The fence fabric bond should be made in at least three points down the fence fabric as shown in Figure 4-49 (MIL-HDBK-419A Volume II, section 1.12).

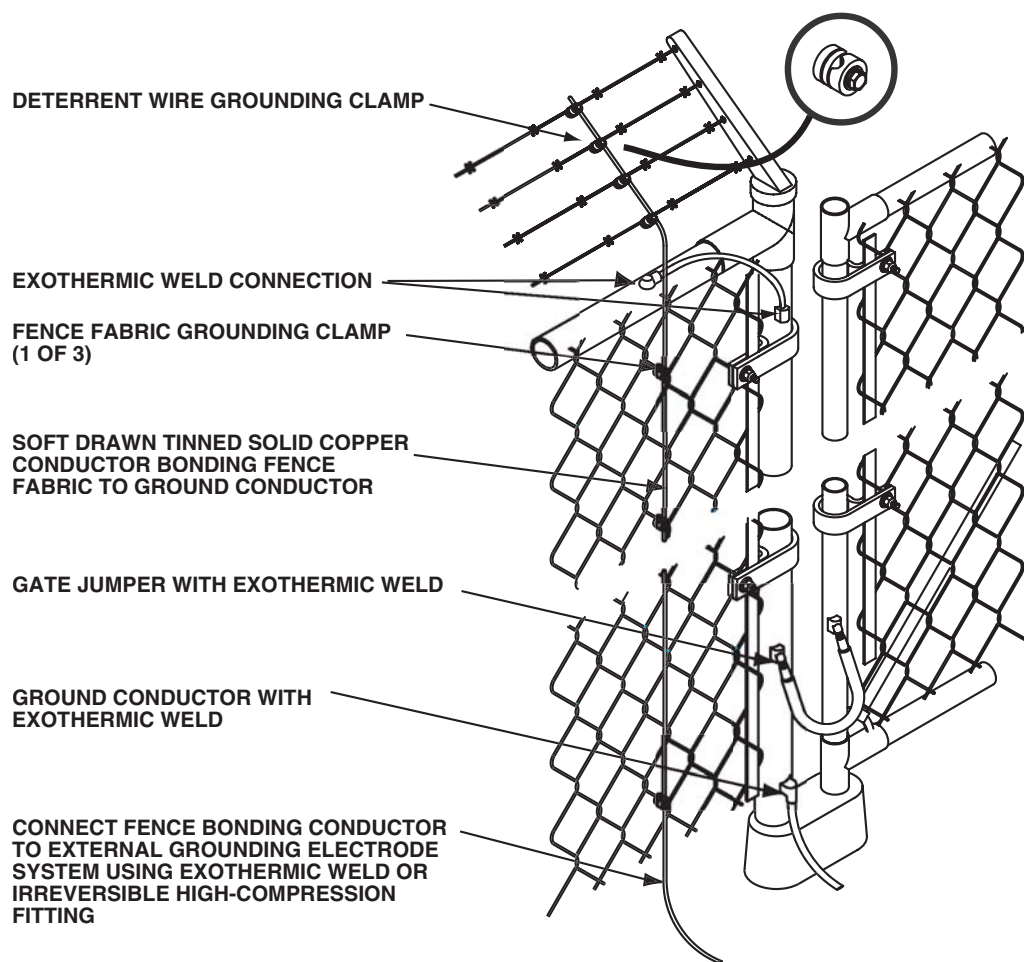


FIGURE 4-49 FENCE FABRIC AND DETERRENT WIRING BONDING EXAMPLE

- All gate posts (on both sides of the gate) **shall** be bonded to the nearest location of the building ground ring using 35 mm² csa (#2 AWG) or coarser, bare, solid or stranded, tinned, copper conductors. The grounding conductors **shall** be buried to the same depth as the building ground ring, whenever practical. (ANSI T1.313-2003, figure 3(a)).
- All gates **shall** be bonded to the gate supporting fence post with 16 mm² csa (#6 AWG) or coarser, stranded, copper conductors. This jumper wire should be constructed with a highly flexible conductor (ANSI T1.313-2003, figure 3(a)). See Figure 4-50 for an example.

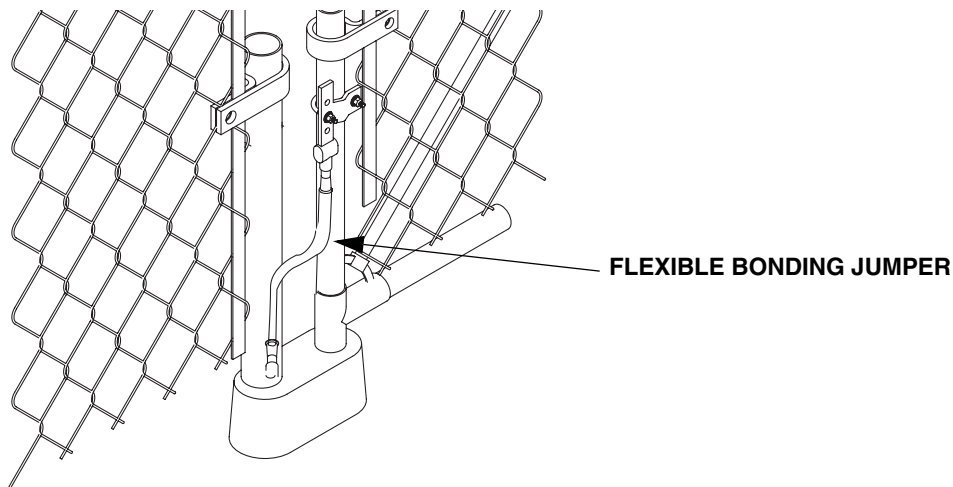


FIGURE 4-50 GATE BONDING EXAMPLE

If the site has non-electrified entry deterrent fence headers of barbed wire, razor wire, or other metallic wiring, the headers **shall** be grounded/bonded as follows:

- The deterrent wiring, near each corner fence post, **shall** be bonded to the nearest location of the building ground ring using 35mm² csa (#2 AWG) or coarser, bare, solid or stranded, tinned, copper conductor. This bond may be made using the same grounding conductor used for bonding the fence fabric. See Figure 4-49 for an example.
- Each individual run of the deterrent wiring **shall** be bonded using a listed bimetallic transition connector. Each connection **shall** be liberally coated with a listed conductive antioxidant compound at the point of insertion into the connector.
- The grounding conductor **shall** be routed so as not come into incidental contact with the deterrent wiring, fence post, fence fabric or support apparatus for the wire. Incidental contact can create an RF interference point.
- The grounding conductor **shall** follow the proper routing methods described in “Bending And Routing Grounding (Earthing) Conductors” on page 4-29.

NOTE: Consult with Motorola Engineering or other engineering firm for the grounding requirements/recommendations of fence systems that extend well beyond the communications building and tower.

Grounding electrode system connections to commercial-grade fencing and gates **shall** be made using the exothermic welding process where possible. Coat all welded connections with zinc-enriched paint to prevent rusting. If exothermic welding is not possible, use the methods described below for residential fencing.

If the site has residential quality fencing and/or preexisting fencing, it **shall** be grounded using heavy duty, tinned pipe clamps designed for fence grounding and stainless steel hardware (or equivalent). Residential-grade and/or preexisting fencing will not typically withstand exothermic welding.

Fences around tower guy anchor points **shall** be bonded to the guy anchor ground rod using 35 mm² csa (#2 AWG) or coarser, bare, solid, tinned, copper conductors and bonded as outlined above. Guy anchor fence gates **shall** be bonded as described above.

**CAUTION**

Braided straps shall not be used because they corrode too quickly and can be a point for RF interference.

4.7.10.2 CABLE BRIDGE/ICE BRIDGE GROUNDING (EARTHING)

Cable bridges and ice bridges are used to protect and support RF transmission lines between the tower structure and the equipment building/shelter. When present, cable bridges and ice bridges **shall** be bonded to the grounding (earthing) electrode system.

Grounding of **self-supported** cable bridges/ice bridges **shall** be completed as follows (Figure 4-51):

- Each support post **shall** bond to the grounding electrode system using a 35 mm² csa (#2 AWG) or coarser, bare, tinned, copper conductor.
- Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40
- Conductor bonding to the support posts **shall** be made using exothermic welding. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40
- To help insure effective bonding connections, the cable bridge/ice bridge should bond to each support post using a using a 16 mm² csa (#6 AWG) or coarser, jacketed (ANSI T1.334-2002, section 5.1), copper conductor (bonding jumper). Conductor bonding to the support post **shall** be made using exothermic welding. Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding, or listed two-hole lugs and stainless steel hardware.
- If more than one span of cable bridge/ice bridge is used between the tower and building, bonding jumpers should be installed between the sections to help ensure effective bonding. The bonding jumpers **shall** be a 16 mm² csa (#6 AWG) or coarser copper conductor. The bonding jumpers should use listed two-hole lugs and stainless steel hardware.

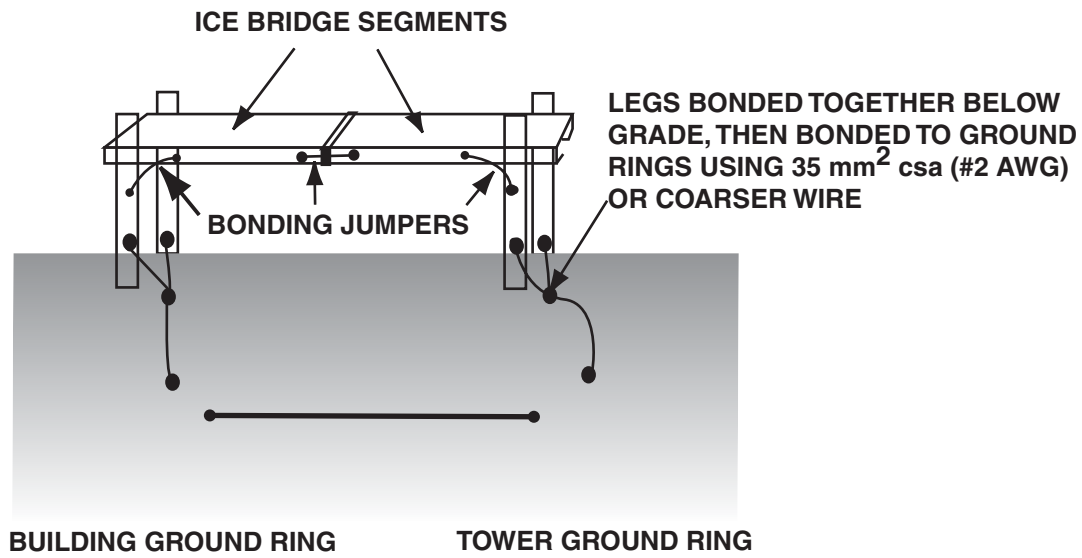


FIGURE 4-51 PROPER GROUNDING OF SELF-SUPPORTING ICE BRIDGE

Grounding of **tower and/or building supported** cable bridges/ice bridges **shall** be completed as follows:

- At the building:** The cable bridge/ice bridge **shall** bond to the grounding electrode system. Bonding to the grounding electrode system may be accomplished using a 16 mm² csa (#6 AWG) or coarser copper conductor bonded to the External Ground Bus bar (EGB). Conductor bonding to the cable bridge/ice bridge and EGB **shall** be made using exothermic welding, or two-hole lugs and stainless steel hardware. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

Bonding of the cable bridge/ice bridge to the grounding electrode system may also be accomplished using a 35 mm² csa (#2 AWG) or coarser, bare, copper conductor bonded directly to the grounding electrode system. Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings. Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding, or listed two-hole lugs and stainless steel hardware. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.
- At the tower:** Cable bridges/ice bridges may be sufficiently grounded when an integral part of the tower construction and bonded directly to the tower through multiple metallic mechanical connections. The metallic connections **shall** be of the same metals and **shall** provide direct metal-to-metal contact without any non-conductive coatings, such as paint. When the cable bridge/ice bridge is not effectively bonded to the tower, additional bonding **shall** be required in order to effectively ground the cable bridge/ice bridge.

The additional bonding **shall** be accomplished using one of the following techniques:

- Installing a 16 mm² csa (#6 AWG) or coarser copper conductor (bonding jumper) between the cable bridge/ice bridge and the tower. Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding, or listed two-hole lugs and stainless steel hardware. Conductor bonding to the tower **shall** be made using exothermic welding, or other suitable hardware. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

- Installing a 16 mm² csa (#6 AWG) or coarser copper conductor (bonding jumper) between the cable bridge/ice bridge and the tower ground bus bar (TGB). Conductor bonding to the cable bridge/ice bridge and TGB **shall** be made using exothermic welding, or listed two-hole lugs and stainless steel hardware. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.
- Installing a 35 mm² csa (#2 AWG) or coarser, bare, copper conductor bonded directly to the grounding electrode system. Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings. Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding, or listed two-hole lugs and stainless steel hardware. The grounding conductor should be installed in a flexible non-metallic conduit to help prevent incidental contact with other metals, allow for protection of the conductor, and to help support the conductor.

In order to reduce the amount of lightning energy diverted towards the equipment building/shelter, and to provide seismic isolation between the building and tower, it is recommended to secure the cable bridge/ice bridge to the tower through a non-conductive slip-joint type device. When a slip-joint type device is used, grounding of the cable bridge/ice bridge at the building **shall** be completed as described above; grounding at the tower end of the cable bridge/ice bridge **shall** be completed as follows:

- Installing a 35 mm² csa (#2 AWG) or coarser, bare, copper conductor bonded directly to the grounding electrode system. Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings. Conductor bonding to the cable bridge/ice bridge **shall** be made using exothermic welding, or listed two-hole lugs and stainless steel hardware. The grounding conductor should be installed in a flexible non-metallic conduit to help prevent incidental contact with other metals, allow for protection of the conductor, and to help support the conductor. See Figure 4-52.

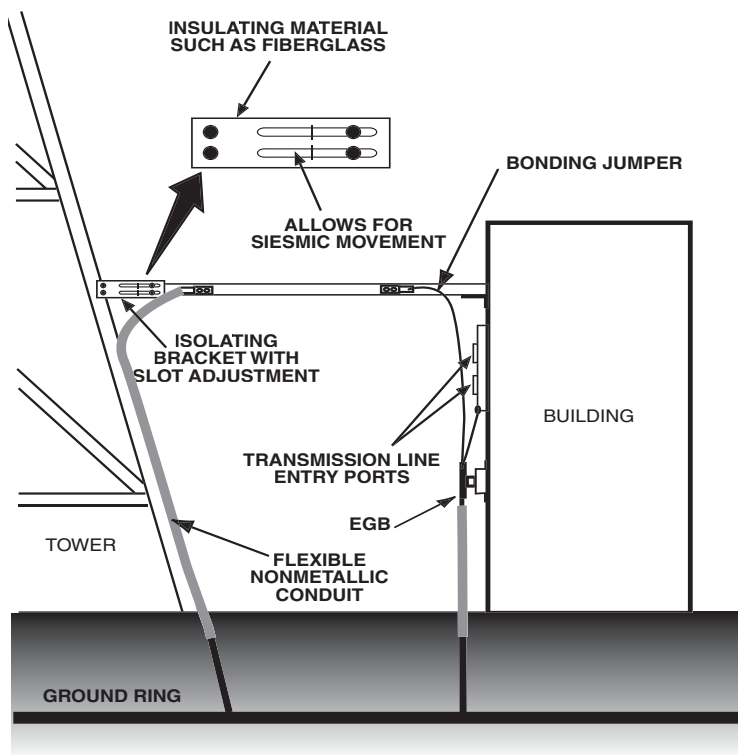


FIGURE 4-52 PROPER GROUNDING OF NON-SELF-SUPPORTING ICE BRIDGE

IMPORTANT: In ice prone areas, if isolating the cable bridge/ice bridge from the tower creates an unprotected area on the RF transmission lines, some type of ice shield **shall** be installed above the isolation point in order to protect the RF transmission lines. The ice shield **shall** be bonded to the tower only.

4.7.11 METALLIC BUILDING SIDING GROUNDING (EARTHING)

Although metallic building siding is not required to be grounded by this standard, grounding the metallic siding can provide additional safety at the site (NFPA 70-2005, Article 250.116-FPN). It is recommended to bond the metallic building siding in at least one location on the building, preferably near the electrical service entrance.

4.8 GROUNDING (EARTHING) ROOF-MOUNTED ANTENNA MASTS AND METAL SUPPORT STRUCTURES

All roof-mounted antenna masts and metal support structures **shall** be grounded (earthed) (NFPA 70-2005, Article 810.15).

NOTE: Rooftop mounted towers are not covered in this section. See “Grounding (Earthing) Rooftop Mounted Tower Structures” on page 4-79 for information about rooftop tower grounding requirements.

In new construction, provisions **shall** be engineered into the building design for effective roof-mounted antenna mast and support structure grounding. Typically this will include a grounding point, or multiple grounding points, with at least two direct connections to the building's grounding electrode system. The direct connection to the building's grounding electrode system may be made using effectively grounded structural building steel (preferred) and/or down-conductors. Other engineered antenna mast and support structure grounding systems may include metallic antenna support structures that are directly and effectively bonded to effectively grounded structural building steel.

When a lightning protection system is installed on the building, roof-mounted antenna masts and support structures **shall** be bonded to the lightning protection system (IEC 61024-1-2 and NFPA 780-2004, section 4.17). The conductor **shall** be of the same size as the Main Roof Perimeter Lightning Protection Ring (FAA STD-019d-2002, section 3.7.9.4). Conductor bonding **shall** be made using exothermic welding, listed irreversible high-compression fittings, or other fittings listed for use in lightning protection systems. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40. No additional grounding **shall** be required of roof-mounted antenna masts and support structures when bonded to a lightning protection system.

When a lightning protection system is not available, roof-mounted antenna masts and metal support structure **shall** be grounded by directly bonding to the building's grounding electrode system, or to a supplemental grounding electrode system (FAA STD-019d-2002, section 3.7.9.4). Bonding to the grounding electrode system **shall** use effectively grounded structural building steel when available. When effectively grounded structural building steel is not available, bonding to the grounding electrode system **shall** use at least two down conductors whenever practical (ANSI T1.334-2002, section 8.2). When effectively grounded structural building steel is not available and the use of two down conductors is not practical, the use of a single down conductor should be approved by an engineer. Available water piping systems may also be used as a grounding down-conductor, but should only be used under the advice of an engineer.

Bonding to the structural building steel **shall** be made using exothermic welding, listed irreversible high-compression fittings, or other fittings listed for use in lightning protection systems. See NFPA 780-2004, section 4.16 for additional information regarding the use of structural building steel as a main grounding conductor. Figure 4-53 shows examples of acceptable building steel bonding connections.

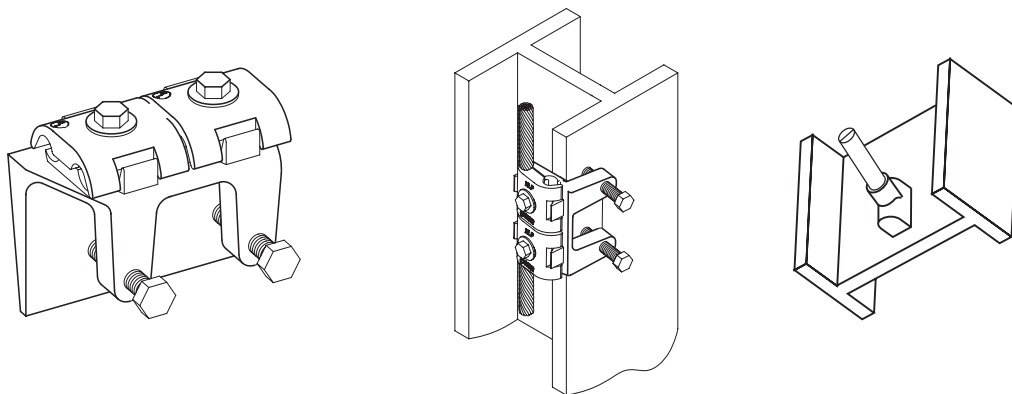


FIGURE 4-53 ACCEPTABLE STRUCTURAL BUILDING STEEL BONDING CONNECTIONS

Down-conductors **shall** be routed to the grounding electrode system from opposite sides of the roof whenever practical (ANSI T1.334-2002, section 8.2). Down-conductors **shall** be physically separated from one another as much as practical (ANSI T1.334-2002, section 8.2). Additional requirements for down-conductors are as follows:

- Grounding down-conductors **shall** be sized as follows:
 - The conductor **shall** be a 35 mm² csa (#2 AWG) or coarser, bare, copper or equivalent, for buildings not exceeding 22.9 m (75 ft.) in height (NFPA 780-2004, Table 4.1.1.1(A)).
 - The conductor **shall** be a 70 mm² csa (#2/0 AWG) or coarser, bare, copper or equivalent, for buildings equal to or exceeding 22.9 m (75 ft.) in height (NFPA 780-2004, Table 4.1.1.1(B)).
- Grounding down-conductors **shall** be protected from physical damage (NFPA 70-2005, Article 810.21(d) and NFPA 780-2004, section 4.9.11). See “Protecting and Securing Grounding (Earthing) Conductors” on page 4-30.
- Grounding down-conductors **shall** be permitted to be run either outside or inside the building or structure (NFPA 70-2005, Article 810.21(g)).

- Grounding down-conductors **shall not** be required to be insulated (NFPA 70-2005, Article 810.21(b)). Insulated conductors are recommended when the grounding conductor may come into incidental contact with other metallic objects. Incidental contact with other metallic object may be a point for RF interference. See Chapter 8, “Minimizing Site Interference.”
- Grounding down-conductor **shall** be run in as straight a line as is practical (NFPA 70-2005, Article 810.21(e)). See “Bending And Routing Grounding (Earthing) Conductors” on page 4-29.
- Grounding down-conductors **shall** have a minimum bend radius of 203 mm (8 in.), and the included angle **shall not** exceed 90 degrees as shown in Figure 4-22 on page 4-29 (ANSI T1.313-2003, section 11.3; MIL-STD-188-124B; and NFPA 780-2004, section 4.9.5). See “Bending And Routing Grounding (Earthing) Conductors” on page 4-29.
- Grounding down-conductors **shall** be securely fastened at intervals not exceeding 914 mm (3 ft.). (See NFPA 70-2005, Article 250.64(b), 810.21(c) and NFPA 780-2004, section 4.10 for additional information.) See “Protecting and Securing Grounding (Earthing) Conductors” on page 4-30.
- Grounding down-conductors run outside from the roof top to ground **shall** be protected for a minimum distance of 1.8 m (6 ft.) above grade level when located in areas susceptible to damage; such areas may include, but are not limited to, runways, driveways, school playgrounds, cattle yards, public walks (NFPA 780-2004, section 4.9.11 and section 4.9.11.2). See “Protecting and Securing Grounding (Earthing) Conductors” on page 4-30.

If the building grounding electrode system resistance cannot be verified or cannot provide a low-resistance to earth (see “Grounding (Earthing) Electrode System Testing/Verification” on page D-1), a supplemental grounding electrode system should be installed to ensure the resistance requirement of the site is met. The supplemental grounding electrode system **shall** be bonded to the existing grounding electrode system (NFPA 70-2005). See “Common Grounding (Earthing)” on page 4-5. See Figure 4-54 for an example of a supplemental grounding electrode system.

NOTE: Consult the building engineer or manager to determine information about any existing building grounding electrode systems. The building engineer should also be informed before attempting to weld or drill on the building rooftop.

NOTE: Depending on the available locations for grounding down-conductors and the entry point of the RF transmission lines into the building, it may be necessary to install a supplemental grounding electrode system.

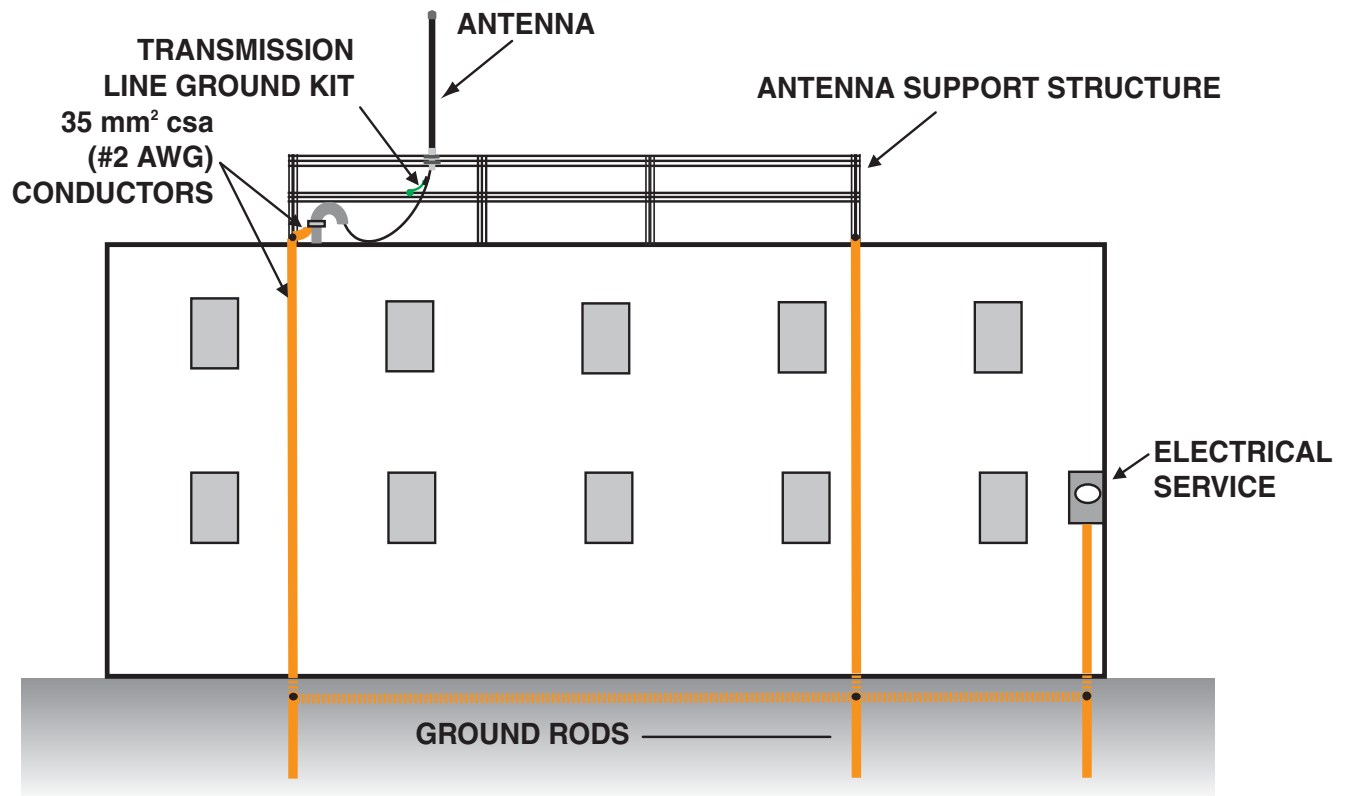


FIGURE 4-54 ROOF MOUNTED ANTENNA MAST GROUNDING WITH SUPPLEMENTAL GROUNDING ELECTRODE SYSTEM

IMPORTANT: When installed, supplemental grounding electrode systems **shall** be effectively bonded to the building grounding electrode system. See “Common Grounding (Earthing)” on page 4-5.

4.8.1 SIDE MOUNTED ANTENNA GROUNDING (EARTHING)

Typically, a side mounted antenna may be grounded (earthed) with a single grounding conductor. The use of two grounding down-conductors may not always be practical. However, two down-conductors should be used whenever practical; this is especially important at buildings that are normally occupied, such as dispatch centers. When two grounding down-conductors are not installed, it is recommended to either use a copper strap or a larger sized grounding down-conductor.

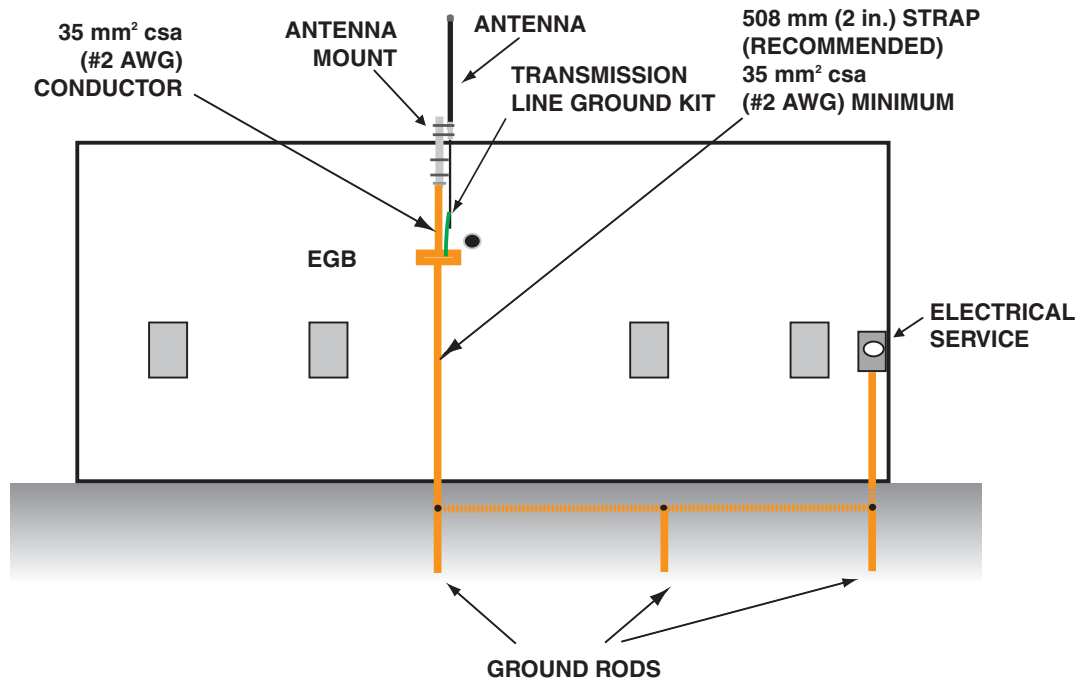


FIGURE 4-55 SIDE-MOUNTED ANTENNA GROUNDING USING COPPER STRAP DOWN CONDUCTOR

When multiple side mounted antennas are installed together, a single horizontal grounding conductor should bond all antenna masts together. The horizontal grounding conductor should bond to the grounding electrode system from each side of the side mounted antennas with a grounding down-conductor. When several antennas are installed together, therefore, creating a long horizontal grounding conductor, it is recommended to install intermediate grounding down-conductors every 6.1 m (20 ft.).

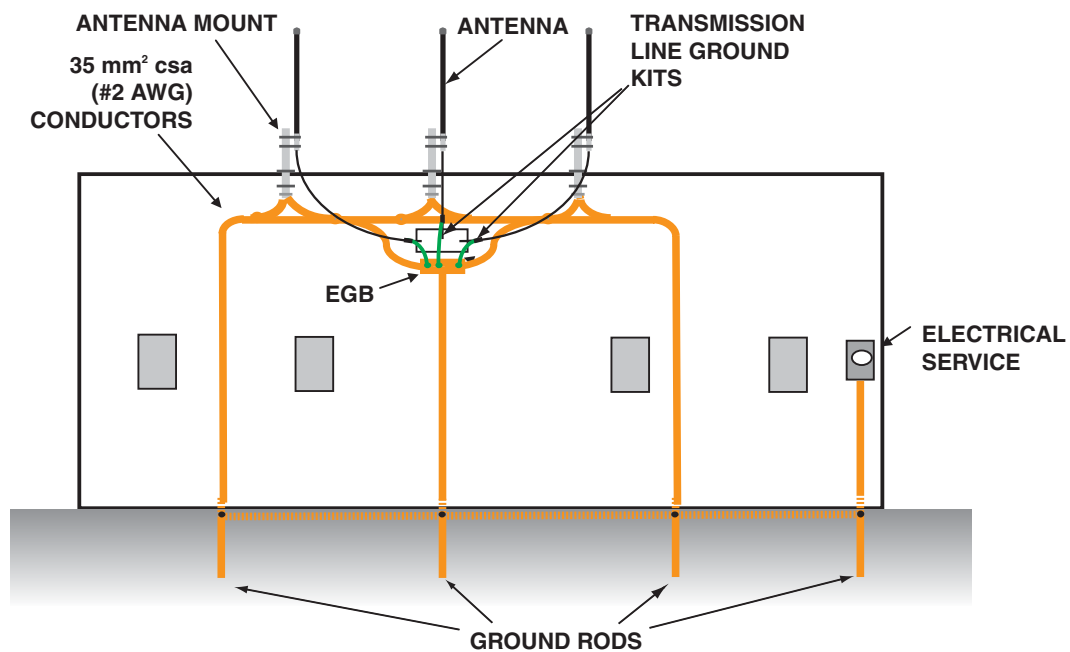


FIGURE 4-56 GROUNDING OF MULTIPLE SIDE-MOUNTED ANTENNAS

4.9 GROUNDING (EARTHING) ROOFTOP MOUNTED TOWER STRUCTURES

Rooftop mounted towers may increase the lightning risk index for the buildings they are installed upon. Due to their increased height and lightning risk probability, all exposed buildings with rooftop towers **shall** be equipped with a lightning protection system, as outlined in NFPA 780-2004 (ANSI T1.313-2003, section 10.3.3). See “Lightning Activity and Exposure” on page 4-3 for information regarding lightning exposure to buildings and towers.

NOTE: Consult the building engineer or manager to determine information about any existing building grounding (earthing) electrode systems. The building engineer should also be informed before attempting to weld or drill on the building rooftop.

An engineering firm specializing in the design and installation of lightning protection systems should be consulted for proper design and installation of the building lightning protection system. A licensed contractor specializing in the installation of lightning protection systems should be used. The lightning protection system **shall** be constructed of only listed components. The lightning protection system **shall** meet the requirements of BS 6651:1999, IEC 61024-1-2, NFPA 780-2004, or other standard in effect and recognized by the local authority having jurisdiction. As a minimum the lightning protection system **shall** contain the following:

- The lightning protection system **shall** contain a grounding conductor installed around the roof perimeter to form the main roof perimeter lightning protection ring. The main roof perimeter lightning protection ring **shall** be sized as follows:
 - The conductor **shall** be a 35 mm² csa (#2 AWG) or coarser, bare, copper or equivalent, for buildings not exceeding 22.9 m (75 ft.) in height (NFPA 780-2004, Table 4.1.1.1(A)).
 - The conductor **shall** be a 70 mm² csa (#2/0 AWG) or coarser, bare, copper or equivalent, for buildings equal to or exceeding 22.9 m (75 ft.) in height (NFPA 780-2004, Table 4.1.1.1(B)).
- Strike termination devices, also known as air terminals, are typically installed along the length of the main roof perimeter lightning protection ring, typically every 6.1 m (20 ft.) or as otherwise required by the standard in effect and recognized by the local authority having jurisdiction.
- The main roof perimeter lightning protection ring **shall** contain at least two down conductors connected to the grounding electrode system. The down conductors **shall** be physically separated from one another as much as practical. The down conductors **shall** be sized as follows:
 - The conductor **shall** be a 35 mm² csa (#2 AWG) or coarser, bare, copper or equivalent, for buildings not exceeding 22.9 m (75 ft.) in height (NFPA 780-2004, Table 4.1.1.1(A)).
 - The conductor **shall** be a 70 mm² csa (#2/0 AWG) or coarser, bare, copper or equivalent, for buildings equal to or exceeding 22.9 m (75 ft.) in height (NFPA 780-2004, Table 4.1.1.1(B)).

NOTE: Available effectively grounded structural building steel can typically be used as a grounding down-conductor. The conductor used to bond the main roof perimeter lightning protection ring to the structural building steel **shall** be sized as required in this section for down-conductors. See Figure 4-53 on page 4-75 for an example of acceptable structural building steel bonding connections.

- Structures exceeding 76 m (250 ft.) in perimeter **shall** have a down conductor for every 30.5 m (100 ft) of perimeter or fraction thereof (NFPA 780-2004, section 4.9.10.1).

- Other metallic objects on the roof **shall** be bonded to the roof perimeter lightning protection system ring as required by BS 6651:1999, IEC 61024-1-2, NFPA 780-2004, or other standard in effect and recognized by the local authority having jurisdiction.
- All grounding electrodes at the building **shall** be bonded together to form a single grounding electrode system. See “Common Grounding (Earthing)” on page 4-5.

The rooftop mounted tower **shall** be effectively grounded by bonding to the lightning protection system. The rooftop mounted tower **shall** bond to the lightning protection system as follows:

- The rooftop mounted tower support legs **shall** be interconnected with a conductor to form a roof tower ground ring. A guyed tower base plate can be used in place of the roof tower ground ring. The conductor **shall** be of the same size as the main roof perimeter lightning protection ring.
- The roof tower ground ring **shall** be exothermically bonded to the tower unless specifically directed otherwise by the tower manufacturer.
- The rooftop mounted tower ground ring or guyed tower base plate **shall** bond to the main roof perimeter lightning protection ring with a minimum of two opposing conductors at or within 610 mm (24 in.) of a grounding down conductor, or other main grounding conductor as defined by NFPA 780-2004, such as effectively grounded structural building steel. The conductor **shall** be of the same size and type as the main roof perimeter lightning protection ring.
 - The conductors **shall** meet the installation requirements of “Grounding (Earthing) Conductors” on page 4-28.
 - Conductor bonding **shall** be made using exothermic welding, listed irreversible high-compression fittings, or other fittings listed for use in lightning protection systems. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.
- All tower guy/anchors that are attached directly to the building **shall** be bonded to the main roof perimeter lightning protection ring (ANSI T1.313-2003, section 10.3.3.).
 - The conductors **shall** meet the installation requirements of “Grounding (Earthing) Conductors” on page 4-28.
 - Conductor bonding **shall** be made using exothermic welding, listed irreversible high-compression fittings, or other fittings listed for use in lightning protection systems. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

See Figure 4-57 for an example of a typical rooftop tower grounding system.

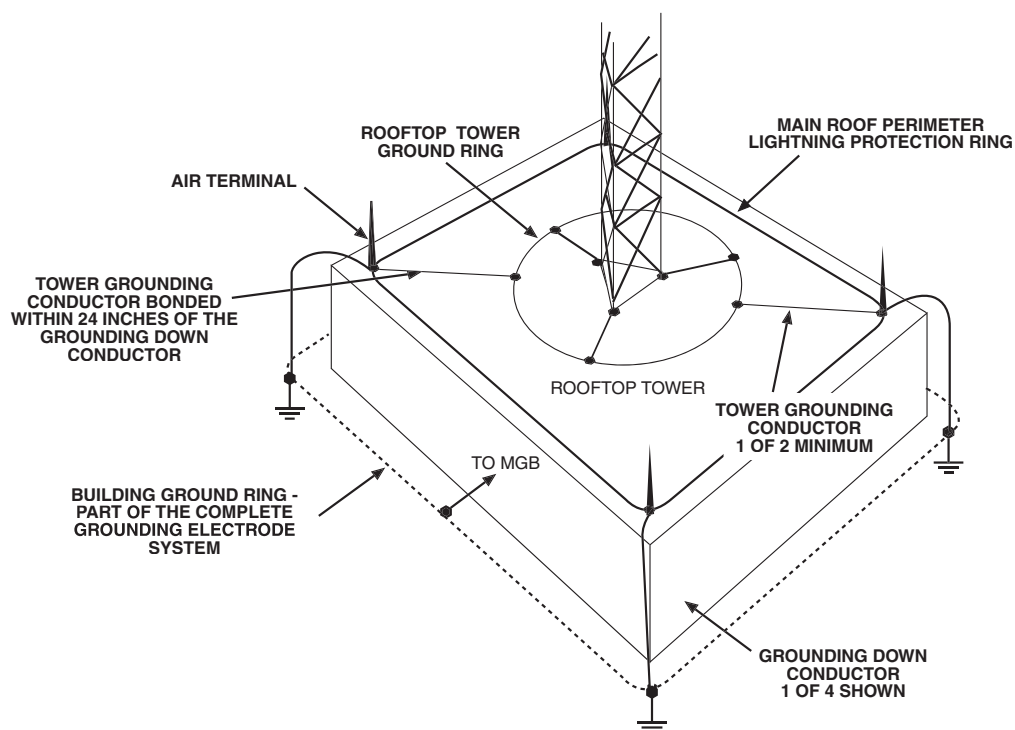


FIGURE 4-57 TYPICAL ROOFTOP TOWER GROUNDING RING

4.10 SPECIAL GROUNDING (EARTHING) APPLICATIONS

Some communications site locations and/or applications require special consideration for effective grounding (earthing). The following sections describe the grounding techniques for some common communications applications. Consultation with Motorola Engineering or other engineering firm may be required in some situations.

4.10.1 EXTERNAL GROUNDING (EARTHING) FOR DISPATCH CENTERS CO-LOCATED WITH COMMUNICATIONS TOWERS

Dispatch centers co-located with communications towers require special protection considerations due to the critical nature of their operation and due to the inherent risk to personnel from lightning. For optimum protection of a dispatch center, the following **shall** be considered:

- Site design recommendations given in “Design Considerations to Help Reduce Effects of Lightning” on page 2-19.
- Internal grounding and bonding as defined in “Grounding (Earthing) for Dispatch Centers and Network Operator Positions” on page 5-62.
- Transient voltage surge suppression (TVSS) As defined in “Surge Protection Considerations for Dispatch Centers and Operator Positions” on page 7-43.

- Electrostatic discharge (ESD) precautions as defined in “Protecting Against Electrostatic Discharge in Equipment Rooms and Dispatch Centers” on page C-1.
- External grounding (earthing) as follows:
 - Grounding electrode system resistance design goal of 5 ohms or less. See “Type “B” Site - Standard Duty” on page 4-45.
 - Installation of all minimum required grounding electrode system components as described in “External Building and Tower Ground Ring” on page 4-22.
 - Bonding of all metallic objects as described in “Metallic Objects Requiring Bonding” on page 4-67.
 - Installation of radial grounding conductors as described in “Radial (Counterpoise) Grounding Conductors” on page 4-24. Radial grounding conductors should be installed regardless if the grounding electrode system resistance is 5 ohms or less without the radial grounding conductors. A minimum of five radial grounding conductors should be installed.

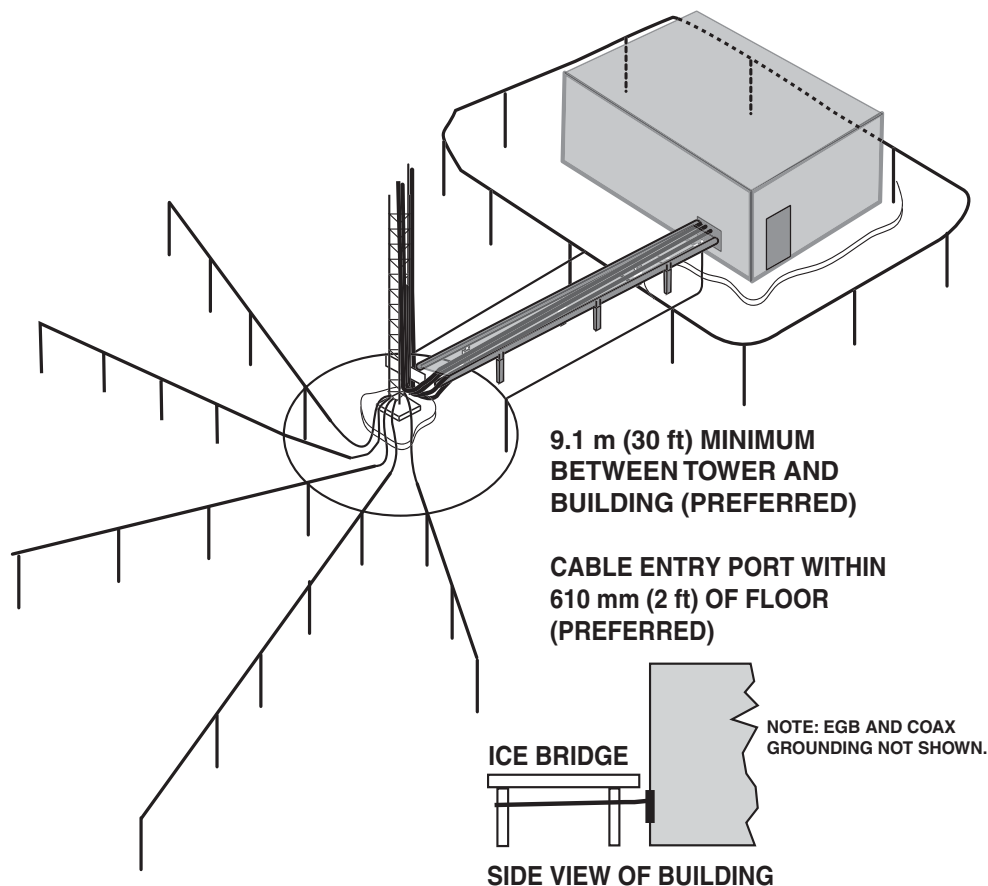


FIGURE 4-58 GROUNDING ELECTRODE SYSTEM FOR DISPATCH CENTER CO-LOCATED WITH A TOWER

4.10.2 TWO OR MORE ELECTRICALLY INTERCONNECTED SEPARATE BUILDINGS LOCATED IN THE SAME GENERAL AREA

When two or more structures or facilities are located in the same general area (less than 61 m (200 ft.) apart) and are electrically interconnected with the continuous metallic shield of signal, control, RF, or monitor circuits, it is recommended to either provide a common grounding (earthing) electrode subsystem, or interconnect the separate grounding electrode systems with two buried grounding conductors. When installed, the grounding conductors **shall** be 50 mm² csa (#1/0 AWG) or coarser, bare, copper. The buried grounding conductors **shall** be installed in separate trenches and buried to a minimum depth of 457 mm (18 in.) below grade. Access to the grounding conductor bonding points should include ground test wells. See Figure 4-59, “Ground Test Wells” on page 4-27, and MIL-HDBK-419A Volume II, section 1.2.3 for additional information.

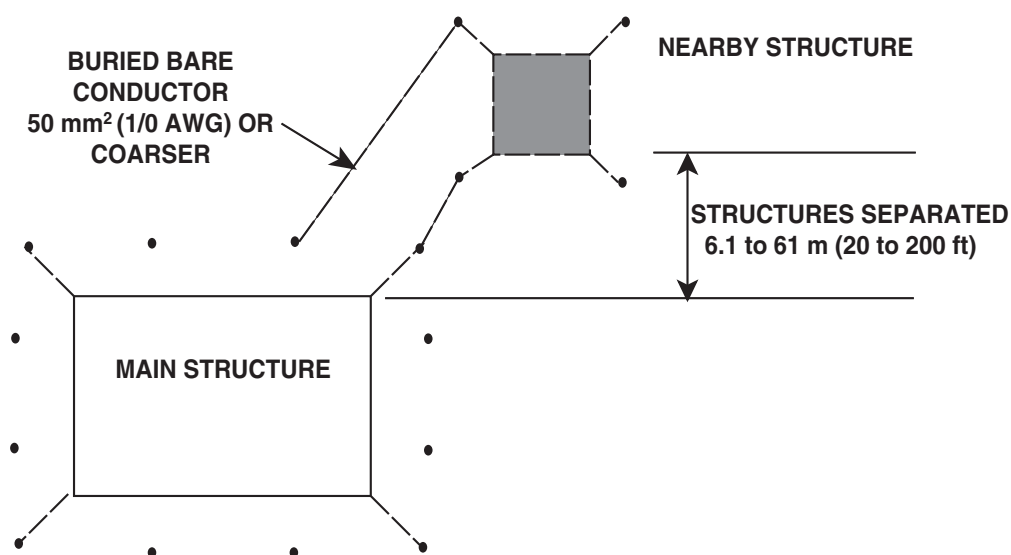


FIGURE 4-59 TWO ELECTRICALLY INTERCONNECTED BUILDINGS LOCATED IN THE SAME AREA

Structures or facilities having no interconnection cables and/or separated by a distance greater than 61 m (200 ft.) generally do not require their grounding electrode systems to be interconnected (MIL-HDBK-419A Volume II, section 1.2.3). Buildings sharing a common tower require bonding of their respective ground rings to the common tower ground ring.

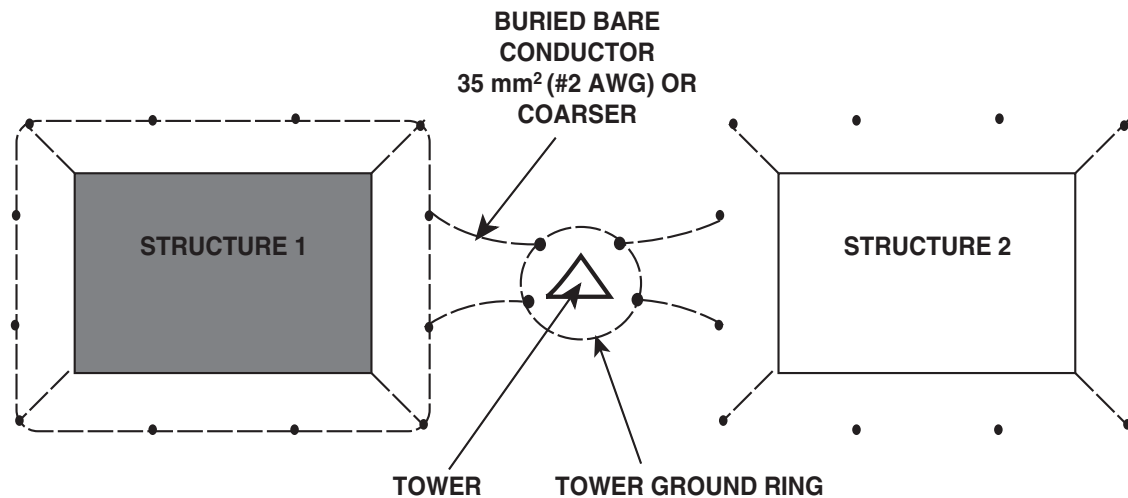


FIGURE 4-60 BONDING TWO STRUCTURES ADJACENT TO THE TOWER

4.10.3 ACCESS POINT AND WIRELESS ROUTER GROUNDING (EARTHING)

Access points, wireless routers, and similar equipment are typically installed in a variety of different locations. Such locations may be on communications towers, building rooftops, or utility light poles. These typical locations are addressed in this section.

4.10.3.1 TOWER MOUNTED

Tower mounted access points and wireless routers **shall** be bonded to the tower using a 16 mm² csa (#6 AWG) or coarser, solid or stranded, tinned and/or jacketed, copper conductor. Connection to access points and wireless routers **shall** be made to an adequately-sized dedicated grounding (earthing) point in accordance with the device manufacturer requirements. Connection to the tower **shall** be made using tower manufacturer-approved methods (typically a type of mechanical clamp). The grounding conductor **shall** meet the specifications and installation requirements of “Grounding (Earthing) Conductors” on page 4-28. The tower **shall** be grounded as described in “Tower Grounding (Earthing)” on page 4-50.

4.10.3.2 BUILDING MOUNTED

Building mounted access points and wireless routers are typically mounted on the side of the building or on the roof of the building. Access points and wireless routers installed inside the building **shall** be grounded (earthed) as required for electronic equipment in Chapter 5, “Internal Grounding (Earthing)”.

4.10.3.2.1 SIDE MOUNTED

Access points and wireless routers mounted to the side of a building **shall** be bonded directly to the building's common grounding (earthing) electrode system using a 16 mm² csa (#6 AWG) or coarser, solid or stranded, copper conductor; grounding conductors installed partially below ground **shall** be 35 mm² csa (#2 AWG) or coarser. Connection to access points and wireless routers **shall** be made to an adequately-sized dedicated grounding point in accordance with the device manufacturer requirements. The grounding conductor **shall** meet the specifications and installation requirements of "Grounding (Earthing) Conductors" on page 4-28.

4.10.3.2.2 ROOF MOUNTED

Access Points and Wireless Routers mounted on the roof a building **shall** be bonded directly to an available location of the building's common grounding (earthing) electrode system using 16 mm² csa (#6 AWG) or coarser, solid or stranded, copper conductor; grounding conductors installed partially below ground **shall** be 35 mm² csa (#2 AWG) or coarser. Connection to access points and wireless routers **shall** be made to an adequately-sized dedicated grounding point in accordance with the device manufacturer requirements. The grounding conductor **shall** meet the specifications and installation requirements of "Grounding (Earthing) Conductors" on page 4-28.

An available location to the building's common grounding electrode system may include the following:

- Effectively grounded structural building steel.
- An existing communications grounding system.
- An existing lightning protection system down-conductor.
- A grounding down-conductor.
- The device's AC power receptacle conduit when no other ground source is available or practical. When the AC power receptacle conduit is used, the effectiveness of its grounding/bonding connection **shall** be verified.

4.10.3.3 UTILITY POLE MOUNTED

4.10.3.3.1 METALLIC POLE MOUNTED

Access points and wireless routers mounted to metallic utility poles are grounded (earthed) in the same manner as described above for tower-mounted units. Metallic utility pole-mounted access points and wireless routers **shall** be bonded to the metallic utility pole using a 16 mm² csa (#6 AWG) or coarser, solid or stranded, tinned and/or jacketed, copper conductor as shown in Figure 4-61. Connection to access points and wireless routers **shall** be made to an adequately-sized dedicated grounding point in accordance with the device manufacturer requirements. The grounding conductor **shall** meet the specifications and installation requirements of "Grounding (Earthing) Conductors" on page 4-28. Connection to the metallic utility pole **shall** be made using appropriate listed grounding hardware (typically a type of mechanical clamp).

The metallic utility pole **shall** be effectively grounded or made to be effectively grounded. If the utility pole must be made effectively grounded, it **shall** minimally be grounded as described for a Type-A site in "Type "A" Site Grounding (Earthing)" on page 4-48.

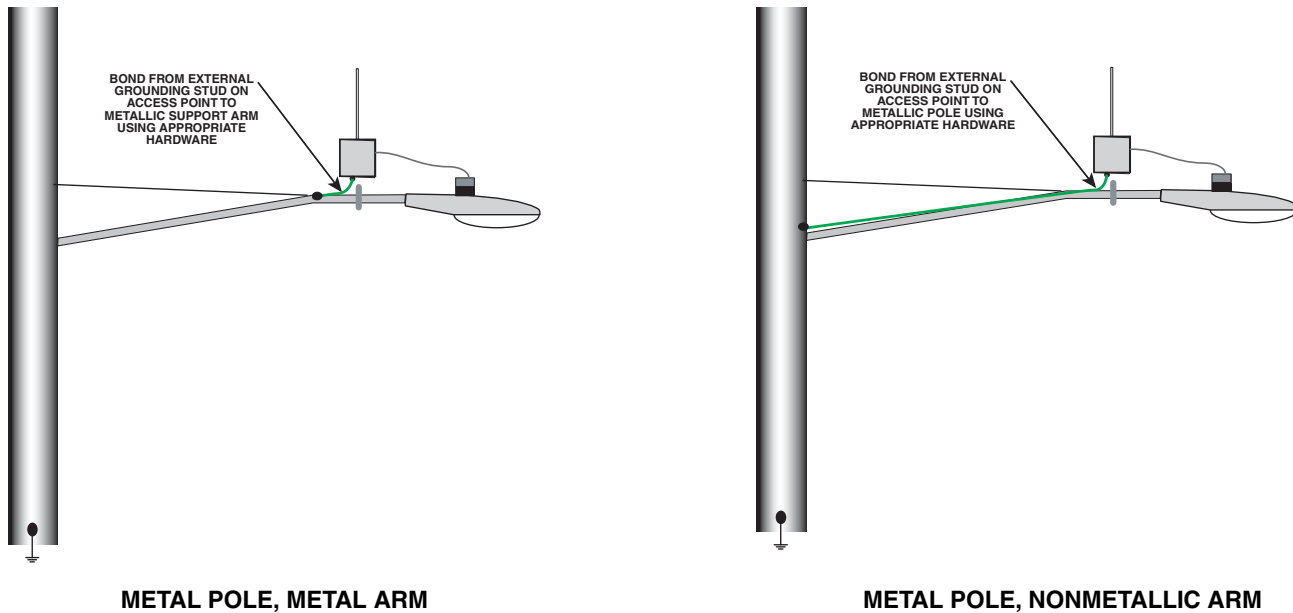


FIGURE 4-61 GROUNDING ACCESS POINT MOUNTED ON METAL POLE

NOTE: If the access point or wireless router is mounted to a non-metallic arm on the metallic utility pole, the access point or wireless router **shall** be grounded as described above by bonding to the metallic portion of the pole as shown in Figure 4-61.

4.10.3.3.2 NON-METALLIC POLE MOUNTED

Non-metallic utility poles used for supporting access points and wireless routers **shall** be grounded (earthed) in the same manner as described in “Wooden Structures (Poles)” on page 4-58. The access points and wireless routers **shall** be bonded to the pole's vertical grounding conductor using a 16 mm² csa (#6 AWG) or coarser, solid or stranded, copper conductor as shown in Figure 4-62. Connection to access points and wireless routers **shall** be made to an adequately-sized dedicated grounding point in accordance with the device manufacturer requirements. Grounding conductors **shall** meet the specifications and installation requirements of “Grounding (Earthing) Conductors” on page 4-28. Bonding to the vertical grounding conductor **shall** be made using listed irreversible compression fittings or exothermic welding as described in “Bonding Methods” on page 4-41.

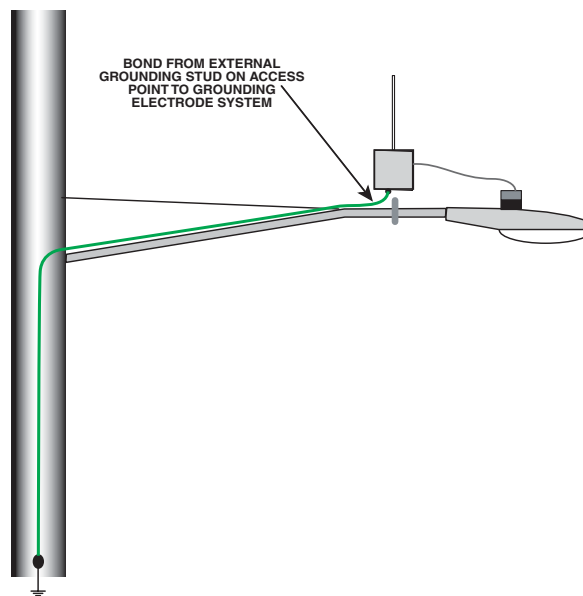


FIGURE 4-62 GROUNDING ACCESS POINT MOUNTED ON NON-METALLIC POLE

4.10.4 METAL SHIPPING CONTAINERS USED AS COMMUNICATIONS BUILDINGS

Grounding (earthing) electrode systems for metal shipping containers used as communications buildings **shall** conform to the requirements specified in this chapter for a dedicated communications building (see “Dedicated Communications Building Grounding (Earthing)” on page 4-59). All equipment inside the shipping container **shall** conform to the grounding requirements of Chapter 5, “Internal Grounding (Earthing).”

In addition to the requirements listed above, the outside of the shipping container **shall** be bonded to the grounding electrode system in at least all four corners using 35 mm² csa (#2 AWG) or coarser, bare, solid, copper conductors. Requirements for bonding the metal shipping container to the grounding electrode system are as follows:

- Each corner of the metal container **shall** bond directly to the grounding electrode system.
- Conductors **shall** meet the requirements of “Grounding (Earthing) Conductors” on page 4-28.
- Conductor bonding to the metal shipping container **shall** be exothermically welded whenever practical. See “Exothermic Welding” on page 4-41. When exothermic welding is not practical, other suitable mechanical connections may be used.
- Conductor bonding to the grounding electrode system **shall** be made using exothermic welding or listed irreversible high-compression fittings. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

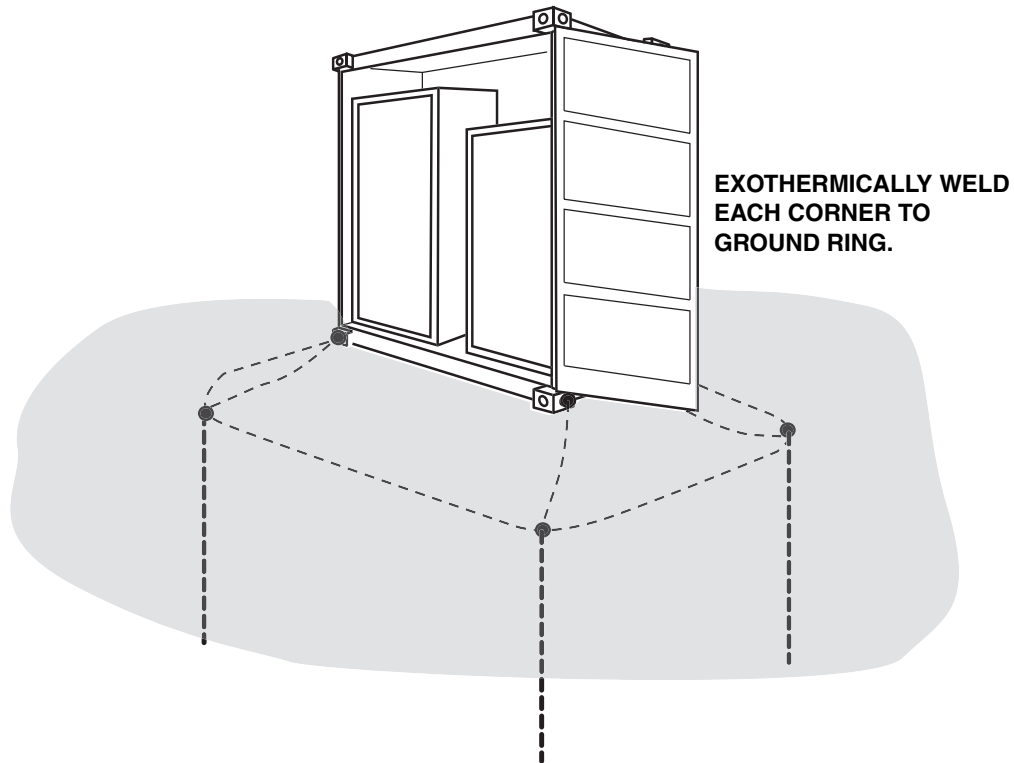


FIGURE 4-63 GROUNDING METAL SHIPPING CONTAINERS

4.10.5 GROUNDING (EARTHING) ELECTRODE SYSTEMS COVERED BY CONCRETE OR ASPHALT

When installing a grounding (earthing) electrode system, every attempt should be made to ensure that the surface area above the grounding electrode system is not covered with concrete or asphalt. Areas covered with concrete or asphalt will dry out over time, therefore increasing the resistance to earth of the grounding electrode system. (See MIL-HDBK-419A for additional information.) Some alternatives to covering the area with concrete and asphalt are listed below:

- Cover the area with gravel.
- Landscape the area.
- Use electrolytic ground rods when the area must be covered with concrete or asphalt.

4.11 SPECIAL GROUNDING (EARTHING) SITUATIONS

Site conditions such as limited area and high (poor) soil resistivity can sometimes require special consideration for effective grounding (earthing). Some methods for achieving an effective grounding electrode system in some common applications are described below in the following sections. Consultation with Motorola Engineering or other engineering firm may be required in some situations.

4.11.1 ROOFTOP AND INTEGRATED COMMUNICATIONS SITES

Rooftop and integrated communications sites (high-rise buildings) may require special techniques for achieving a suitable grounding (earthing) electrode system when effectively grounded structural steel is not available and when encircling the building with a ground ring would not be feasible, such as in a downtown metropolitan location. Some options may be:

- Consult with Motorola Engineering or other engineering firm.
- Installation of a small ground ring in an available location. See Figure 4-64.
- Installation of multiple parallel rods in a straight line. See Figure 4-65.
- Installation of electrolytic ground rod systems.

IMPORTANT: If a supplemental grounding electrode system is installed, it **shall** be bonded to the existing building grounding electrode system. See “Common Grounding (Earthing)” on page 4-5

NOTE: In order to maintain maximum efficiency of parallel ground rods, the ground rods **shall** be separated from one another by twice the length of the individual ground rods.

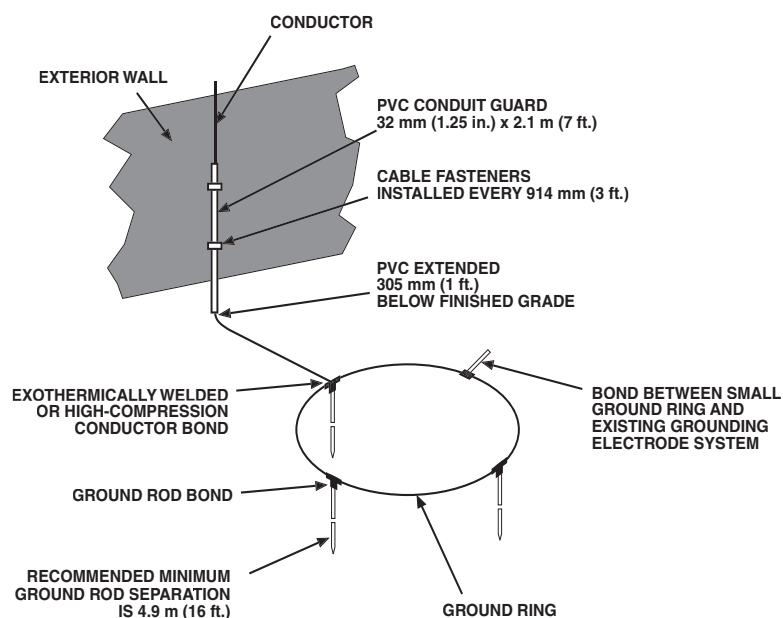


FIGURE 4-64 SMALL GROUND RING INSTALLATION

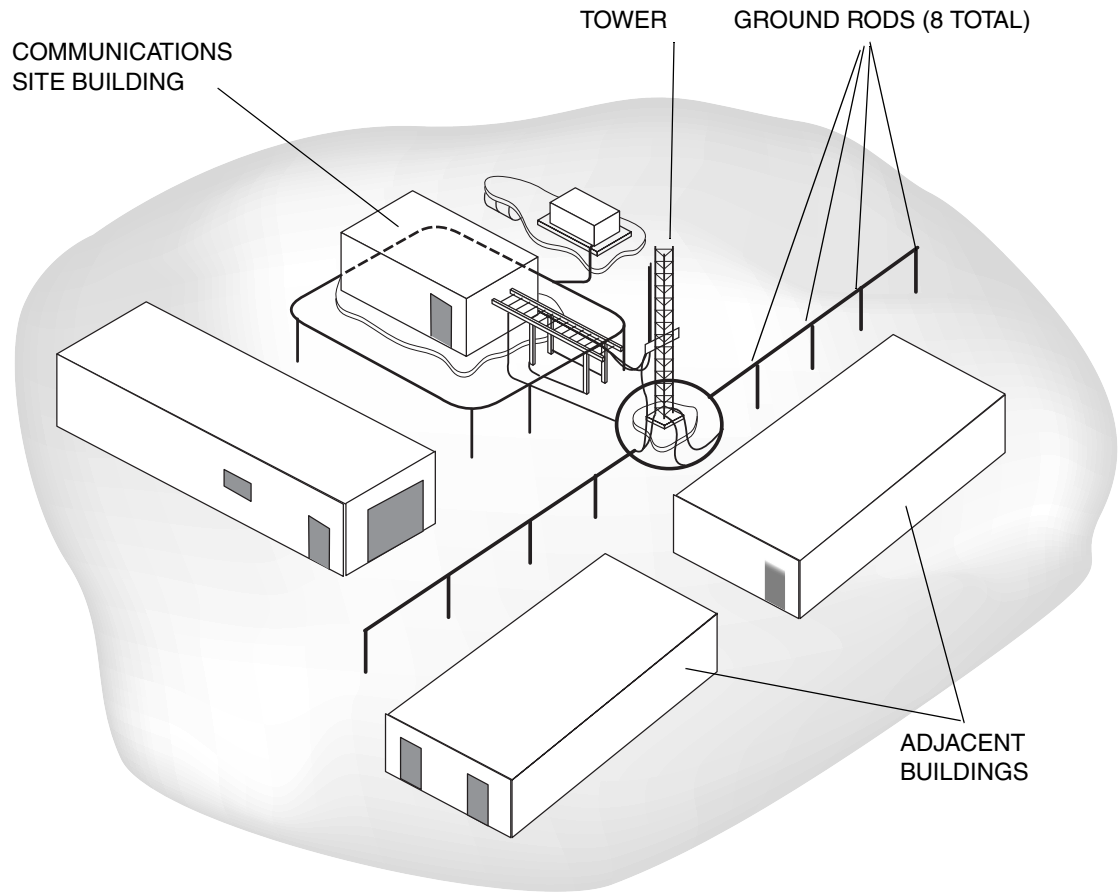


FIGURE 4-65 TYPICAL LINEAR GROUNDING ELECTRODE SYSTEM

4.11.2 SITES WITH LIMITED SPACE FOR THE GROUNDING (EARTHING) ELECTRODE SYSTEM

Some sites, such as locations in metropolitan areas or areas close to adjacent buildings or property lines, have very little space available for installing a grounding (earthing) electrode system. One solution for achieving an acceptable grounding electrode system that meets the resistance requirements defined in this chapter may be to install a grounding electrode grid system using all available space on the property.

A grounding electrode grid system consists of grounding electrodes, typically rods, installed in a grid pattern. The grounding electrodes are all equally spaced and connected together underground with a grounding conductor. See MIL-HDBK-419A for additional information. Requirements for a grounding electrode grid system are as follows:

- The grounding electrodes **shall** meet the specifications and installation requirements of “Grounding (Earthing) Electrodes” on page 4-9.

- Grounding conductors used to connect the grounding electrode **shall** meet the specifications and installation requirements of “Grounding (Earthing) Conductors” on page 4-28. Whenever possible, the grounding conductors **shall** be buried at least 762 mm (30 in.) deep or below the frost line, whichever is deeper.
- Grounding conductors **shall** be bonded together wherever they intersect; this is typically completed at a ground rod or other grounding electrode.
- Bonding of all components **shall** be made using exothermic welding or listed irreversible high-compression fittings. See “Bonding to the External Grounding (Earthing) Electrode System” on page 4-40.

See Figure 4-66 for an example of a grounding electrode grid system for an available area of 9.1 m × 9.1 m (30 ft. × 30 ft.), with all ground rods separated by 3 m (10 ft.).

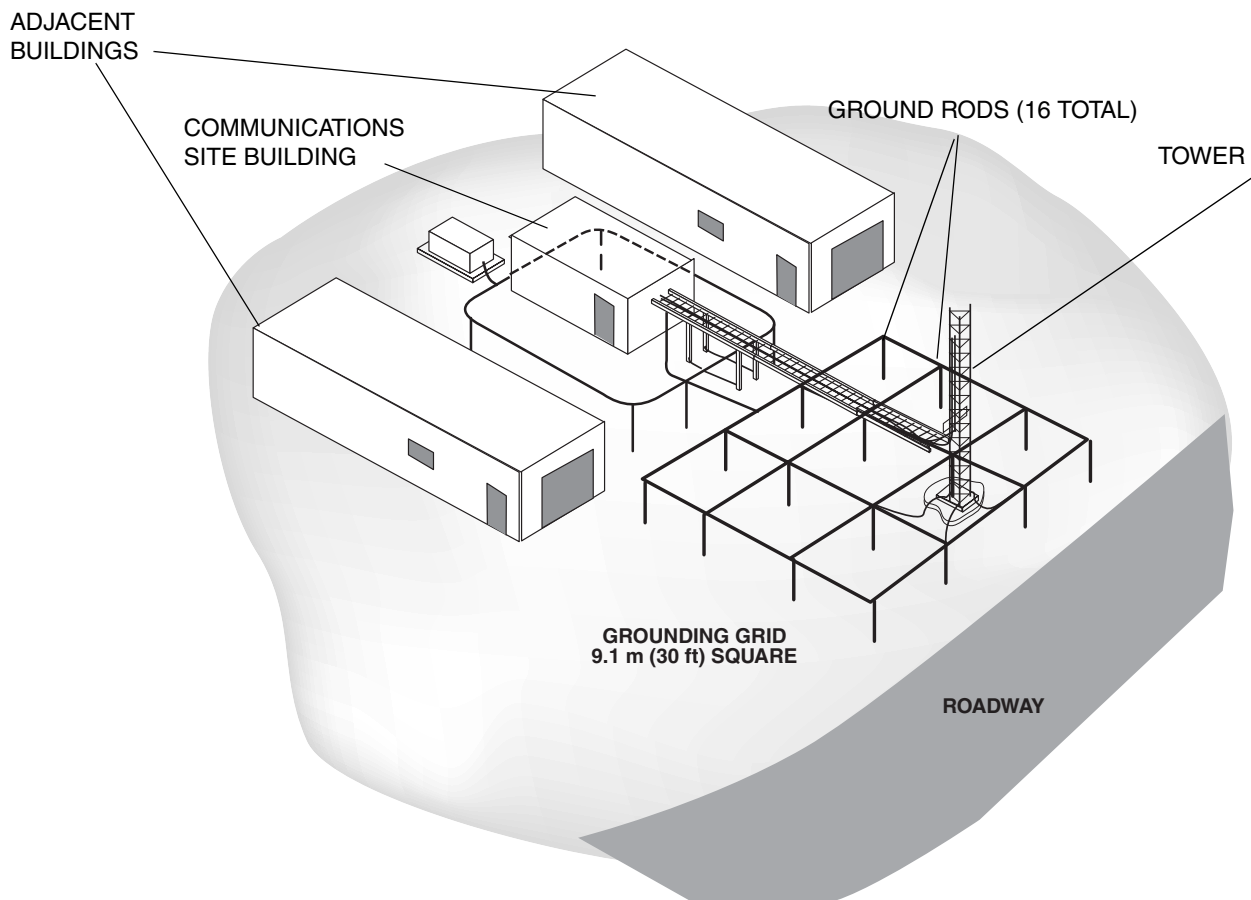


FIGURE 4-66 TYPICAL GROUNDING GRID

See “Interpreting Test Results” on page B-10 to determine if the desired resistance to earth can be achieved using different rod lengths and/or separation. If the resistance to earth cannot be achieved using standard rods, electrolytic rods should be considered. Burying the grounding conductor in at least 152 mm (6 in.) of grounding electrode encasement material should also be considered as a method of improving the resistance to ground. (See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.)

NOTE: In shallow topsoil conditions, the above grounding electrode grid system can utilize ground plates instead of ground rods.

4.11.3 TOWERS WITH LIMITED SPACE FOR A GROUND RING

Towers installed close to a building may not have adequate space for a complete tower ground ring or for ground rods spaced properly to achieve the resistance requirements of the site. Depending on the available space, the tower can be grounded (earthed) using multiple parallel rods and/or ground radials. (See “Radial (Counterpoise) Grounding Conductors” on page 4-24 and Figure 4-65 on page 4-90.)

See “Interpreting Test Results” on page B-10 to determine the number of rods and rod spacing required to achieve the resistance requirements of the site.

4.11.4 STONE MOUNTAIN TOPS

Some sites are located on mountaintops because of their RF propagation characteristics. In the instances where there is no, or very little, top soil at the site, special designs will be needed. Some options for an effectively grounded (earthed) site are listed below; reasonable attempts should be made to use as many options as possible and as needed to meet the ground resistance requirements of the site:

- Consult with Motorola Engineering or other engineering firm.
- Installation of concrete-encased electrodes as part of new construction. See “Concrete-Encased Electrodes” on page 4-20.
- Installation of radial grounding conductors from the tower and building throughout the property. Install the radial grounding conductors to a depth allowed by the soil, preferably 457 to 762 mm (18 to 30 in.) Encasing the radial grounding conductors in a grounding electrode encasement material can further increase the effectiveness of the grounding electrode system. See “Radial (Counterpoise) Grounding Conductors” on page 4-24.
- Installation of ground rings around the building and tower, with the ground rings buried as deep as the soil will allow. The ground rings should be encased in a grounding electrode encasement material. A conductive concrete may be the best grounding electrode encasement material for use in shallow topsoil environments, since the conductive concrete would not require a covering of topsoil for protection. See “External Building and Tower Ground Ring” on page 4-22 and “Grounding (Earthing) Electrode Encasement Materials” on page 4-27.
- Installation of horizontal ground rods or horizontal electrolytic ground rods along the length of the ground rings instead of vertical ground rods. The ground rods **shall** be installed perpendicular to the building and tower. Encasing the ground rings and horizontal ground rods in a grounding electrode encasement material can further increase the effectiveness of the grounding electrode system.

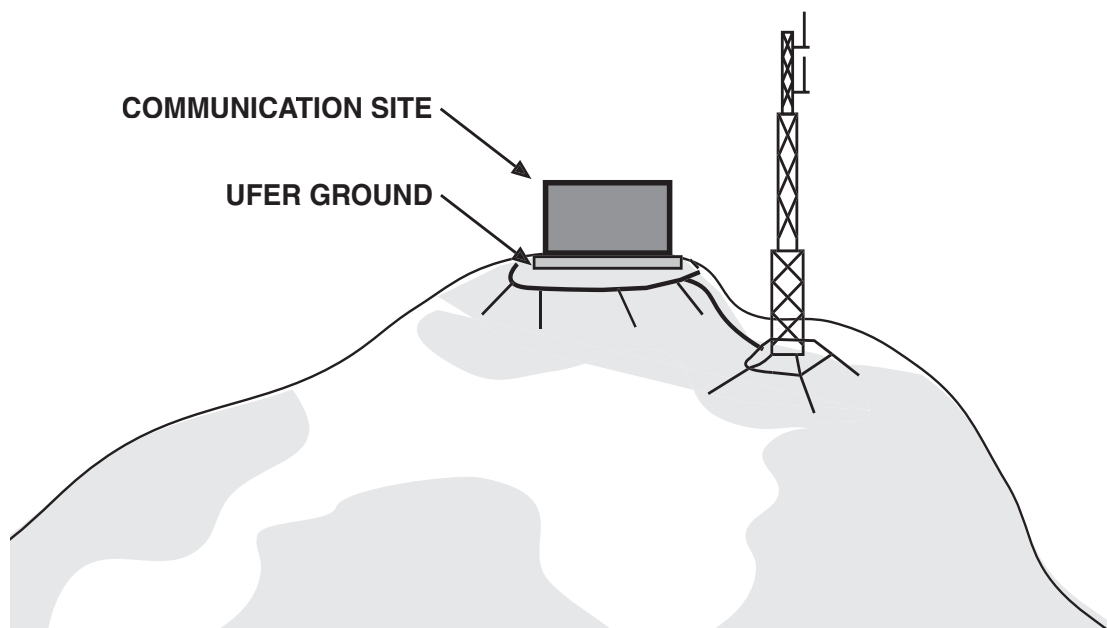


FIGURE 4-67 MOUNTAINTOP SYSTEMS: INSTALLATION OF HORIZONTAL GROUND RODS

- Installation of ground plates along the length of the ground rings instead of vertical ground rods. Encasing the ground rings and ground plates in a grounding electrode encasement material can further increase the effectiveness of the grounding electrode system. See “Ground Plate Electrodes” on page 4-19.

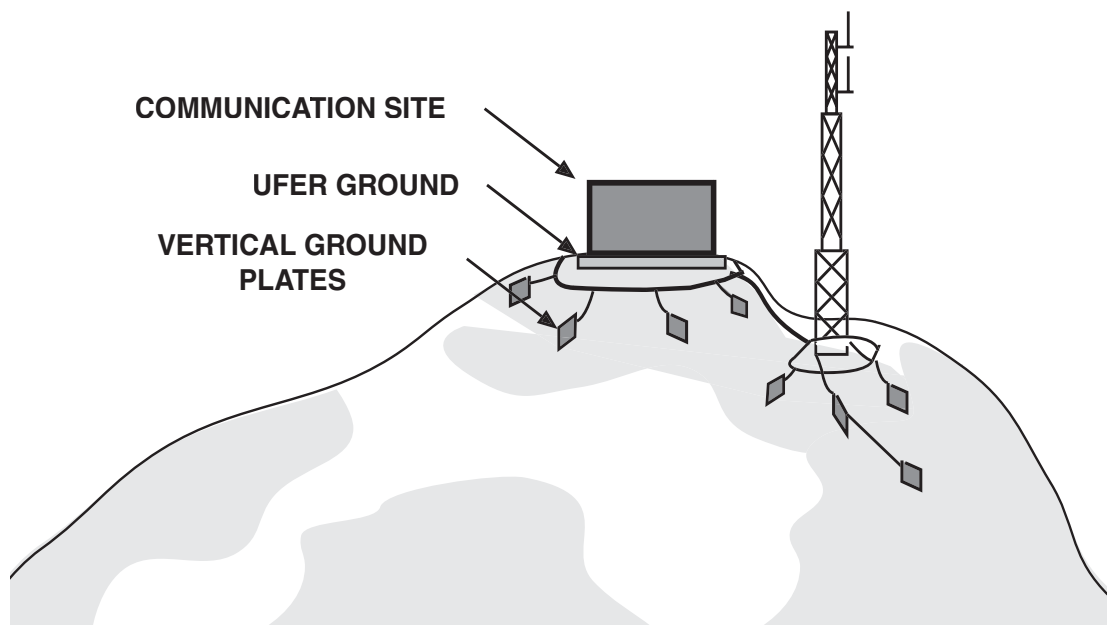


FIGURE 4-68 MOUNTAINTOP SYSTEMS: INSTALLATION OF GROUND PLATES

- Installation of down conductors to a lower area where there is usable soil for the installation of vertical ground rods. The down conductors would be more effective if buried below ground like a radial grounding conductor, wherever possible. The down conductors **shall** be sized according to length as shown below in Table 4-8 (based on MIL-HDBK-419A). See Figure 4-69 on page 4-96.

TABLE 4-8 GROUNDING CONDUCTOR SIZING

Conductor length in linear m (ft)	Conductor size in mm ² csa (AWG / MCM)
Less than 10 (Less than 33)	33.62 (2)
10.36 – 12.5 (34 – 41)	42.4 (1)
12.8 – 16 (42 – 53)	52 (1/0)
16.5 – 20 (54 – 66)	67.4 (2/0)
20.4 – 25.6 (67 – 84)	85 (3/0)
25.9 – 32 (85 – 105)	107 (4/0)
32.3 – 38.1 (106 – 125)	126.70 (250 MCM)
38.4 – 45.7 (126 – 150)	152 (300 MCM)
46 – 53.34 (151 – 175)	177 (350 MCM)
53 – 76.1 (176 – 250)	253.4 (500 MCM)
76.4 – 91.39 (251 – 300)	300 (600 MCM)
Greater than 91.39 (300)	380 (750 MCM)

TABLE 4-9 STANDARD WIRE SIZES AVAILABLE FOR INTERNATIONAL MARKET

Conductor size in mm ² csa	Conductor size in AWG / MCM
6	10
10	8
16	6
25	4
35	2
50	1/0
75	2/0
95	3/0
120	4/0
150	300 MCM
185	350 MCM
240	500 MCM
300	600 MCM
400	800 MCM

NOTE: Down conductors alone should not be relied on for an effective grounding electrode system. Other methods listed in this section, such as building and tower ground rings, should also be used to help achieve an effective grounding electrode system.

- Installation of copper strap radial grounding conductors on the surface of the rocks in all directions from the tower. The copper straps may be covered with top soil and/or ground enhancing material, such as conductive concrete. Each copper strap radial should be a different length to help prevent ringing of the tower during a lightning strike.

IMPORTANT: At sites, such as stone mountain tops, where it is difficult to achieve an effective grounding electrode system, the need for single-point grounding and transient voltage surge suppression (TVSS) on all input/outputs is of paramount importance.

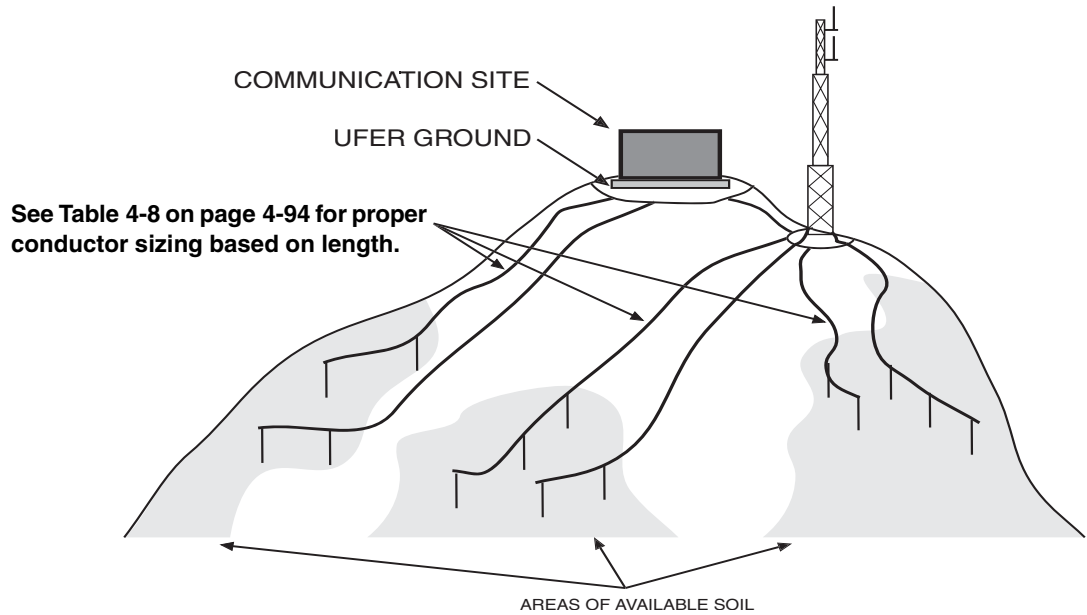


FIGURE 4-69 EXAMPLE OF SOILLESS GROUND SYSTEM

NOTE: The concept of drilling holes in solid rock to insert a ground rod surrounded by a grounding electrode encasement material is generally considered to be ineffective and should not be used without additional grounding electrode system components. Solid rock is no more conductive in a hole than on the surface. Radial grounding conductors encased in a grounding electrode encasement material, such as conductive concrete, would be more effective and more economical.

4.11.5 SAND, CORAL, OR LIMESTONE ENVIRONMENTS

Sites with very high soil resistivity, such as sites with sand, coral and limestone, may require special grounding (earthing) techniques in order to achieve an effectively grounded site. Some options to help achieve an effectively grounded site are as follows:

- Consult with Motorola Engineering or other engineering firm.
- Installation of concrete-encased electrodes as part of new construction. See “Concrete-Encased Electrodes” on page 4-20.
- In addition to the building and tower ground rings, installation of radial grounding conductors with vertical ground rods throughout the available property. Install radial grounding conductors and rods as specified in this chapter. Encasing all components in a grounding electrode encasement material can further increase the effectiveness of the grounding electrode system.
- Installation of electrolytic ground rod systems instead of standard ground rods. See “Electrolytic Ground Rods” on page 4-16.
- In addition to the building and tower ground rings, installation of a grounding electrode grid system throughout the site. See “Sites With Limited Space for the Grounding (Earthing) Electrode System” on page 4-90.

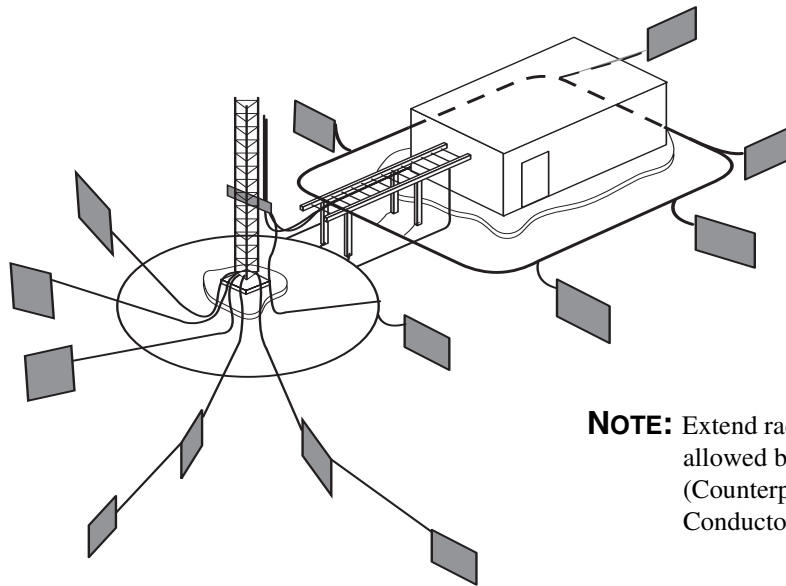
- Using multiple large copper plates (0.88 to 1.8 m² (10 to 20 ft².) buried to an optimal depth of 1.5 m to 2.4 m (5 to 8 ft.). The plates are placed vertically on edge and bonded to the grounding electrode system using exothermically welded 35 mm² csa (#2 AWG) solid copper wire. Placing the plates on vertical edge allows the plates to be buried with a minimum of excavation and may make it possible to obtain more surface area contact with the soil when backfilling. The use of a number of well-placed ground plates in parallel is preferred to placing longer rows of ground plates (IEEE STD 142-1991, section 4.2.4). Encasing the ground plates in a grounding electrode encasement material can further increase the effectiveness of the grounding electrode system.

4.11.6 SHALLOW TOPSOIL ENVIRONMENTS

Some sites are located in areas where bedrock is near the surface or where the top soil is less than 305 mm (1 ft.) deep. These areas require installation of specialized grounding (earthing) electrode systems and may require the support of an engineering firm.

Requirements and recommendations for grounding electrode systems in areas with shallow topsoil are provided below. Reasonable attempts should be made to use as many options as possible and as needed to meet the ground resistance requirements of the site. See NFPA 780-2004, section 4.13.8.1 for additional information.

- Consult with Motorola Engineering or other engineering firm.
- Installation of concrete-encased electrodes as part of new construction. See “Concrete-Encased Electrodes” on page 4-20.
- Installation of ground rings around the building and tower, with the ground rings buried as deep as the soil will allow. The ground rings should be encased in a grounding electrode encasement material. A conductive concrete may be the best grounding electrode encasement material for use in shallow topsoil environments, since the conductive concrete would not require a covering of topsoil for protection. See “External Building and Tower Ground Ring” on page 4-22.
- Installation of ground plates along the length of the ground rings instead of vertical ground rods. The ground plates should be encased in a grounding electrode encasement material. See “Grounding (Earthing) Electrode Encasement Materials” on page 4-27 and “Ground Plate Electrodes” on page 4-19.
- Installation of a grounding electrode grid system, using ground plates instead of vertical ground rods. The grounding conductors and ground plates **shall** be buried as deep as the soil will allow. The grounding conductors should be encased in a grounding electrode encasement material. A conductive concrete may be the best grounding electrode encasement material for use in shallow topsoil environments, since the conductive concrete would not require a covering of topsoil for protection. See “Sites With Limited Space for the Grounding (Earthing) Electrode System” on page 4-90 and Figure 4-66 on page 4-91 for additional information on grounding electrode grid systems.
- Installation of electrolytic ground rod systems. See “Electrolytic Ground Rods” on page 4-16.



NOTE: Extend radial grounding conductors as allowed by available soil. See “Radial (Counterpoise) Grounding Conductors” on page 4-24.

FIGURE 4-70 GROUNDING ELECTRODE SYSTEM WITH GROUND PLATES

- Installation of building radial grounding conductors in a trench extending away from the building at each corner. The radial grounding conductors **shall** be buried as deep as the soil will allow. The radial grounding conductors **shall** bond to the building ground ring using exothermic welding or listed irreversible high-compression fittings. The radial grounding conductors should be encased in a grounding electrode encasement material. A conductive concrete may be the best grounding electrode encasement material for use in shallow topsoil environments, since the conductive concrete would not require a covering of topsoil for protection. Each radial grounding conductor may have ground plates installed every 1.8 to 4.9 m (6 to 16 ft.) along its length. See Figure 4-71.
- Installation of tower radial grounding conductors in a trench extending away from the tower and building. The radial grounding conductors **shall** be buried as deep as the soil will allow. The radial grounding conductors **shall** bond to the tower ground ring using exothermic welding or listed irreversible high-compression fittings. The radial grounding conductors should be encased in a grounding electrode encasement material. A conductive concrete may be the best grounding electrode encasement material for use in shallow topsoil environments, since the conductive concrete would not require a covering of topsoil for protection. Each radial grounding conductor may have ground plates installed every 1.8 to 4.9 m (6 to 16 ft.) along its length. See Figure 4-71.

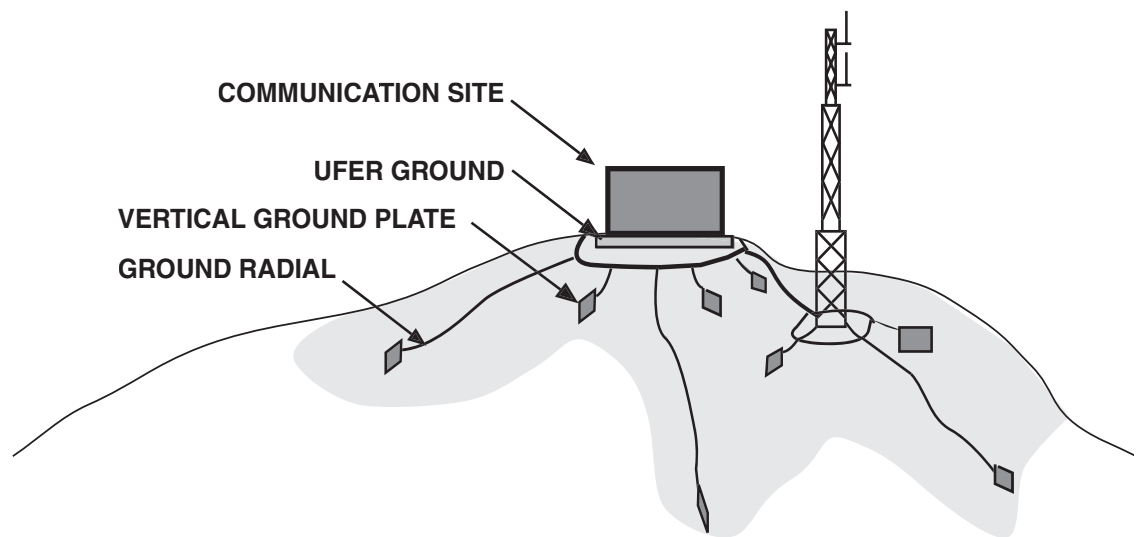


FIGURE 4-71 GROUNDING ELECTRODE SYSTEM WITH GROUND PLATES AND RADIALS

4.11.7 GROUNDING (EARTHING) IN ARCTIC REGIONS

It may be difficult to achieve an effective low resistance grounding (earthing) electrode system at sites located in arctic regions (or similar cold climates). In these cases, consultation with an engineering firm is recommended. The primary issue with achieving an effective grounding electrode system in arctic regions is making good contact with frozen high-resistivity soils. Where frozen high-resistivity soils are encountered, optimum grounding can only be accomplished by special attention to both surface and subsurface terrain. The resistivity of frozen soils can be 10 to 100 times greater than in the unfrozen state; therefore, seasonal changes in temperature and moisture greatly affect the resistance to earth of the grounding electrode system. (See Appendix B for additional information regarding soil resistivity changes as a function of temperature and moisture.) See MIL-HDBK-419-A Volume I, section 2.11.1 for additional information.

Seasonal freezing accounts for an increase in grounding electrode system resistance. If frozen soil has a high resistivity, then providing larger electrodes reduces the resistance to earth. In arctic areas that generally have very shallow surface thaw layers, horizontal rods or conductors may be easier to install than driven rods and provide an equivalent resistance to earth. Whether to install multiple electrodes, or a single deep-driven rod, or horizontal conductors is usually dependent on soil conditions at the site and the economics of installation. See MIL-HDBK-419-A Volume I, section 2.11.1 for additional information.

An option for an effective grounding electrode system may be to install electrolytic ground rods that are encased in a grounding electrode encasement material. See “Electrolytic Ground Rods” on page 4-16 and “Grounding (Earthing) Electrode Encasement Materials” on page 4-27. See MIL-HDBK-419-A Volume I, section 2.11.2 for additional information.

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