EXTERNAL GROUNDING

This chapter provides requirements and guidelines for designing, installing, and testing the external grounding electrode system at a communications site.

NOTE: Refer to Appendix [look up table C] for grounding cellular installations. This chapter contains information on the following topics:

23.2 DESIGN REQUIREMENTS FOR GROUNDING ELECTRODE

SYSTEMS

At a communications site, there shall be only one grounding electrode system. For example, the telephone system ground, AC power system ground, underground metallic piping, and any other existing grounding system shall be bonded together to form a single grounding electrode system
[per NFPA 70, Articles 250-90, 800-40, 810-21,
and 820-40; and NFPA 780, Section 3-14.1].

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.

All grounding media in or on a structure shall be interconnected to provide a common ground potential. This shall include lighting protection, electric service, telephone and antenna system grounds, as well as underground metallic piping systems.

Underground metallic piping systems typically include water service, well castings located within 25 ft [7.6m] 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 [per NFPA 780, Section 3-14].

The impedance requirement for a communications site's grounding electrode system is determined based on the classification of the site. Communications sites can be classified into two categories, described below
[per IEEE Standard 142-1991 and NFPA 70, Article 250]

23.2.1 Type A - Light Duty

Requirement: Type A sites shall achieve a resistance to earth of 25 ohms

Type A sites have the following characteristics:
1. Typically one repeater, single chassis, base station or outdoor cabinet
2. Not typically part of a larger system infrastructure
3. Single voting receiver site
4. RF alarm /reporting site
5. Single control station
6. Maybe located in a commercial office or residence
7. Grounding electrode system is bonded to an existing grounding electrode system

23.2.2 Type B - Light Industrial/Commercial

Note: A site meeting Type A criteria but that is considered critical to system operation by the operator, or is located in an area particularly susceptible to lightning strikes, should be classified as Type B.

Requirement: Type B sites shall achieve a resistance to earth of **5 ohms or less**.
Type B sites have the following characteristics

1. Telecommunications repeater equipment is installed, such as a cellular, PCS, or wide-area repeater site.
2. Communication system dispatch console equipment is installed.
3. Equipment with specific manufacturer requirements for a 5 ohm grounding electrode system is installed [telephony].
4.Power for the site is supplied only by a generator.
5. Large installations or multiple systems, such as telephone or electronic switches, LANs/WANs,and Mobile Switching offices (MSC) are installed.

23.2.3 Soil pH

The pH [Hydrogenion concentration] of the soil where a grounding electrode system is to be installed should be tested before the system is installed. Acidic soils [pH below 7] can have a destructive affect on copper and other metals.

Test soil pH using a commercially available soil pH tester or a swimming pool acid/ base tester. If using a swimming pool acid/base tester, mix and test a solution containing one part site soil and one part distilled water.

In strongly acidic soils (pH of 5 or below), it is recommended that precautionary measures be taken to help maintain the life expectancy of the grounding electrode system . Some options may be as follows:
1.Consult an engineering firm.
2. Encase all grounding electrode system components in a ground enhancing material [see “Ground Enhancing Materials” on page 23-13].
3. Use electrolytic ground rods encased in a ground enhancing material and installed in accordance with the manufacturer’s instructions.
See paragraph 23.3.1.2 on page 23-8 and paragraph 23.3.1.6 on page 23-13.

4. Use solid copper ground rods instead of copper-clad rods.
5. Use larger connecting conductors, such as # 2/0 AWG [67.43mm2 csa] instead of #2 AWG [35 2]
6. Test the grounding electrode system at least once a year, [see "Ground System Testing/Verification" on page 23-63"].

23.3 GROUNDING ELECTRODE SYSTEM COMPONENT REQUIREMENTS

The external grounding system may consist of, but is not limited to, the following components, shown in Figure 6-1:
1. Grounding electrodes
2. Grounding conductors
3. Tower ground bus bar
4. External ground bus bar
5. Tower ground ring
6. Building or shelter ground ring
7. Ground radials
9. Guy wire grounding conductors (guyed towers only)
10 Fence grounding conductors

FIGURE x-x TYPICAL TYPE B EXTERNAL GROUNDING ELECTRODE SYSTEM

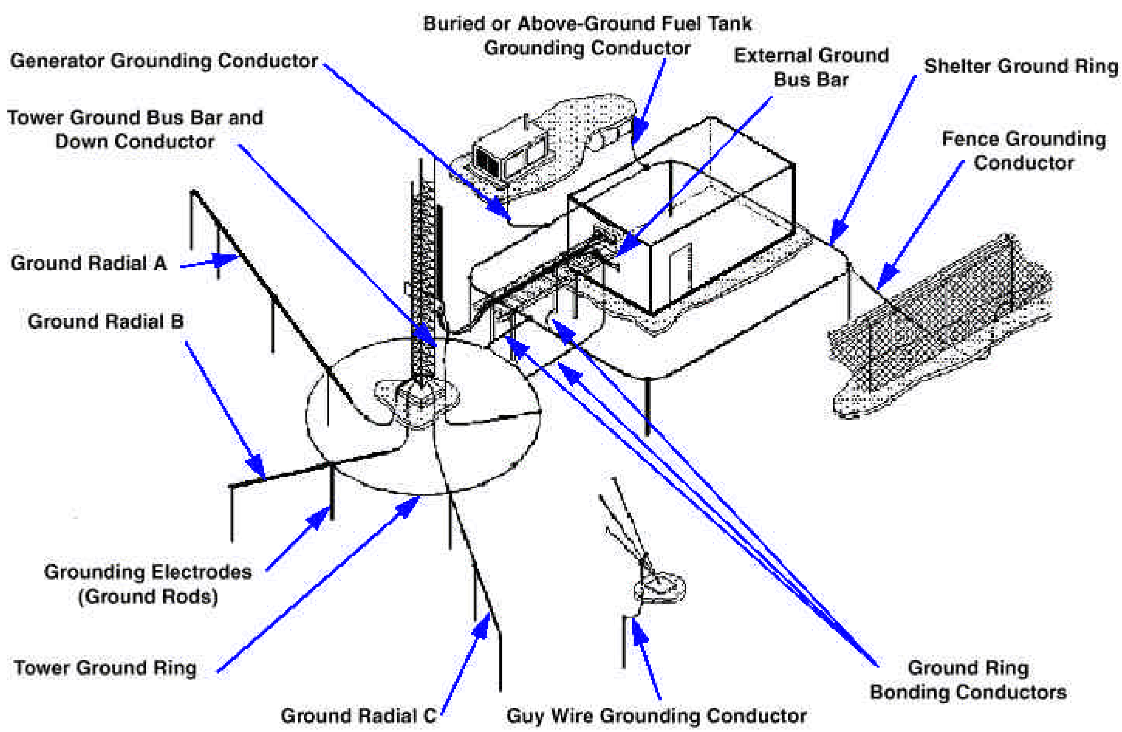


FIGURE 6-1 TYPICAL TYPE B EXTERNAL GROUNDING ELECTRODE SYSTEM

23.3.1 GROUNDING ELECTRODES

Grounding 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 and to dissipate over-voltages into the earth. Grounding electrodes may be ground rods, metal plates, concrete encased conductors, ground rings, electrolytic ground rods, the metal frame of building or structure and metal underground water pipes
[per NFPA 70, Article 250 (c) and NFPA 780, Section 3]

NOTE: Metallic underground gas piping shall not be used as a grounding electrode [per NFPA 70, Article 250-52[a]], but shall be bonded upstream from the equipment shutoff valve to the grounding electrode system as required by NFPA 70, Article 250-104(b) and NFPA 780, Section 3-14.1.

WARNING
Before excavating or digging at a site, have the local utility company or utility locator service locate the underground utilities.

23.3.1.1 GROUND RODS

Typical ground rods are shown in Figure 23-2. Requirements for ground rods are listed below.

Figure 23-2

[Picture not available]

1.Ground rods shall be copper-clad steel, solid copper, hot-dipped galvanized steel, or stainless steel. The rods shall have a minimum length of 8 ft [2.44m] and minimum diameter of 0.625 in [15.9 c], or as otherwise required by NFPA 70, Article 250-52. The actual diameter, length, and number of rods required may vary with site dimensions and/or as determined by an engineering study based on the soil resistivity profile of the site. Refer to "Soil Resistivity Measurements" on page 4-13, *NFPA 70, Article 250-52,* and *NFPA 780, Section 3-13* for more information.
2. The method of bonding grounding conductors to ground rods shall be compatible with the types of metals being bonded.
3.Ground rods shall be free of paint or other nonconductive coatings [NFPA 70, Article 250-52 and NFPA 780, Section 3-13.1].
4. Where practical, ground rods shall be buried below permanent moisture level [NFPA 70, Article 250-52].
5.Ground rods shall not be installed more than 16ft [4.9m] apart [or twice the length of the rod] and not less than 6ft [1.8] apart [per NFPA 70, Article 250-56].
6. Ground rods shall be buried to a minimum depth of 30.0in [0.76m] below finished grade, where possible, or buried below the freeze line, whichever depth is greater.
7. 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 30 in [0.76cm] deep, as shown in Figure 23-3. [See *NFPA 70, Article 250-52* and *NFPA 780, Section 3-13.1.5* for more information]

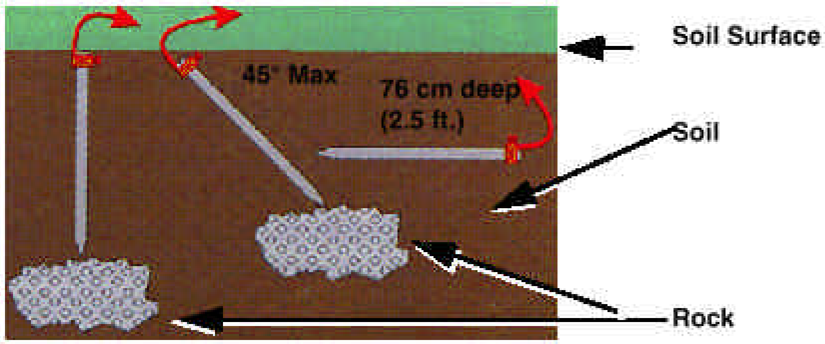


Figure 23-3

WARNING

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

1.Hammer drills or electric jackhammers may be used to drive in the ground rods. Do not deform the head of the ground rod.
2. 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.
3. Ground rods used to ground galvanized tower guy wires shall be installed in accordance with "Self-supporting Towers and Guyed Lattice Towers" on page 23-29.
4. When the grounding system design requires a deeper grounding electrode, two or three ground rods shall be exothermically welded end-to-end as shown in Figure 23-4. Other methods of connecting the rods together shall not be used.

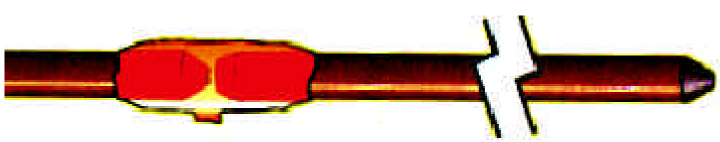


Figure 23-4

23.3.1.2 ELECTROLYTIC GROUND RODS

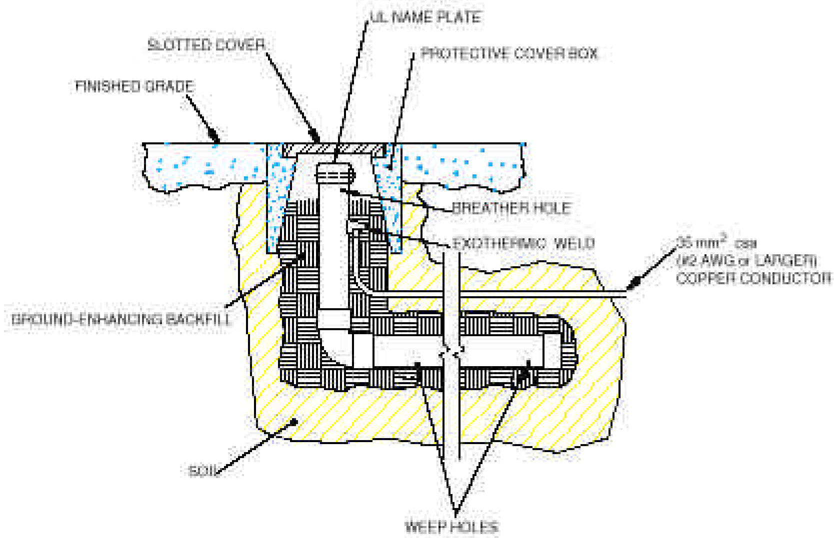
At sites where, due to poor soil conductivity [high resistivity] and/or limited space, an acceptable grounding electrode system resistance cannot be achieved using copper-clad steel rods and other methods described in this chapter, commercially available electrolytic ground rods may be used. Electrolytic ground rods [Figure 23-5] are available in straight or L-shaped versions and in various lengths from 10 ft [3.05m] to 20 ft [6.1m], or longer as a special order. Electrolytic ground rods are generally constructed of 2.125 in. [5.4 c] 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 often inserted into a pre-drilled hole, or in the case of L-shaped rods, placed into a trench at least 30 in [76 c] deep, and encased in a ground enhancing material [Refer to "Ground Enhancing Materials" on page 23-13]
.
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 systems may be routed to the ground
rod area to keep the soil moist, in proving conductivity.
So electrolytic ground rods provide significant improvement over copper-clad steel rods of the same length and may last several years longer than the copper-clad steel rods.

The resistance to earth of some electrolytic ground rods is more stable in environments with variations in temperature and moisture.
Requirements for the use of electrolytic ground rods are listed below.

1. Electrolytic rods shall be UL listed.
2. Electrolytic rods shall be installed per manufacturers' recommendation.
3. Electrolytic rods shall be maintenance free.
4. Electrolytes within the rod shall be environmentally safe and approved by the environmental jurisdiction having authority.
5. Ground enhancing backfill materials shall be environmentally safe and approved by the environmental jurisdiction having authority.

L-Shaped



Straight

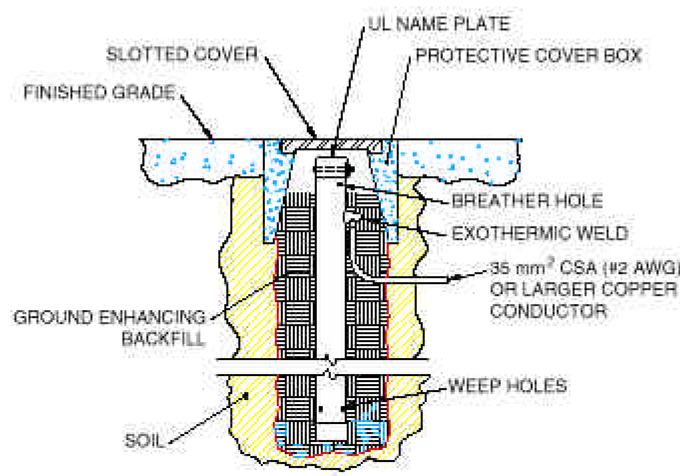


FIGURE 23-5 Electrolytic Ground Rods

23.3.1.3 GROUND PLATES

Ground plates [Figure 23-6] may be used in special cases if specifically engineered into the design of the grounding electrode system or otherwise required due to soil conditions. A ground plate electrode shall expose not less than 2 sq ft [0.186 2] of surface to exterior soil and shall be buried not less than 2.5 ft [76.2 c] below the surface of the earth. If soil conditions do not allow the ground plate to be buried at this depth, see NFPA 780, Section 3-13.1.5 for ore information. Refer to “Sand, Coral, or Limestone Environments” on page 23-53 for a recommended example of the use of ground plates in unfavorable environments.

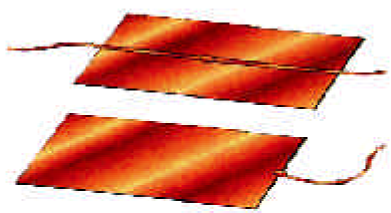


Figure 23-6

23.3.1.4 CONCRETE-ENCASED ELECTRODES

Though concrete-encased electrodes [also known as Ufer electrodes] are not required by this standard, they should be used in new construction as a method of supplementing the grounding electrode system . Concrete-encased electrodes [Figure 23-7] enhance the effectivity 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 may be especially helpful at sites with high soil resistivity and/or limited area for installing a grounding electrode system. Requirements for a concrete-encased electrode, if used, are listed below [per NFPA 70, Article 250-50 and NFPA 780, Section 3-13.2].

1.Concrete-encased electrode shall be encased by at least 2in [5 c] of concrete, located within and near the bottom of a concrete foundation or footing that is in direct contact with the earth.
2. Concrete-encased electrode shall be at least 20 ft [6.1m] of bare copper conductor not smaller than #4 AGW [25 2 csa] or at least 20 ft [6.1m] of one or ore bare or zinc galvanized or other conductive coated steel reinforcing bars or rods at least 0.5 in [12.7cm] diameter.
3. Concrete-encased electrode shall be bonded to any other grounding electrode system at the site.

FIGURE 23-7 Typical Concrete-Encased Electrode

23.3.1.5 GROUND TEST WELLS

Ground test wells are not required, but may be desired for troubleshooting and/or inspecting the grounding electrode system components. Ground test wells are typically constructed of PVC tubing 8 in. [20.3 c] or more in diameter and have a detachable cover to keep debris out. A typical PVC ground test well is shown in Figure 23-8.

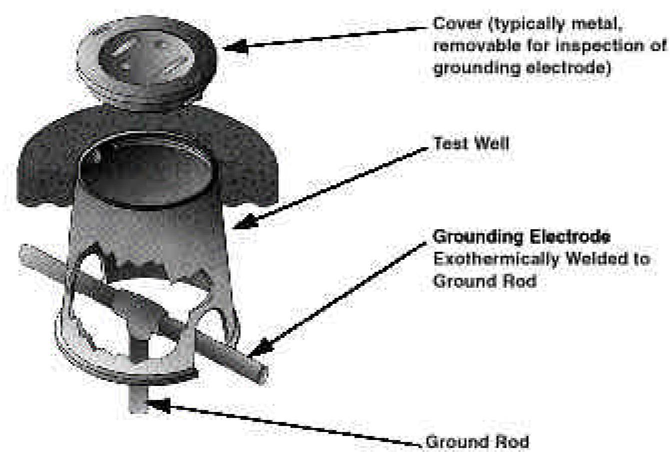


FIGURE 23-8 Typical Ground Test Wells

23.3.1.6 GROUND ENHANCING MATERIALS

Ground enhancing material may be used as needed to improve the grounding electrode system resistance or to protect the grounding electrode system components from very acidic soil. Ground enhancing material is generally used with electrolytic ground rods, but may also be used on grounding conductors, ground rods and ground plates as a way to improve the resistance to ground of a grounding electrode system . Requirements for the use of ground enhancing material are as follows:

1.Ground enhancing material shall be packaged specifically for the purpose of ground enhancement.
2. Ground enhancing material shall be environmentally safe and approved by the environmental jurisdiction having authority.
3. Ground enhancing material shall be used in accordance with manufacturers' instructions.
4. Ground enhancing material shall not have a corrosive effect on the grounding electrode system components.

23.3.2 GROUNDING CONDUCTORS

Grounding 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 be the wires that connect grounding electrodes together, for buried ground rings, and connect objects to the grounding electrode system .
[See *NFPA 70, Article 100* for more information.]

23.3.2.1 GENERAL SPECIFICATIONS

All external grounding conductors shall be bare tinned solid or stranded #2 AGW [35 ^{2} csa] or larger copper wire and shall meet the size requirements of NFPA 70, Article 250-66. Solid wire is recommended below grade to prolong longevity. For areas highly prone to lightning and/or areas with highly acidic soil, larger conductors should be considered.
Solid straps or bars may be used as long as the cross-sectional area equals or exceeds that of the specified grounding conductor.

23.3.2.2 BENDING GROUNDING CONDUCTORS

The following requirements apply when installing grounding conductors:

1.Sharp bends shall be avoided because the sharp bend increases the impedance and may produce flash points. See Figure 23-9.
2. Grounding conductors shall be run as short, straight, and smoothly as possible, with the fewest possible number of bends and curves. [See *NFPA 70*, *Articles 800-40*, *810-21*, and *820-40*].
3. A minimum bending radius of 8 in. [20 c] shall be maintained, applicable to grounding conductors of all sizes [per NFPA 780, Section 3-9.5 and ANSI T1.313-1997]. A diagonal run is preferable to a bend even though it does not follow the contour or run parallel to the supporting structure.
4. All bends, curves, and connections shall be toward the ground location, rod or ground bar (grounded end) of the conductor.

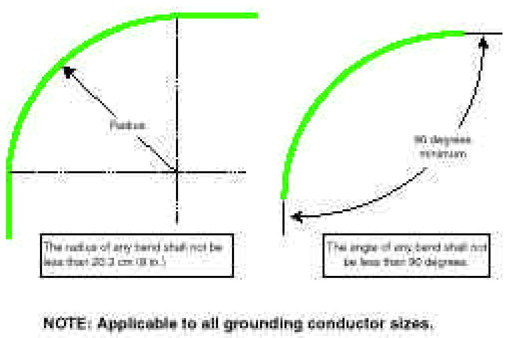


Figure 23-9 Minimum Bending Radius for Grounding Conductors

23.3.2.3 SECURING GROUNDING CONDUCTORS

External grounding conductors, especially copper 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:

1. The grounding conductor or its enclosure shall be securely fastened to the surface on which it is carried.
2. Grounding conductors shall be attached using nails, screws, bolts, or adhesives as necessary.
3.The fasteners shall not be subject to breakage and shall be of the same material as the conductor or of a material equally resistant to corrosion as that of the conductor.
4. Approved bonding techniques shall be observed for the connection of dissimilar metals.
5. Grounding conductors shall be securely fastened at intervals not exceeding 3 ft [91 c] [See *NFPA 70, Articles 250- 4[b], 810-21[c]*, and *NFPA 780, Section 3-10]*

23.3.2.4 EXTERNAL GROUND RING

The buried external ground ring should encircle the site structures and provides a means of bonding ground rods together and bonding other grounding electrode system components together, improving the overall grounding electrode system. Requirement for external ground rings are listed below. [See Figure 6-10; refer to *NFPA 70, Article 250-50* and *NFPA 780, Section 3-13.3* for more information]

1.Building ground ring shall encircle the building or shelter.
2.Tower ground ring shall encircle the tower structure whenever possible.
3. Building ground ring and tower ground ring shall be bonded together in at least two points using a #2 AGW [35 2 csa] minimum bare tinned copper conductor.
4.Ground rings shall be installed in direct contact with the earth at a depth of 30 in. [76 c] below the earth's surface whenever possible, or below the frost line, whichever is deeper.
5.Ground rings shall be installed at least 3 ft [0.9m] 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 2 to 6 ft [0.6 to 1.8m] 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]
6. Tower ground rings shall be installed at least 3ft. [0.9m] from the tower foundation.
7.Ground rings shall consist of bare solid or stranded tinned copper conductor not smaller than # 2AWG [35 2 csa] For highly lightning prone areas, larger conductors should be considered.

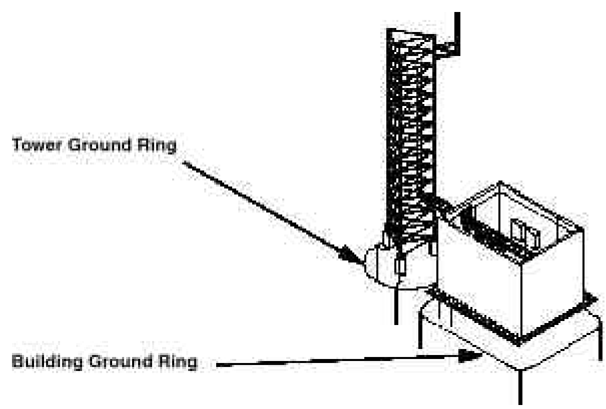


Figure 23-10 site ground Ring Ground system

23.3.3 EXTERNAL GROUND BUS BAR

The purpose of the external ground bus bar is to provide a convenient termination point for multiple grounding conductors. When required, the external ground bus [EGB] shall be constructed and minimally sized in accordance with Table 23-1, ensuring that the ground bus bar is large enough to accommodate all coaxial connections and connection to the grounding electrode system. The external ground bus bar **shall** be installed at the point where the antenna transmission lines enter the building, and **shall** be connected to the external ground ring using the straightest possible downward run of # 2 AGW [35 2 csa] or larger bare solid or stranded tinned copper conductor. See Figure 23-11.

For reduced impedance to the grounding electrode system, the EGB can be connected to the external ground ring using solid copper strap. Relatively s all copper strap has significantly less inductance [impedance to lightning] than large wire conductors. For example, 1.5 in.[3.8 c] copper strap has less inductance than #2/0 AWG [67.43 2 csa] 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 23-12.

Figure 23-11 External Ground Bus Bar

FIGURE 23-12 Intergraded Cable Entry Port with Ground Straps

TABLE 23-1 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
Minimum Dimensions	Width: 2in. [5cm] Length: 12 in. [30.5cm] Thickness: ¼ in. [0.635cm]
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 7/16 in [1cm] minimum on ¾ in. [1.9cm] centers to permit the convenient use of two-hole lugs.
Method of attachment of Grounding electrode conductor.	Exothermic welding Irreversible crimp connection Other suitable irreversible crimp connection process

23.3.4 TOWER GROUND BUS BAR

The purpose of the Tower Ground Bus Bar [TGB] is to provide a convenient termination point for multiple transmission line grounding conductors. The tower ground bus bar should be an integral part of the tower construction or vertical transmission line cable ladder assembly. If the tower ground bus bar is not part of the tower construction, it shall be constructed and minimally sized in accordance with Table 23-2, ensuring the ground bus bar is large enough to accommodate all coaxial cable connections and connection to the grounding electrode system. The tower ground bus bar shall be physically and electrically connected to the tower.

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 bar shall be directly bonded to the tower, using hardware of materials suitable for preventing dissimilar metal reactions, if possible and allowed by the tower manufacturer. The tower ground bus bar shall also be connected to the tower ground ring with a #2 AWG [35 2 csa] or larger bare tinned solid copper conductor. Avoid bending this conductor. This conductor may be sleeved in PVC for protection if desired. [See *ANSI T1.313-1997*]

For reduced impedance to the grounding electrode system, the TGB can be connected to the external ground ring using solid copper strap. Relatively s all copper strap has significantly less inductance [impedance to lightning] than large wire conductors. For example, 1.5 in. [3.8 c] copper strap has less inductance than #2/0 AWG[67.4 2 csa] 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, 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.

Vertical Mount Horizontal mount

Figure 23-13 Typical Tower Ground Buss Bars

Table 23-2 Tower Ground Bus Bar Specifications

Item	Specification
Material	Bare, Solid Alloy 110 [99.9%] copper bus bar or plate of One piece construction
Minimum Dimensions	Width: 2in. [5cm] Length: 12 in. [30.5cm] Thickness: ¼ in. [0.635cm]
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 7/16 in [1cm] minimum on ¾ in. [1.9cm] centers to permit the convenient use of two-hole lugs.
Method of attachment of Grounding electrode conductor.	Exothermic welding Irreversible crimp connection Other suitable irreversible crimp connection process

23.4 MINIMUM SITE GROUNDING REQUIREMENTS

This section provides the minimum grounding requirements for installing a grounding electrode system at a communications site and for bonding site equipment to the grounding electrode system . Develop a grounding electrode system engineering design, using either a consulting firm or an A &E engineering firm. The grounding electrode system shall achieve the ground resistance specified in "Design Requirements for Grounding Electrode Systems" on page 23-3.
The requirements for installing a grounding electrode system are as follows:

1. Performa soil resistivity test at the site as described in "Soil Resistivity Measurements" on page 21-13.
2. Calculate the resistance of a single ground rod as described in "Interpreting Test Results" on page 21-20.
3. Calculate the number of equally spaced ground rods that are needed to meet the resistance requirements of the site using "Interpreting Test Results" on page 21-20. If the required resistance cannot be met, recalculate using longer and/or larger diameter ground rods. If the resistance still cannot be met, refer to "Special Grounding Situations" on page 23-49 and/or consult an engineering firm.
4. Using a site drawing, determine where to install the needed rods, while maintaining equal separation between rods.
5. Develop a detailed site grounding electrode system drawing based on the previous steps.
6. Install the grounding electrode system using components and techniques as specified throughout this chapter.
7. Bond all external metal objects to the grounding electrode system as required throughout this chapter.
8. Test the grounding electrode system as described in "Ground System Testing/ Verification" on page 23-63.

23.4.1 METALLIC OBJECTS REQUIRING BONDING

All metal objects, as allowed by their manufacturer, that are located within 10 ft. [3.05m]of the external grounding electrode system, or are associated with the communications site equipment, shall be bonded to the external grounding system using #2AWG [35 ^{2} csa] conductors as described in "Grounding Conductors" on page 23-13 [ANSI T1.313-1997]. This includes but is not limited to:

1. Internal Master Ground Bar (MGB)
2. Metallic entry points
3. Ice bridge
4. Building ice shields

1. Antenna tower
2. Tower guy wires

3. Transmission lines
4. Piping
5.Air conditioner
6. Solid metal siding on buildings
7.Vent covers
8. Generator and support skids
9. Storage tanks (above and below grade) if allowed
10. Anchors and/or skids on prefabricated buildings
11. Satellite masts and mounts
12.GPS masts
13.CCTV masts
14. Conduits or raceways
15. External light fixtures or support masts
16.Fences
17. Main electrical service grounding electrode system
18. Main telephone company ground (if external)
19. Metal roofing and truss systems
20. Metallic structures on the building roof or rain gutter systems
21. Any other grounding electrode systems at the site

Series or daisy chain type of connection arrangements shall not be used. [See Figure 24-21 on page 24-39 for an example of a "daisy-chained" ground connection.)

NOTE: 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.

23.4.2 FENCES AND GATES

All site fencing within 10 ft .[3.05m] of the grounding electrode system , or any object grounded to the grounding electrode system , shall be bonded to the external grounding electrode system as shown in Figure 23-14 to prevent shock hazard to personal from lightning or other electrical anomalies [ANSI T1.313-1997]. Figure 23-15 shows an example of one method of bonding a fence gate to the adjacent fence post.

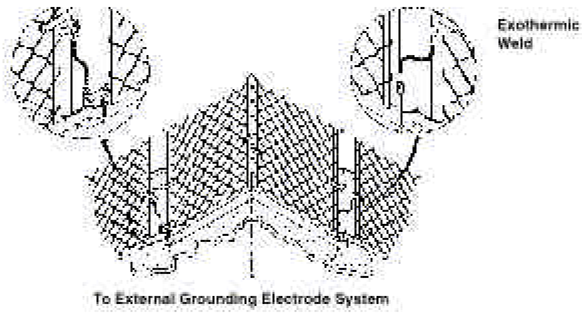


Figure 23-14 Fence Grounding Method

A minimum of four bare tinned # 2 AGW [35 2 csa] solid or stranded tinned copper conductors shall be brought from the external building ground ring. Each lead shall be bonded to its respective corner fence post. [See *IEEE STD-80* and *ANSI T1.313-1997* for ore information].

Grounding electrode system connections to a 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.

Figure 23-15 Example of Gate Bounding

If the site has residential quality fencing and/or preexisting fencing, it shall be grounded using heavy duty, tinned listed pipe clamps designed for grounding and stainless steel hardware. Residential-grade and/or preexisting fencing will not typically withstand exothermic welding.
All gates shall be bonded to the gate supporting fence post with #2 AGW [35 2 csa] minimum stranded copper wire using methods described above. This jumper wire should be constructed with a highly flexible conductor. The gate supporting fence post shall also be bonded to the opposite gate post. See Figure 23-16.

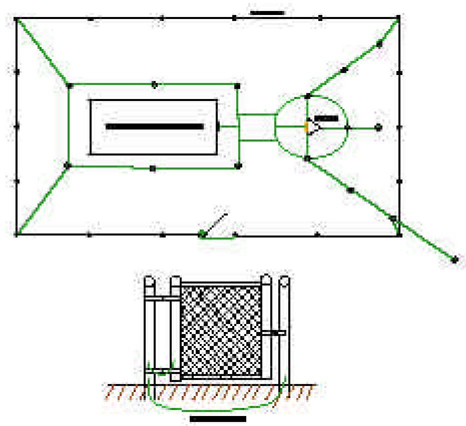


Figure 23-16 Fence & Gate Grounding Method

Fences around tower guy anchor points shall be bonded to the guy anchor ground rod 8 ft. [2.4m] , connected with a #2 AGW [35 2 csa] bare tinned solid copper conductor and bonded as outlined above. Guy anchor fence gates shall be bonded as described above.

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

If the site has non-electrified entry deterrent fence headers of barbed wire, razor wire, or other metallic wiring, the headers shall be bonded back to each corner fence post. The corner fence posts shall be bonded back to the grounding electrode system as described above [see Figure 23-17 for an example]. The following method shall be used for bonding the deterrent wiring:

1. The deterrent wiring shall be bonded to the corner fence post using a bare tinned # 2 AGW [35 2 csa] solid or stranded copper conductor.
2. The copper conductor shall be attached by an approved bonding method to the corner fence post just below the wire support apparatus.
3. Each individual run of the deterrent wiring shall be bonded to the copper conductor using a listed bi-metallic transition connector.
4.Each connection shall be liberally coated with a conductive antioxidant co pound at the point of insertion into the connector.
5. The tinned copper conductor shall be routed so as not co e into direct contact with the deterrent wiring, fence post, fence fabric or support apparatus for the wire.
6. The grounding conductor shall follow the proper routing methods described in this section.

Figure 23-17 Proper Bonding of Entry Deterrent Wire Fence Headers

23.4.3 CABLE RUNWAYS/ICE BRIDGES

Tower cable runway/ice bridges shall be bonded to the external ground bus bar and grounded at all support posts using exothermic welding or other suitable method. This connection shall be of #2 AGW [35 2 csa] minimum bare tinned solid or stranded copper wire attached to each post and connected to the external grounding electrode system.

The tower cable runway/ice bridge shall not be bonded to the tower ground bus bar. Unsupported ice bridges shall be kept isolated from the tower using electrical isolation hardware as required, as shown in Figure 23-18. This increases the impedance from the tower to the building, reducing the a mount of energy reaching the communications shelter in the event of a lightning strike. This does not lessen the cable runway/ice bridge grounding requirements.

If more than one span of cable runway is used between the tower and building, it is recommended that bonding jumpers be installed between the sections. The bonding jumpers should use two hole lugs and stainless steel hardware, or other suitable methods should be installed between each section to prevent loss of ground continuity with weathering.

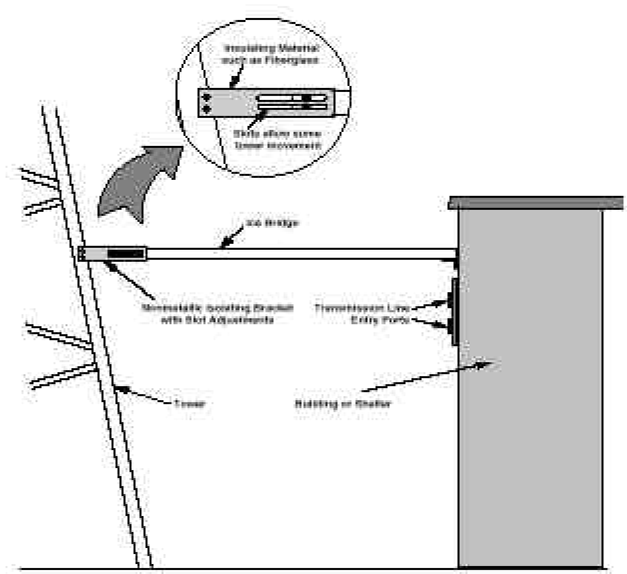


Figure 23-18 Electrically Isolating the Ice Bridge from the Tower

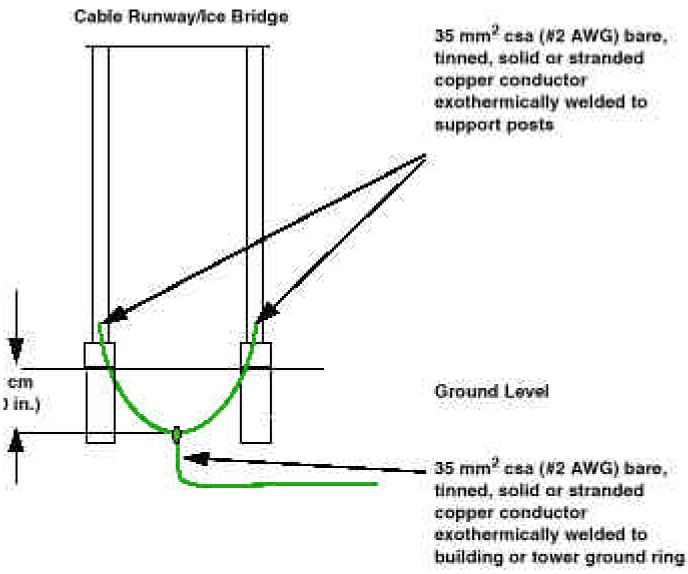


Figure 23-19 Proper Grounding of Self-Supporting Ice Bridge

FIGURE 23-20 Example of Ice Bridge Isolated from the Tower

23.4.4 ROOF-MOUNTED ANTENNA MASTS AND METAL SUPPORT STRUCTURES

All roof-mounted antenna masts and metal antenna support structures shall be bonded to the building grounding electrode system . If a separate antenna and/or tower grounding electrode system is installed, it shall be bonded to the building electrical grounding electrode system . Consult the building engineer or manager to determine information about existing building grounding electrode systems. The building engineer should also be informed before attempting to weld or drill on the building rooftop [See *NFPA 70, Article 250-52* and *Article 810-21* for ore details].
NOTE: Rooftop mounted towers are not covered in this section. Refer to "Rooftop Mounted Tower Structures" on page 23-34 for information about rooftop tower grounding requirements.
Grounding shall co ply with the following:

1. NFPA 70, Article 810-21.
2. Roof-mounted antenna masts and metal support structures shall be bonded to any existing lightning protection system as required by NFPA 780, Section 3-17.
3. Grounding conductor shall not be required to be insulated [per NFPA 70, Article 810-21[b]] Green-jacketed conductor or equivalent is recommended for runs inside.
4. Grounding conductor shall be protected from physical damage [per NFPA 70, Article 810-21[d] and NFPA 780, Section 3-9.11].
5. Grounding conductor shall be run in as straight a line as is practical [per NFPA 70, Article 810-21[e] and ANSI T1.313-1997].
5. Grounding conductor shall be securely fastened at intervals not exceeding 3 ft [91 c] [See *NFPA 70, Article 250- 4[b], 810-21[c]* and *NFPA 780, Section 3-10* for ore information.]
6. Minimum bend radius of grounding conductors shall be 8 in. [20.3 c], and the included angle shall not exceed 90 degrees as shown in Figure 23-9 [per NFPA 780, Section 3-9.5 and ANSI T1.313-1997].
7. Grounding conductors shall be permitted to be run either outside or inside the building or structure [per NFPA 70, Article 810-21[g]].
8. Grounding conductors run outside from the roof top to ground shall be protected for a minimum distance of 6 ft.[1.8m] above grade level when located in areas susceptible to damage [per NFPA 780, Section 3-9.11].

The roof-mounted antenna mast and support structure shall be grounded using grounding conductors sized as follows:

1.Using #2 AGW [35 2] or larger tinned solid or stranded copper conductor for overall building heights or conductor runs of 75 ft [23m] or less. [See *NFPA 780, Section 3-1.1* for more information.) Untinned green-jacketed conductor may also be used.

2. Using #2/0 AWG [67.43 2 csa] or larger tinned solid or stranded copper conductor for overall building heights or conductor runs more than 75ft.[23m] [See *NFPA 780, Section 3-1.1* for more information.] Untinned green jacketed 1conductor may also be used.
3. The grounding conductor shall be connected to the nearest accessible location on at least one of the following and ore than one if practical and available. [See *NFPA 70, Article 810-21[f], NFPA 780, Sections 3-9* and *3-9.10* for more information.]
4. The building or structure grounding electrode system as covered in NFPA 70, Article 250-50, using down conductors from the roof-top directly to the building's grounding electrode system. Down conductors should not be used as the only means of grounding the roof mounted antenna mast and metal support structures, unless no other secondary means are available.
5. Connection to the grounding electrode system may include items listed below. [See *NFPA 70, Article 810-21[f]* for more information].
6. Underground connection directly to the grounding electrode system, or directly to a supple mental grounding electrode system and bonding the grounding electrode systems together [see Figure 23-41].

Connection to the grounding electrode system shall comply with “Bonding to the External Grounding Electrode System ” on page 23-56.

1.The metallic power service raceway.
2. The service equipment enclosure.
3. The electrical service grounding electrode conductor.
4. The power service accessible means external to enclosures as covered in NFPA 70, Article 250-92[b], using grounding conductors as described above.
5. The power service accessible means external to enclosures as covered in NFPA 70, Article 250-92[b].
6. Effectively grounded interior metal water piping system as covered in NFPA 70, Article 250-104[a].
7. Effectively grounded metal structure, including exposed structural building steel. See also *NFPA 780, Section 3-1* for more information.

See Figure 23-39 for examples of rooftop grounding.
NOTE: Before metal piping systems are relied upon for use in a grounding electrode system, electrical continuity shall be verified. See *NFPA 70, Article 250- 8* for more details.

NOTE: Ground conductors may be green, green with a yellow stripe or black with green tape on a black conductor at points designated by
NFPA 70, Article 250-119 or jurisdictional codes.

If the building grounding electrode system resistance cannot be verified or cannot provide a low-impedance path to ground [see "Ground System Testing/Verification" on page 23-63], a supplemental grounding electrode system should be installed to ensure the resistance requirements of this chapter are et. The supplemental grounding electrode system shall be bonded to the existing grounding electrode system [per NFPA 70, Article 810-21[j] and NFPA 780, Section 3-14.1]. See Figure 23-41 for an example of a supplemental grounding electrode system.

WARNING
Do not attempt to install a separate grounding electrode system without bonding it to the existing grounding electrode system. A difference in potentials could result.

23.4.5 TOWERS

Antenna masts and metal support structures shall be grounded [See *NFPA 70, Articles 810-15* and *810-21*, *ANSI T1.313-1997*, and *ANSI/EIA/TIA 222-f* form more information]. Antenna towers shall be bonded to the tower ground ring, as described in this section. The tower ground ring shall be bonded to the building ground ring with at least two conductors of #2 AWG [35 2 csa] bare solid or stranded tinned copper conductor. Conductors bonded to the tower structures shall be exothermically welded or as required to co ply with the tower manufacturer's requirements. It is recommended that ground radials be used on all tower ground rings when the necessary land area is available. [See "Enhancing Tower Grounding Systems" on page 23-49.)
So e antenna structures, such as water storage tanks, require special grounding and bonding techniques and should be specifically engineered.

23.4.5.1 SELF-SUPPORTING TOWERS AND GUYED LATTICE TOWERS

Self-supporting and guyed lattice towers shall be grounded as follows:

1.The tower shall be encircled by a ground ring containing at least 3 equally spaced ground rods. For optimum ground rod spacing of 16 ft. [4.88m] for 8 ft. [2.44m] ground rods, the tower ground ring should have a minimum diameter of 18 ft. [5.49m]
2. Self-supporting towers exceeding 5 ft. [1.5m] in base width shall have 4 ground rods (ANSI T1.313-1997 and ANSI/EIA/TIA-222f). For a optimum ground rod spacing of 16ft. [4.88] for 8 ft. [2.44m] ground rods, the tower ground ring should have a minimum diameter of 23ft [7m].
3. The tower ground ring shall be installed in accordance with "External Ground Ring" on page 23-15.

4.Ground rods shall meet the specification and be installed in accordance with "Ground Rods" on page 23-6. Ground rods used for grounding steel antenna towers, or installed in close proximity of the tower should be galvanized to prevent galvanic corrosion of the tower [See *ANSI/TIA/EIA-222-F]*. This is especially important when the resistivity of the soil is at or below 2,000 ohm [See *ANSI/TIA/EIA-222-F, Annex J]*.

5. Each leg of a self-supporting tower shall be bonded to the tower ground ring using grounding conductors of #2 AGW [35 2 csa] minimum, bare tinned solid or stranded copper conductor. See Figure 23-21.

Figure 23-21Self-Supporting Tower Leg Grounding

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. Bonding shall be done using #2 AGW [35 2 csa]minimum, bare solid or stranded tinned copper conductor. See Figure 23-22.

Figure 23-22 Guyed Tower Grounding

The tower grounding conductors shall be exothermically bonded to the tower unless specifically directed otherwise by the tower manufacturer.
The tower grounding conductors shall each be bonded to the tower ground ring at the location of the respective closest ground rod. Bonding shall meet the requirements of "Bonding to the External Grounding Electrode System" on page 23-56.
Guy wires shall be grounded as follows [see Figure 23-23 and Figure 23-24]

1. A ground rod shall be installed at each guy anchor point, with the following exception: if the guy anchor is not encased in concrete, the tower anchor itself will serve as the ground point.
2. If the guy wire anchor is encased in concrete, keep copper rods a minimum of 2 ft. [61c] away. A galvanized rod can be used if desired without any minimum spacing requirements. Ground rods used for grounding guy wires should be galvanized to prevent galvanic corrosion of the guy anchor [See *ANSI/TIA/EIA-222-F]*. This is especially important when the resistivity of the soil is at or below 2,000 ohm [See *ANSI/TIA/EIA-222-F, Annex J* for ore information].
3.The ground rod shall be installed in accordance with "Ground Rods" on page 23-6.
4. A grounding conductor of #2 AGW [35 2 csa] solid or stranded bare tinned copper shall be bonded to the ground rod in accordance with "Bonding to the External Grounding Electrode System" on page 23-56. Do not use untinned wire.
5. The grounding conductor shall be connected to each guy wire using stainless steel clamps. Each connection shall be coated in an anti-oxidant co pound.

WARNING
Do not attempt to exothermically weld to tower guy wires.

1. The grounding conductor shall be connected to the guy wires above the turnbuckles.
2. A continuous vertical drop shall be maintained.

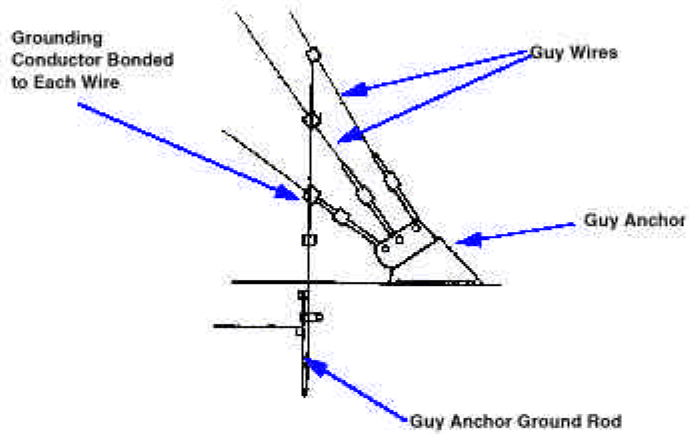


FIGURE 23-23 Tower Guy Wire Grounding

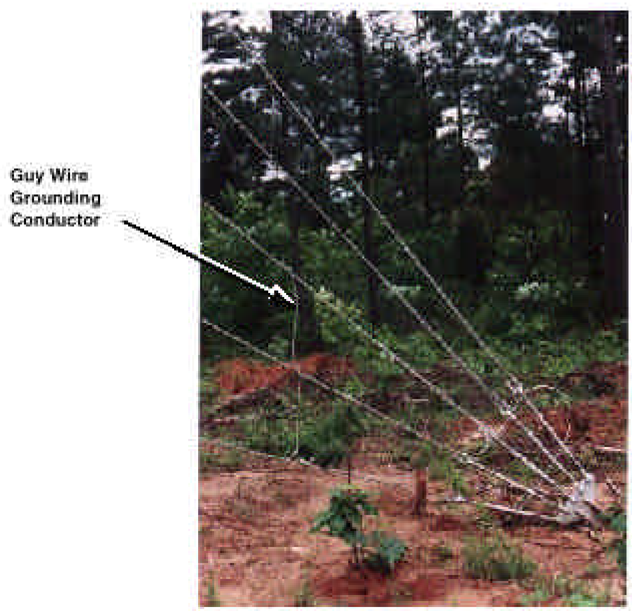


Figure 23-24 Example of Tower Guy Wire Grounding

23.4.5.2 MONOPOLE TOWERS
WARNING

No welding, heating, or drilling of tower structural members shall be performed without written approvals from the tower manufacturer.

Monopole towers shall be grounded as follows [see Figure 23-25 and Figure 23-26]

1.The tower shall be encircled by a ground ring containing at least four equally spaced ground rods. For a optimum ground rod spacing of 16ft. [4.88m] for 8 ft. [2.44m] ground rods, the tower ground ring should have a minimum diameter of 23ft. [7m]
2. The tower ground ring shall be installed in accordance with "External Ground Ring" on page 6-15.
3.Ground rods shall meet the specification and be installed in accordance with "Ground Rods" on page 23-6.
4.The tower shall be bonded to the tower ground ring using at least four equally spaced grounding conductors of # 2 AWG [35 2 csa] minimum, bare tinned solid copper conductor. For high lightning prone geographical areas, larger conductors and/or more conductors should be used.
5. The tower grounding conductors shall be exothermically bonded to the tower unless specifically directed otherwise by the tower manufacturer.
6. The tower grounding conductors shall be bonded to the tower ground ring using exothermic welding or high compression fittings co pressed to a minimum of 12 tons [13.3 tonnes] of pressure.

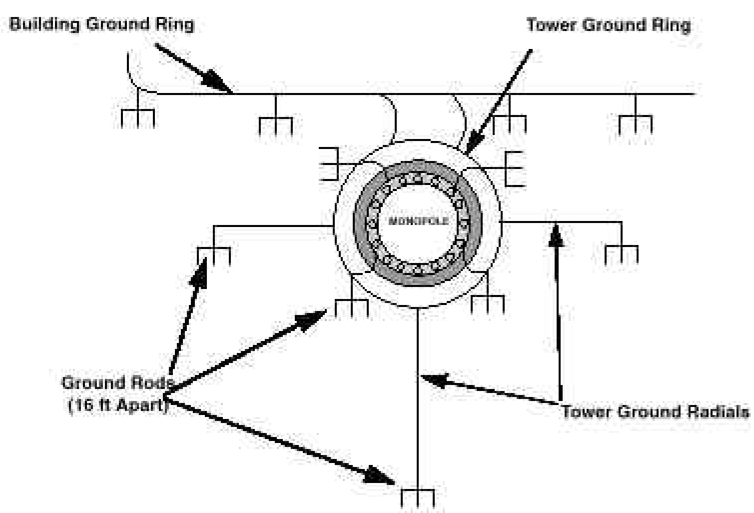


FIGURE 23-25 Monopole Tower Grounding

FIGURE 23-26 Example of Monopole Tower Ground Conductor

23.4.5.3 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 [See *ANSI T1.313-1997* for more information]. 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. Rooftop mounted tower structures shall be grounded in accordance with the following requirements

1. ANSI T1.313-1997
2. The lightning protection system shall meet the requirements of NFPA 780.
3. The rooftop mounted tower support legs shall be interconnected with a conductor to for a roof tower ground ring. A guyed tower base plate can be used in place of the roof tower ground ring.
4. The conductors shall meet the requirements of "Grounding Conductors" on page 23-13.
5. Bonding to the tower shall meet the requirements of the tower manufacturer and "Bonding Methods" on page 23-60.
6. The roof tower ground ring or guyed tower base plate shall bond to the main roof perimeter lightning protection ring by a minimum of two opposing conductors at or within 24 in. [61 c] of a grounding down conductor, or other main grounding conductor as defined by NFPA 780, such as effectively grounded structural steel.
7. The conductors shall meet the requirements of "Grounding Conductors" on page 23-13.
8. Bonding of the conductors shall meet the requirements of "Bonding Methods" on page 23-60.

1.All tower guy/anchors that are attached directly to the roof shall be bonded to the lightning protection system ring.
2. The bonding conductors shall meet the requirements of "Grounding Conductors" on page 23-13.
3. Bonding of the tower guy/anchors to the lightning protection system ring shall meet the requirements of "Bonding Methods" on page 23-60.
4. Other metallic objects on the roof shall be bonded to the roof perimeter lightning protection system ring as required by NFPA 780 and ANSI T1.313-1997.
5. All grounding electrodes at the building shall be bonded together to for a grounding electrode system. See *NFPA 70, Articles 250-90, 800-40, 810-21*, and *820-40*; and *NFPA 780, Section 3-14*.

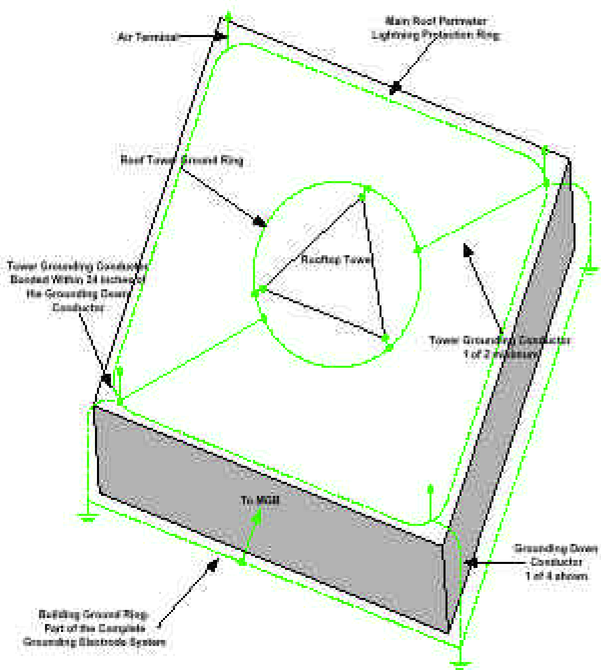


Figure 23-27 Typical Rooftop Tower Grounding Ring

23.4.6 RF TRANSMISSION LINES AND PREAMPLIFIERS

Tower mounted antenna preamplifiers shall be grounded to the tower using # 2 AGW [35 2 csa] 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 exothermic welding unless another method, such as mechanical clamps, is specified by the tower manufacturer. See Figures 23-29 through 23-32 for examples of transmission line grounding conductor attachment methods.
Transmission lines shall be grounded to prevent lightning from creating a difference of potential between the tower and the transmission lines. Such a potential difference could cause arcing between the tower and the coaxial transmission line cable, resulting in damage to the transmission lines. All transmission lines shall be grounded using ground kits as follows [See *ANSI T1.313-1997* for more information]

1. Transmission line ground kits shall be installed per manufacturer specifications.
2. Transmission line ground kits shall be sealed fro the weather to prevent water and corrosion damage to the transmission line.
3. Transmission line ground kits attached to the tower shall be attached to a tower manufacturer approved ground bus bar or other tower manufacturer approved locations on the tower structure. Cable ladders shall not be used as a grounding point for transmission lines unless effectively grounded using low impedance methods and specifically designed by the tower manufacturer as a transmission line grounding point.
4. Transmission line ground kits shall be attached to the tower using tower manufacturer approved methods, such as clamps or exothermic welding. See Figure 23-28 through Figure 23-33 for examples of methods used to attach to the tower.
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.
6. Transmission lines shall be grounded at the top of the vertical run, near the antenna.
7. Transmission lines shall be grounded at the bottom of the vertical run, no more than 6ft. [1.8m] above the horizontal transition to the building, shelter, equipment housing, or cabinet.
8. Additional transmission line ground kits shall be installed as needed to limit the distance between ground kits to 75 ft. [22.8m]. High lightning prone geographical areas should consider ground kits at intervals no more than 50 ft. [15.24m].
9. Transmission lines at the bottom of the vertical run shall be bonded to the tower ground bus bar, when provided. If no tower ground bus bar is provided, then the transmission line shall bond directly to the tower using methods described above.
10. Transmission lines shall be grounded to the external ground bus bar within 2 ft. [61 c] of the building, shelter, equipment housing, or cabinet entry [See *NFPA 70, Article 820-33*]

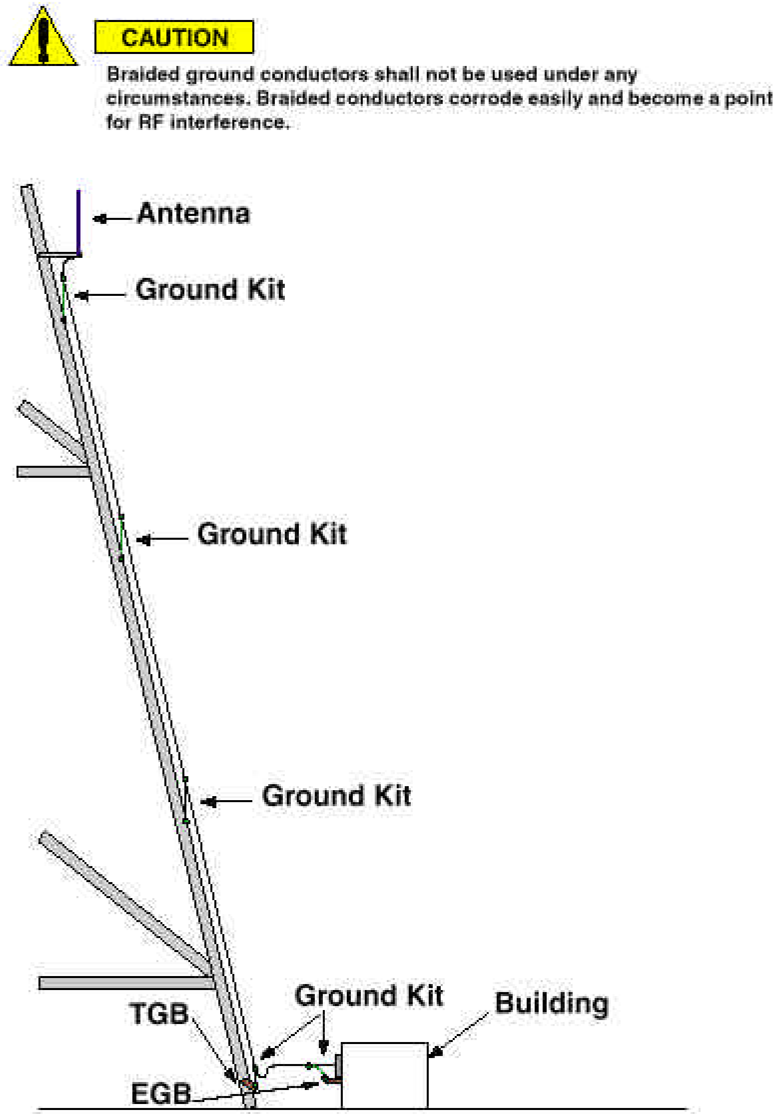


Figure 23-28 Location of Transmission Line Ground Kits

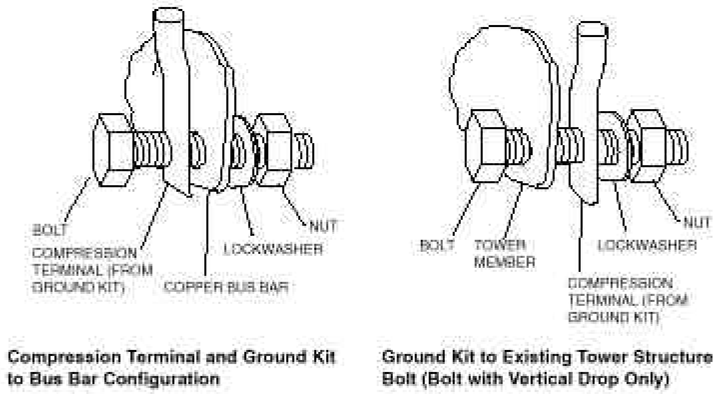


Figure 23-29 Tower Ground Kits

NOTE:
Except for Tower Member and Bus Bar, all materials shall be stainless steel or equivalent.

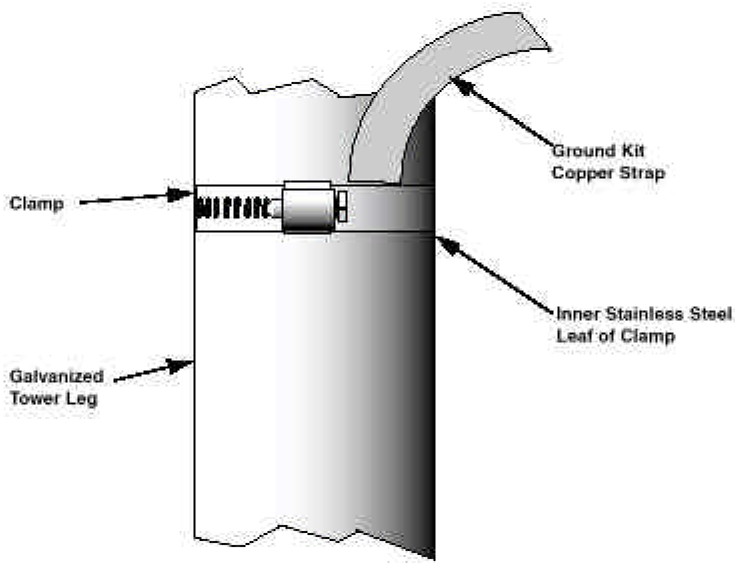


Figure 23-30 Grounding Transmission Line Top and Middle [Tubular Tower]

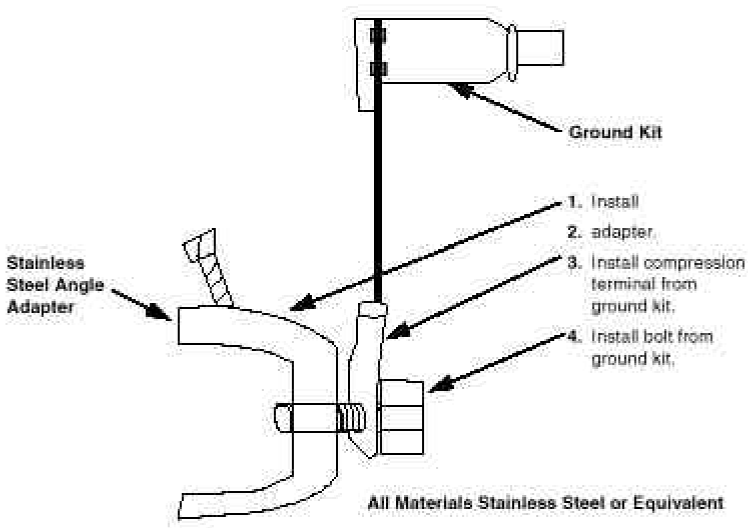


FIGURE 23-31 Ground Transmission Line Top and Middle [Angular Tower]

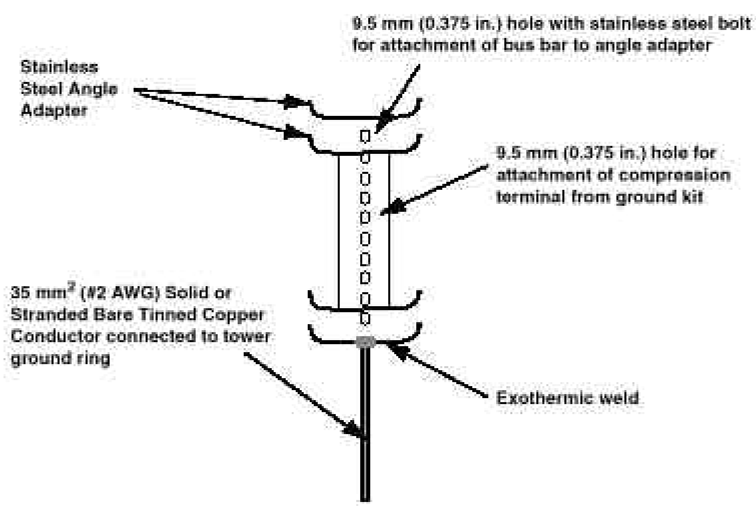


FIGURE 23-32 Bus Bar Configuration.. Bottom Ground Kit [Angular Tower]

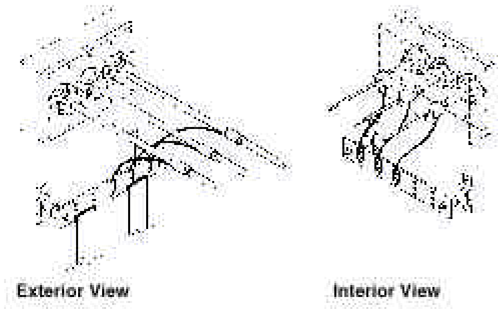


Figure 23-33 Transmission Line Grounding at Building Entry Point

23.4.7 METALLIC BUILDING SIDING

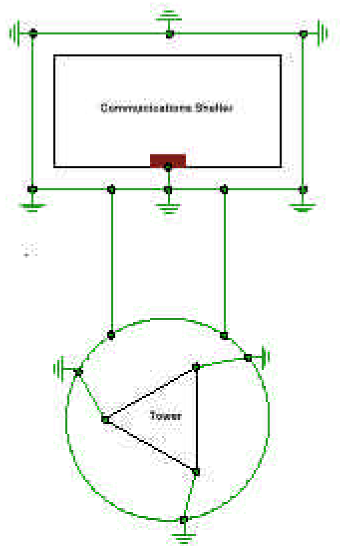
Metal siding through which electrical service or utility conductors penetrate [per NFPA 70, Article 250-116 FPN] and prefabricated shelter frames and anchors shall be bonded to the site grounding electrode system . When solid metal siding panels are insulated from one another [by weatherstripping], each panel shall be bonded to the external grounding electrode system.

23.4.8 DEDICATED COMMUNICATIONS SITE BUILDING

All dedicated communications site buildings shall have an external grounding electrode system installed. The grounding electrode system resistance shall meet the requirements of “Design Requirements for Grounding Electrode Systems” on page 23-3. [See *ANSI T1.313-1997* for more information.]

A typical site grounding electrode system layout is shown in Figure 23-34. The building grounding electrode system requirements are as follows and shall also include any additional grounding electrode system components needed to achieve the resistance requirements of the site [see “Minimum Site Grounding Requirements” on page 23-20]

1.The building shall be encircled by a ground ring installed in accordance with paragraph 23.3.2.4 on page 23-15.
2. The building ground ring shall have a ground rod, as specified in paragraph 23.3.1.1 on page 23-6, at each corner of the shelter and rods as necessary to reduce the distance between rods to a maximum 16 ft. [of 4.9m], or twice the rod’s length.
3.The ground rods shall be installed in accordance with paragraph 23.3.1.1 on page 23-6.
4.The ground rods shall be exothermically bonded to the ground ring or as otherwise allowed in “Bonding to the External Grounding Electrode System” on page 23-56.
5. The building ground ring shall be bonded to the tower ground ring using a minimum of two #2 AWG [35 2 csa] bare tinned copper conductors.
6.Tower shall be grounded in accordance with “Towers” on page 23-29.



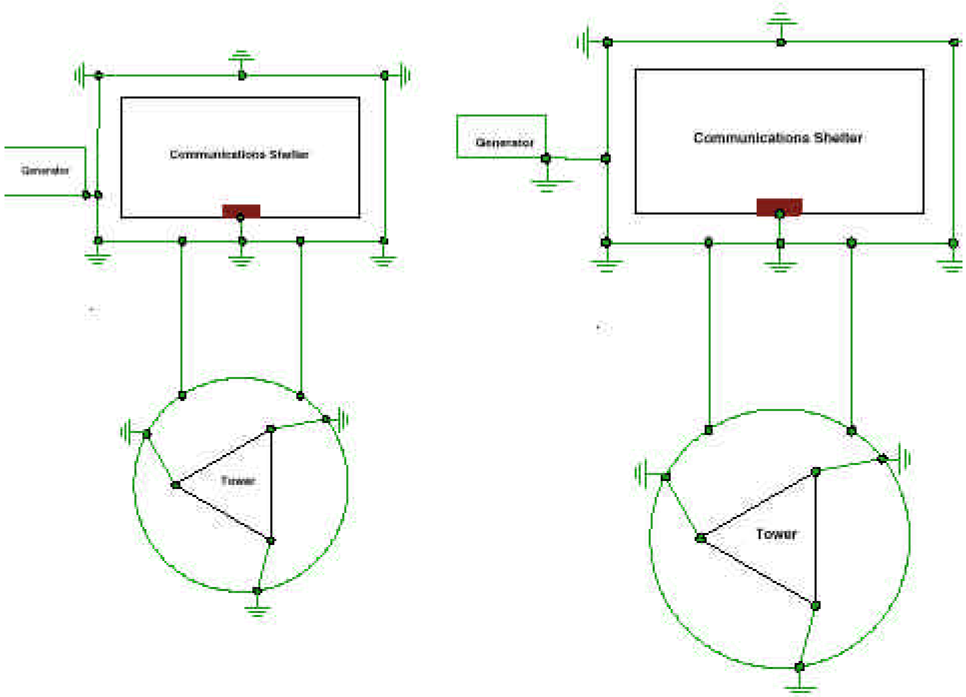
NOTE: Maintain rod separation of 16 ft. [4.88 m] when possible.

Figure 23-34 SITE GROUNDING ELECTRODE SYSTEM

23.4.8.1 GENERATORS EXTERNAL TO THE BUILDING

Generators installed outside of the building, within 6 ft. [1.8m]of the building, shall be bonded to the nearest practical location on the grounding electrode system as shown in Figure 23-35. External generator grounding shall co ply with the following

1. Bonding to the generator chassis shall be done in accordance with the manufacturer's requirements.
2. Grounding conductors shall meet the requirements of "Grounding Conductors" on page 23-13.
2. Bonding to the grounding electrode system shall be done in accordance with "Bonding to the External Grounding Electrode System " on page 23-56.
3. Generators installed more than 6 ft. [1.8m] away from the building, shelter, equipment housing, or cabinet grounding electrode system shall have an additional ground rod installed near the generator and bonded to the generator [ANSI T1.313-1997]. See Figure 23-35.
4. The additional ground rod shall meet the requirements of "Ground Rods" on page 23-6.
5. The additional ground rod shall be installed using methods described in "Ground Rods" on page 23-6.



Generator less than 1.8 m (6 ft.) from Building   Generator more than 1.8 m (6 ft.) from Building

Figure 23-35 Generator Grounding

23.4.9 Integrated Communications Sites

For communications sites located on the rooftop or within a building whose primary purpose is something other than a communications site, connection of the communications internal grounding system as described in Chapter 24, “Internal Grounding,” shall be made to the building grounding electrode system [See ANSI/ TIA/EIA-607]. Connection of the communications site master ground bus bar [MGB] to the building grounding electrode system shall be as made using the following techniques:

NOTE: Gas piping systems shall not be used as part of a grounding electrode system [per NFPA 70, Article 250-52]

NOTE: Before metal piping systems are relied upon for use in a grounding electrode system, electrical continuity shall be verified. [See *NFPA 70, Article 250- 8* for more details.]

1. For integrated communications sites with roof mounted antennas or antenna structures, the requirements of “Roof-Mounted Antenna Masts and Metal Support Structures” on page 6-27 shall be followed.
2. Grounding conductor shall be protected from physical damage [per NFPA 70, Article 810-21[d] and NFPA 780, Section 3-9.11].
3. Grounding conductor shall be run in as straight a line as is practical [per NFPA 70, Article 810-21[e] and ANSI T1.313-1997].
4. Grounding conductor shall be securely fastened at intervals not exceeding 3ft. [91 c] [See *NFPA 70, Articles 250- 4(b), 810-21(c)* and *NFPA 780, Section 3-10* for more information]
5. Minimum bend radius of grounding conductors shall be 8 in. [20.3 c], and the included angle shall not exceed 90 degrees as shown in Figure 23-9 per NFPA 780, Section 3-9.5 and ANSI T1.313-1997.
6. Grounding conductors shall be permitted to be run either outside or inside the building or structure [per NFPA 70, Article 810-21[g]].
7. Grounding conductors run outside from the roof top to ground shall be protected for a minimum distance of 6 ft. [1.8m] above grade level when located in areas susceptible to damage [per NFPA 780, Section 3-9.11].

* The integrated communications site shall be grounded using grounding conductors sized as follows:
1.Using#2 AWG [35 2 csa] or larger tinned copper conductor for conductor runs of 75 ft. [23m]or less. [See *NFPA 780, Section 3-1.1* for more information.] Untinned green jacketed 1 conductor or equivalent may also be used.
2. Using #2/0 AWG [67.43 2 csa] or larger tinned copper conductor for conductor runs more than 75 ft. [23m]. [See *NFPA 780, Section 3-1.1* for ore information.] Untinned green jacketed 1 conductor may also be used.

* The grounding conductor shall be connected to the nearest accessible location on at least one of the following and ore than one if practical and available [See *NFPA 70, Article 810-21[f]*, *NFPA 780, Sections 3-9* and *3-9.10* for more information]

* The building or structure grounding electrode system as covered in NFPA 70, Article 250-50, using down conductors from the integrated communications site directly to the building's grounding electrode system. Down conductors should not be used as the only means of grounding the integrated communications site, unless no other secondary means are available. Connection to the grounding electrode system may include items listed below. [See *NFPA 70, Article 810-21[f]* for more information.]

* Underground connection directly to the grounding electrode system, or directly to a supplemental grounding electrode system and bonding the grounding electrode system s together [See Figure 23-39]. Connection to the grounding electrode system shall comply with "Bonding to the External Grounding Electrode System " on page 23-56.

1.The metallic power service raceway.
2. The service equipment enclosure.
3. The electrical service grounding electrode conductor.
4. The power service accessible means external to enclosures as covered in NFPA 70, Article 250-92(b), using grounding conductors as described above.
5. Effectively grounded interior metal water piping system as covered in NFPA 70, Article 250-104[a], using grounding conductors as described above.
6. Effectively grounded metal structure, including exposed structural building steel, using grounding conductors as described above.
[See *NFPA 780, Section 3-1* for more information.]
Figure 23-37 and Figure 23-38 show grounding options for integrated sites, based on ANSI/TIA/EIA-607.

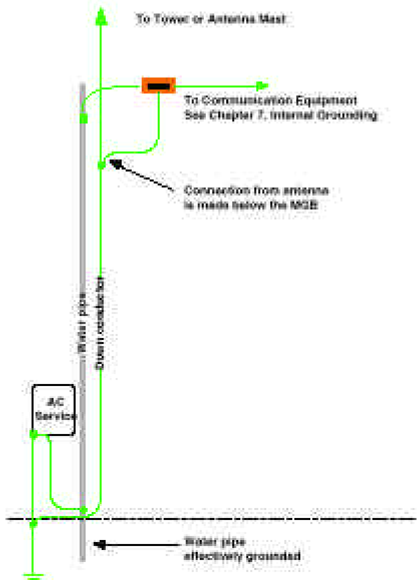


Figure 23-36 Site on Different Floor than AC Service Feed, Building Steel not Available

NOTES:
1. #2 AWG [35 mm 2 csa] conductor for runs of 75 ft. [22.9 m] or less
2. #2/0 AWG [67.43 mm 2 csa] conductor for runs longer than 75 ft. [22.9 m]

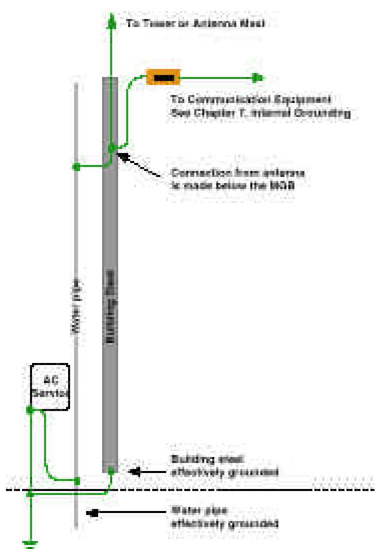


Figure 23-37 Site on Different Floor that AC Service Feed, Building Steel Available

NOTES:
1. #2 AWG [35 mm 2 csa] conductor for runs of 75 ft. [22.9 m]or less
2. #2/0 AWG [67.43 mm 2 csa] conductor for runs longer than 75 ft. [22.9 m]

#2 AWG [35 mm csa] conductor for runs of 75 ft. [22.9 m] or less

#2/0 AWG [100 mm csa] conductor for runs longer than 75 ft.[22.9m]

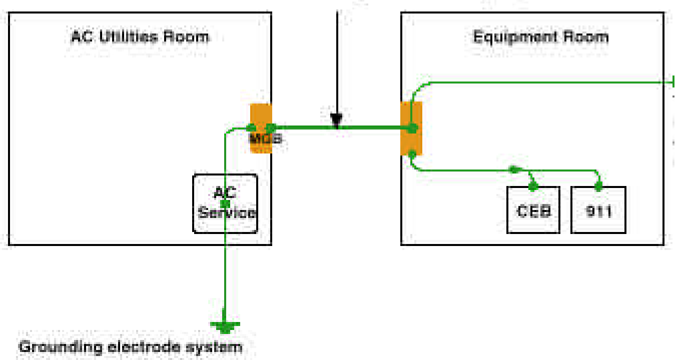


FIGURE 23-38 Site on Same Floor but Different Room than AC Service Feed

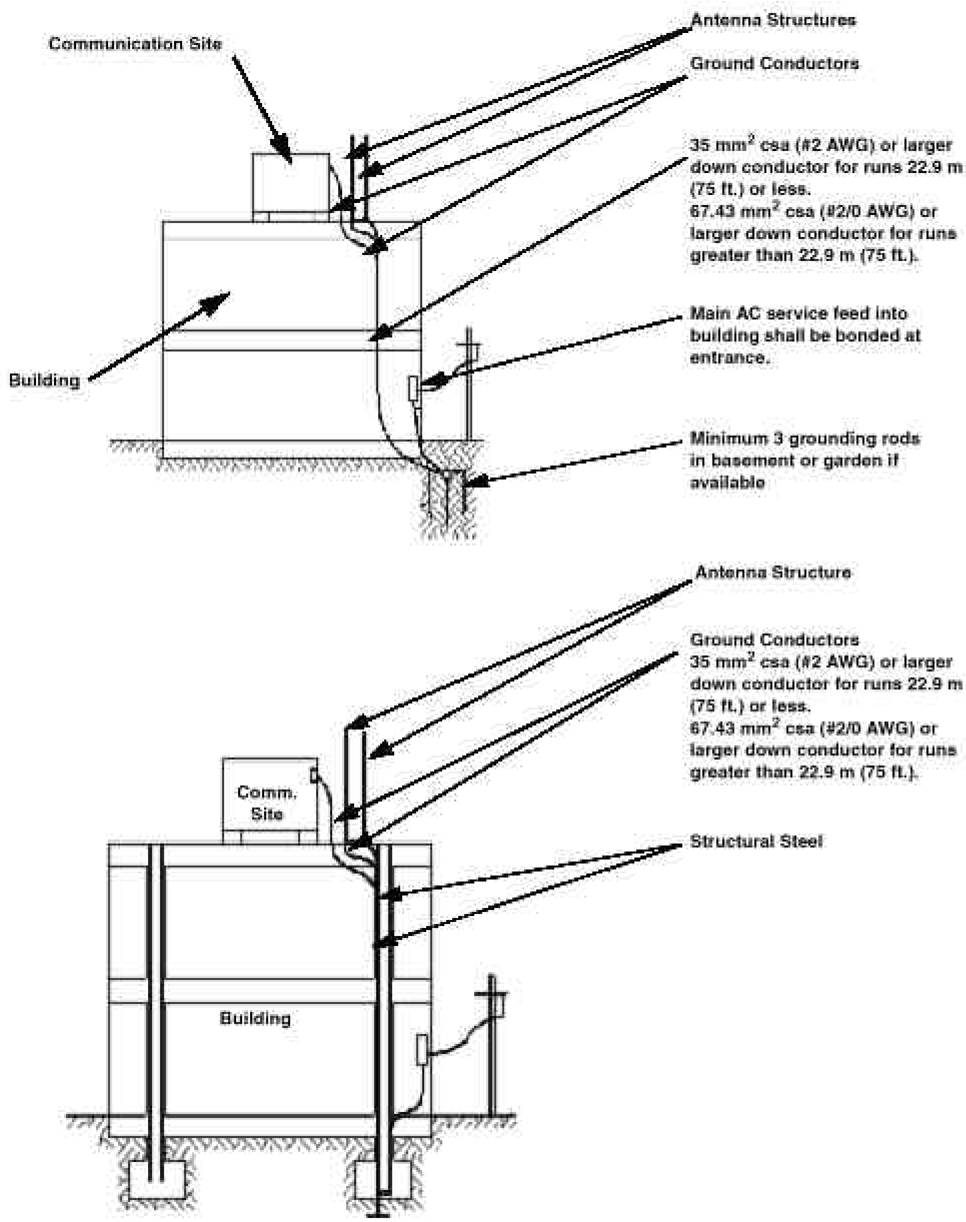


FIGURE 23-39 GROUNDING ROOFTOP INSTALLATIONS

6.4.10 CLASS A SITES

In sites defined as Class A, a single ground rod may be sufficient if it can achieve 25 ohms or less. Refer to “Soil Resistivity Measurements” on page 22-13 to determine the necessary requirements of a single ground rod achieving 25 ohms or less. If a single ground rod cannot achieve 25 ohms or less, alternate methods shall be used. Such methods may be small ground ring [see Figure 23-41], multiple ground rods installed in a straight line [see Figure 23-42]), electrolytic ground rods, other methods described in this chapter, or specific design by a engineering firm specializing in grounding electrode system design. See “Interpreting Test Results” on page 22-20 to calculate the resistance of a ground ring, ground grid, or parallel ground rods. Requirements for burying grounding electrode system components in soil with good resistivity are shown in Figure 23-40.

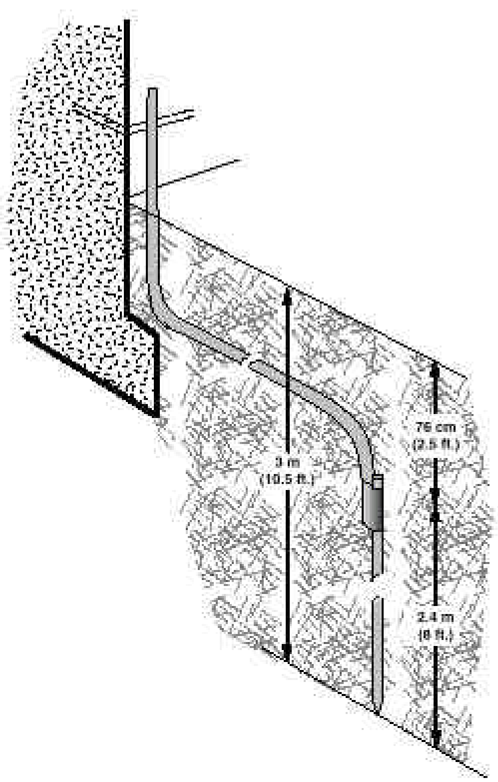


FIGURE 23-40 GROUNDING IN MOIST CLAY SOIL

23.4.11 Special Grounding Situations

Site conditions such as limited area and high (poor) soil resistivity can sometimes require additional enhancements to the external grounding system. So e techniques for enhancing the grounding system are described below.

23.4.11.1 Enhancing Tower Grounding Systems

For high lightning prone geographical areas and/or sites with high soil resistivity, additional tower grounding should be considered. Additional tower grounding should include ground radials, which are conductors installed horizontally into the ground away fro the tower and building. [See *ANSI T1.313-1997* for more information.]

1. The ground radials shall be bonded to the tower ground ring near each leg.
2. The ground radials shall be #2 AWG [35 2 csa] minimum bare tinned copper conductor.
3. The ground radials should be installed a minimum of 30 in.[76 c] below the surface of the earth when possible.
4. The ground radials should include a ground rod every 16 ft. [4.87m] [or twice the length or the ground rods] installed as described in "Ground Rods" on page 23-6.
5. Ground radials may be up to 48 ft. [14.6m] long or more if the property allows [more parallel radial extensions ay be ore effective than extending radial length].
6. Tower ground radials at a site should be of different lengths to prevent resonance during a lightning strike.
7. See Figure 23-1 on page 23-5 for an example of ground radials.

23.4.11.2 Roof-top and Integrated Communications Sites

Roof-top and integrated communications sites may require special techniques for achieving a suitable grounding electrode system when encircling the building would not be feasible, such as in a downtown metropolitan location. Some options may be:

1. Consulting an engineering fir specializing in grounding electrode system design.
2. Installing a s all ground ring in an available location. See Figure 23-41.
3. Installing multiple parallel rods in a straight line. See Figure 23-42.
4. Installing electrolytic ground rods.
5. Supplemental grounding electrode systems shall be bonded to the existing building grounding electrode system.

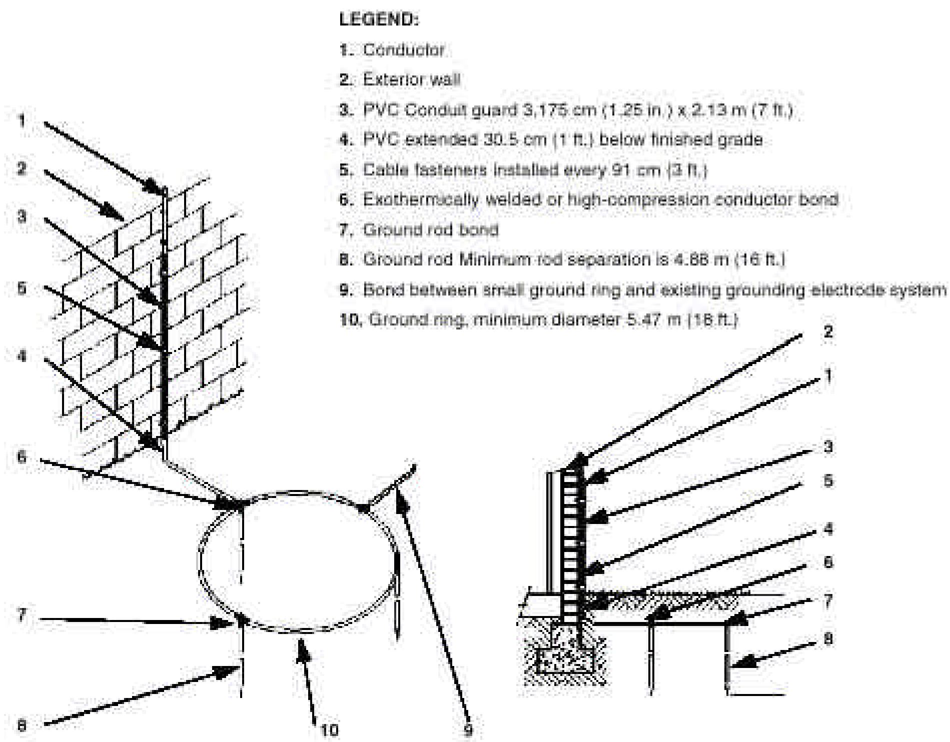


FIGURE 23-41 SMALL GROUND RING INSTALLATION

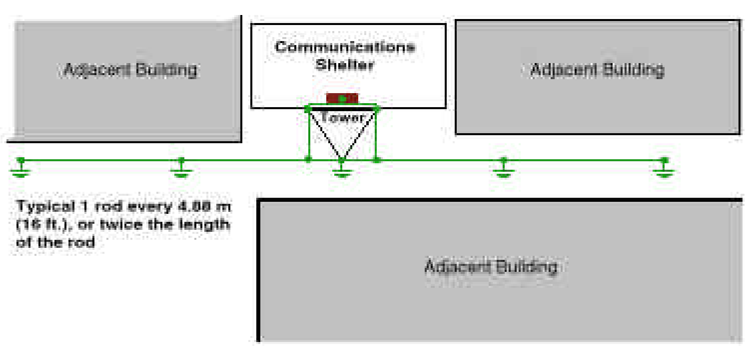


FIGURE 23-42 TYPICAL LINEAR GROUNDING ELECTRODE SYSTEM

23.4.11.3 METAL SHIPPING CONTAINERS USED AS COMMUNICATIONS BUILDINGS

Grounding electrode systems for metal shipping containers used as communications buildings shall conform to the standards specified in this chapter. All equipment inside the shipping container shall conform to the grounding requirements of Chapter 24, Internal Grounding.

The outside of the shipping container shall be bonded to the external grounding electrode system at all four corners as a minimum. Requirements for grounding a metal shipping container are as follows:

1. Grounding conductors shall meet the requirements of “Grounding Conductors” on page 23-13.
2. Connection to the grounding electrode system shall meet the requirements of “Bonding to the External Grounding Electrode System ” on page 23-56.
3. Connection to the metal shipping container shall be exothermically welded. See “Exother ic Welding” on page 23-60.

23.4.11.4 SITES WITH LIMITED SPACE FOR THE GROUNDING 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 electrode system. one solution for achieving the required impedance to ground 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. The grounding electrodes shall meet the specifications and installation requirements of “Grounding Electrodes” on page 23-6. Grounding conductors used to connect the grounding electrode shall meet the specifications of “Grounding Conductors” on page 23-13 and shall be buried at least 30 in. [76 c] deep or below the frost line, whichever is deeper.
Bonding of all components shall meet the requirements of paragraph 23.5. See Figure 23-42 for an example of a grounding electrode grid system for an available area of 30 ft x 30 ft. [9.14   x 9.14] with all ground rods separated by 10 ft. [3m]

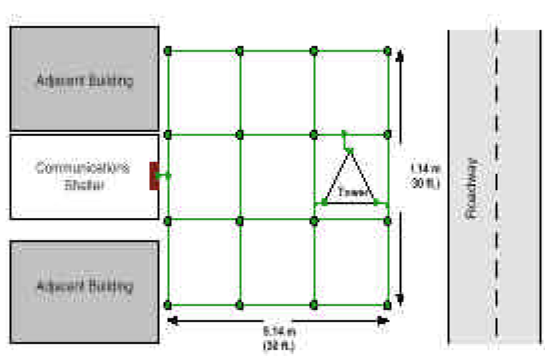


FIGURE 23-43 TYPICAL GROUNDING GRID

Refer to “Interpreting Test Results” on page 21-20 to determine if the desired resistance to ground can be achieved using different rod lengths or thickness and/or separation.

If the resistance to ground cannot be achieved using standard rods, electrolytic rods should be considered. Burying the grounding conductor in at least 6 in. [15.2 c] of ground enhancing material should also be considered (see "Ground Enhancing Materials" on page 23-13) as a method of improving the resistance to ground.

23.4.11.5 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 using multiple parallel rods and/or ground radials [See paragraph 23.4.11.1 and Figure 23-42]. Refer to "Interpreting Test Results" on page 21-20 to determine the number of rods and rod spacing required to achieve the resistance requirements of the site.

23.4.11.6 Grounding Electrode Systems Covered by Concrete or Asphalt

When installing a grounding 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 ground of the grounding electrode system. So e alternatives to covering the are with concrete and asphalt are listed below.

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

23.4.11.7 Stone Mountain Tops

So e sites are located on mountaintops because of their RF propagation characteristics. In the instances where there is no soil or very little soil at the site, special designs will be needed. Some options may be

1. Consulting an engineering firm specializing in grounding electrode system design.
2. Using down conductors to a lower area where there is usable soil. See Figure 23-44.
3.Installing the standard design system as required for a dedicated communications site [see paragraph 23.4.8 on page 23-40] with components buried as deep as the soil will allow and encasing all components with a ground enhancing material.
4. Installing ground plates instead of ground rods and encasing the plates with ground enhancing material.
5. Installing tower radial extensions and/or radial extensions from the building throughout the property. Install radials and rods as specified in this document or to a depth allowed by the soil.
6.Installing horizontal electrolytic rods.
7.Using concrete encased electrodes as part of the building construction wherever possible.
8. Installing copper strap radials 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. Each copper strap radial should be a different length to prevent ringing of the tower during a lightning strike.

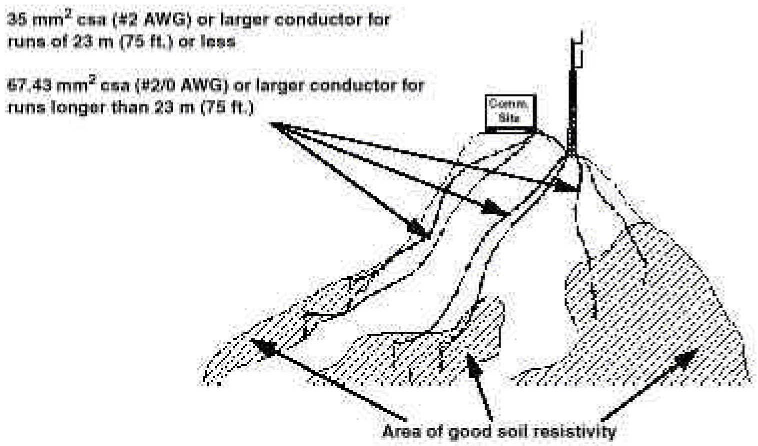


FIGURE 23-44 EXAMPLE OF SOILLESS GROUND SYSTEM

23.4.11.8 SAND, CORAL, OR LIMESTONE ENVIRONMENTS

Sites with very high soil resistivity, such as sites with sand, coral and limestone, require special grounding techniques. Some options are

1. Consulting an engineering firm specializing in grounding electrode system design.
2. Electrolytic ground rod systems.
3. Installing tower ground radials fro the building throughout the property. Install radials and rods as specified in this chapter and encase all components with a ground enhancing material.
4. Installing radials and rods throughout the site to for a grid system and using a ground enhancing material if needed. See “Sites With Limited Space for the Grounding Electrode System” on page 23-51.
5. Using concrete encased electrodes as part of the building construction wherever possible.
6. Using multiple large copper plates 10 to 20 sq ft.[9.29 to 18.6 2 m] buried to an optimal depth of 5 to 8 ft. [1.52   to 2.44] The plates are placed on edge and bonded to the grounding electrode system using exothermically welded #2AWG [35 2 csa] solid copper wire. Placing the plates on edge allows the plates to be buried with a minimum of excavation and may make it possible to obtain more surface area contact with ground-enhancing backfill material. Laying the plates flat does not significantly lower the resistance. 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, p. 183].

23.4.11.9 SHALLOW TOPSOIL ENVIRONMENTS

Some sites are located in areas where bedrock is near the surface or where the top soil is less than 1 ft [30.5 c] deep. These areas require installation of specialized grounding electrode systems and may require the support of a consulting or engineering firm specializing in grounding electrode system design.

Requirements and recommendations for grounding electrode systems in areas with shallow topsoil are provided below. [See *NFPA 780, Section 3-13* for more information.]

1.Encircle the building with a ground ring as described in "External Ground Ring" on page 23-15, burying the ground ring as allowed by the soil conditions. Bond a ground plate to the ground ring at each corner of the building, and install additional ground plates as required to keep the maximum distance between ground plates 16 ft.[4.9m]. The ground plates shall be buried no less than the depth of the ground ring and shall meet the requirements of "Ground Plates" on page 23-11. Bonding shall meet the requirements "Bonding to the External Grounding Electrode System " on page 23-56. See Figure 23-45.

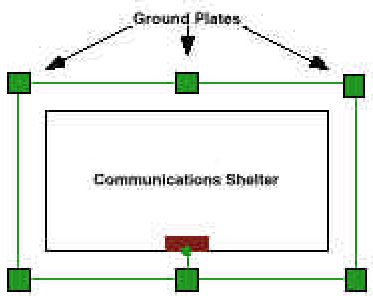


FIGURE 23-45 GROUNDING ELECTRODE SYSTEM WITH GROUND PLATES

* Encircle the building with a ground ring and ground plates as describe above. Install a ground radial conductor in a trench extending away from the building at each corner of the building and bond the ground radials to the ground ring in accordance with "Bonding to the External Grounding Electrode System" on page 23-56. Each ground radial may have ground plates installed every 16 ft. [4.9m] or less along its length. See Figure 23-46.

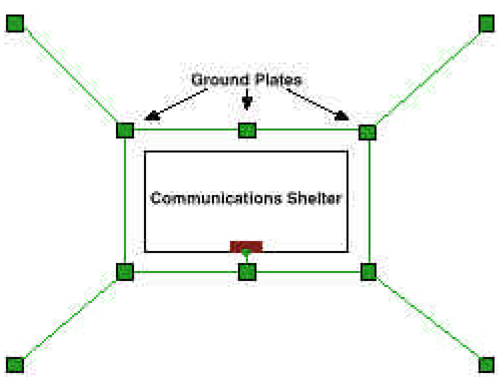


FIGURE 6-46 GROUNDING ELECTRODE SYSTEM WITH GROUND PLATES AND RADIALS

1. Additional ground radials extending away from the building may be used

as needed to meet the resistance requirements of the grounding electrode system.
2. In clay soils, trenches shall be at least 12 ft. [3.7m] long and from 1 to 2 ft deep [0.3 to 0.6 m]
3. In sandy or gravelly soil, trenches shall be at least 24 ft. [7.5m] long and from 2 ft. [0.6] deep.
4. In sandy, gravelly, or other soils of poor conductivity, ground enhancing materials should be used to improve the grounding electrode system resistance to ground. Ground enhancing material shall meet the requirements of "Ground Enhancing Materials" on page 23-13.
5. All soil and backfill materials shall be tamped around buried grounding conductors and grounding plates.
6. If the required grounding electrode system resistance cannot be achieved using the above recommendations, consider supplementing the system with horizontal electrolytic ground rods.
7. The tower can be grounded in the same manner.

23.5 BONDING TO THE EXTERNAL GROUNDING ELECTRODE SYSTEM

23.5.1 REQUIREMENTS

Single point grounding systems installed within equipment shelters, as described in Chapter 24, "Internal Grounding," and the ANSI/TIA/EIA-607 standard, shall be bonded to the external grounding electrode system. Any grounding electrode system installed as part of a communications equipment installation shall be bonded to the existing electrical service grounding electrode system. (See *NFPA 70, Articles 250-90 FPN, 800-40, 810-21*, and *820-40* for more information.)
All below-grade grounding connections shall be joined using exothermic welding or high-compression fittings co pressed to a minimum of 12 tons (13.3 tonnes) of pressure, or as otherwise required by the specific component manufacturer. 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 connections shall be joined using exothermic welding, listed 1 lugs, listed pressure connectors, listed clamps, or other listed means required by the specific component manufacturer. 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 an anti-oxidant co pound. (See *NFPA 70, Article 250-70* for more information.)
All exothermic and irreversible compression connections for use on external grounding applications shall be UL 467 listed, IEEE 837 approved. 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 ground connections:

1.Paint, enamel, lacquer and other nonconductive coatings shall be removed fro threads and surface areas where connections are made to ensure good electrical continuity
[per NFPA 70, Article 250-12]. Use of a star washer does not alleviate the requirement to remove nonconductive coatings from attachment surfaces.
2.After bonding to a painted or galvanized structure, the area shall be primed and painted.
3. Two-hole lugs secured with fasteners in both holes should be used to prevent movement of the lug.
4. Exothermic welding is the preferred method for bonding connections to the external grounding electrode system.
5. If exothermic welding is not used, irreversible compression fittings compressed with a compression tool with a minimum of 12 tons of pressure shall be used.
6. 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 23-47. Sheet metal screws and/or self-tapping screws shall not be used.

NOTE. Listed means that the item or device is listed by UL or an approved testing laboratory or complies with the definition as specified in NFPA 70, Article 100.

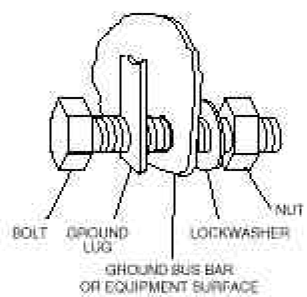


FIGURE 23-47 PROPER LOCATION OF WASHER WHEN CONNECTING GROUND LUG

6.5.2 DISSIMILAR METALS

The bonding of two dissimilar metals may result in Galvanic corrosion, a reaction that occurs at the junction of dissimilar metals when they are exposed to moisture. The degree and rate of corrosion depends on the relative position of the metals in the electrochemical series. The metals at the top of Table 23-3 corrode more easily than those at the bottom. To determine the likelihood of two metals reacting, determine the difference between their listed EMFs. If it is greater than 0.6 Volts, Galvanic corrosion resulting in an undesirable high-resistance connection will result if the two metals are bonded together. If the difference is 0.6 Volts or less, the metals may be safely bonded, but shall be coated with anti-oxidant compound or joined with an exothermic weld designed specifically for bonding the two different metals.
Some methods for preventing galvanic corrosion are listed below.
• Use the same metal throughout the system when possible.
• Exothermically weld connections of different metals when weld material is available for the metals being bonded. See “Exothermic Welding” on page 23-60.
• Copper conductors shall not be installed on aluminum roofing or siding.
• Aluminum and copper shall not be directly connected to each other unless using exothermic welding materials specifically intended for these two metals to make the connection.
Aluminum and copper may be joined with the use of a listed
bimetallic transition connector of stainless steel. These connectors shall be listed

for the size and number of conductors and marked with AL/CU. These connections shall be liberally coated with a conductive antioxidant at the point of insertion into the connector.

1. Copper shall not come in contact with galvanized steel.
2. Tinned copper shall be used when connecting to a galvanized steel structure.

TABLE 23-3 GALVANIC ACTION OF DISSIMILAR METALS

METAL	EMF (Volts)
Magnesium	+2.37
Magnesium Alloys	+0.95
Beryllium	+1.85
Aluminum	+1.66
Zinc	+0.76
Chromium	+0.74
Iron or Steel	+0.44
Cast Iron	Reliable Values N/A
Cadmium	+0.40
Nickel	+0.25
Tin	+0.14
Stainless Steel	Reliable Values N/A
Lead	+0.13
Brass	Reliable Values N/A
Copper	-0.34
Bronze	Reliable Values N/A
Copper-Nickel Alloys	-0.35
Monel	Reliable Values N/A
Silver Solder	-0.45
Silver	-0.80
Graphite	-0.50
Platinum	-1.20
Gold	-1.50
Lead	+0.13

23.5.3 BONDING METHODS

The following paragraphs describe acceptable methods for bonding to the external grounding electrode system. Exothermic welding and the use of high-compression fittings are the only acceptable methods for below-grade bonding. Split bolts and other mechanical connection methods shall not be used.

23.5.3.1 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
Follow manufacturer's warnings and safety 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:
1. Follow manufacturer's safety warnings and requirements.
2. Follow the manufacturer's recommendations.
3. Use the proper molds for the conductors being welded.
4. Use the proper weld material for the metals being welded.
5. Properly clean all metal parts prior to welding.
6. Properly dry all metal parts and molds prior to welding.

The exothermic welding process is shown in Figures 23-48 and 23-49.

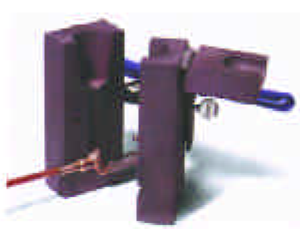


FIGURE 23-48 EXOTHERMIC WELDING MOLD (LEFT) AND PROCESS (RIGHT)

FIGURE 23-49 COMPLETED EXOTHERMIC WELDS IN TRENCH AND ON TOWER

6.5.3.2 HIGH COMPRESSION FITTINGS

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

When using 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 23-50 for examples of high-compression fittings.

1. Use fittings properly sized for the conductors being bonded.
2. Use fittings and compression tools rated at 12 tons of force.
3. Use only UL-listed tap connectors.
4. To ensure good contact, clean conductors using a wire brush before crimping.
5. Coat all crimped connections with antioxidant co pound before crimping.

FIGURE 23-50 HIGH-COMPRESSION CONNECTORS AND TYPICAL CRIMPING TOOLS