NFPA 780
Standard for the Installation of Lightning Protection Systems

1997 Edition

NFPA

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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NFPA 780

Standard for the Installation of

Lightning Protection Systems

1997 Edition

This edition of NFPA 780, *Standard for the Installation of Lightning Protection Systems,* was prepared by the Technical Committee on Lightning Protection and acted on by the National Fire Protection Association, Inc., at its Annual Meeting held May 19–22, 1997, in Los Angeles, CA. It was issued by the Standards Council on July 24, 1997, with an effective date of August 15, 1997, and supersedes all previous editions.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

This edition of NFPA 780 was approved as an American National Standard on August 15, 1997.

Origin and Development of NFPA 780

The National Fire Protection Association first adopted *Specifications for Protection of Buildings Against Lightning* in 1904. Revised standards were adopted in 1905, 1906, 1925, 1932, and 1937. In 1945, the NFPA Committee and the parallel ASA Committee on Protection Against Lightning were reorganized and combined under the sponsorship of the NFPA, the National Bureau of Standards, and the American Institute of Electrical Engineers (now the IEEE). In 1946, the NFPA acted to adopt Part III and in 1947 published a revised edition incorporating this part. Further revisions, recommended by the Committee, were adopted by the NFPA in 1949, 1950, 1951, 1952, 1957, 1959, 1963, 1965, 1968, 1975, 1977, 1980, 1983, 1986, 1989, and 1992.

Commencing with the 1992 edition of the *Lightning Protection Code,* the NFPA numerical designation of the document was changed from NFPA 78 to NFPA 780.

With the issuance of the 1995 edition, the name of the document was changed from *Lightning Protection Code* to *Standard for the Installation of Lightning Protection Systems.* This change was directed by the Standards Council in order to make the title more accurately reflect the document's content. In addition, the Council directed certain changes to the scope of the document in order to clarify that the document does not cover lightning protection installation requirements for early streamer emission systems or lightning dissipator array systems.

The 1997 edition of NFPA 780 incorporates editorial changes to make the document more user friendly.

In issuing this document, the Standards Council has noted that lightning is a stochastic, if not capricious, natural process. Its behavior is not yet completely understood. This standard is intended to provide requirements, within the limits of the current state of knowledge, for the installation of those lightning protection systems covered by the standard.

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Committee Scope: This Committee shall have primary responsibility for documents on the protection from lightning of buildings and structures, recreation and sports areas, and any other situations involving danger from lightning to people or property, except those concepts utilizing early streamer emission air terminals. The protection of electric generating, transmission, and distribution systems is not within the scope of this Committee.

This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in membership may have occurred. A key to classifications is found at the back of this document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Appendix A.

Information on referenced publications can be found in Appendix M.

Chapter 1 Introduction

1-1 Scope.

1-1.1 This document shall cover traditional lightning protection system installation requirements for the following:

(a) Ordinary structures

(b) Miscellaneous structures and special occupancies

(c) Heavy duty stacks

(d) Watercraft

(e) Structures containing flammable vapors, flammable gases, or liquids that can give off flammable vapors

1-1.2* This document shall not cover lightning protection system installation requirements for the following:

(a) Explosives manufacturing buildings and magazines

(b) Electric generating, transmission, and distribution systems

1-1.3 This document shall not cover lightning protection system installation requirements for early streamer emission systems or charge dissipation systems.

1-2 Purpose. The purpose of this standard is to provide for the practical safeguarding of persons and property from hazards arising from exposure to lightning.

1-3 Listed, Labeled, or Approved Components. Where fittings, devices, or other components required by this standard are available as Listed or Labeled, such components shall be used. Otherwise, such components shall be approved by the authority having jurisdiction.

1-4 Mechanical Execution of Work. Lightning protection systems shall be installed in a neat and workmanlike manner.

Chapter 2 Terms and Definitions

2-1 General Terminology. The following general terms commonly used in describing lightning protection methods and devices are defined or redefined to conform to recent trends.

Lightning Protection System. Refers to systems as described and detailed in this standard. A lightning protection system is a complete system of strike termination devices, conductors, ground terminals, interconnecting conductors, surge suppression devices, and other connectors or fittings required to complete the system. A traditional lightning protection system used for ordinary structures is described in Chapter 3. Mast and catenary type systems typically used for special occupancies and constructions are described in Chapter 6.

2-2 Definitions.

Air Terminal.* A strike termination device that is essentially a point receptor for attachment of flashes to the lightning protection system and is listed for the purpose. Typical air terminals are formed of a tube or solid rod. Air terminals are sometimes called lightning rods. *[See Figure A-2-2(a).]*

Approved.* Acceptable to the authority having jurisdiction.

Authority Having Jurisdiction.* The organization, office, or individual responsible for approving equipment, an installation, or a procedure.

Bonding.* An electrical connection between an electrically conductive object and a component of a lightning protection system that is intended to significantly reduce potential differences created by lightning currents. *[See Figure A-2-2(b).]*

Cable.* A conductor formed of a number of wires stranded together. *[See Figure A-2-2(c) and Tables 3-1.1*(a) *and 3-1.1(b).]*

Catenary Lightning Protection System. A lightning protection system consisting of one or more overhead ground wires meeting the requirements of Chapter 6. Each overhead ground wire forms a catenary between masts and serves the functions of both a strike termination device and a main conductor.

Chimney.* A smoke or vent stack having a flue with a cross-sectional area less than 500 in.^{2} (0.3 m^2) and a total height of 75 ft (23 m) or less. *[See Figure A-2-2(d).]*

Class I Flammable Liquid. A liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 psia (275 kPa) at 100°F (37.8°C) shall be known as a Class I liquid.

Class I liquids shall be subdivided as follows:

(a) Class IA shall include those having flash points below 73°F (22.8°C) and having a boiling point below 100°F (37.8°C).

(b) Class IB shall include those having flash points below 73°F (22.8°C) and having a boiling point at or above 100°F (37.8°C).

(c) Class IC shall include those having flash points at or above 73°F (22.8°C) and below 100°F (37.8°C).

Class I Materials.* Lightning conductors, air terminals, ground terminals, and associated fittings required by this standard for the protection of structures not exceeding 75 ft (23 m) in height. *[See Figure A-2-2(e) and Table 3-1.1(a).]*

Class II Materials.* Lightning conductors, air terminals, ground terminals, and associated fittings required by this standard for the protection of structures exceeding 75 ft (23 m) in height. *[See Figure A-2-2(e) and Table 3-1.1(b).]*

Combustible Liquid. A liquid having a flash point at or above 100°F (37.8°C).

Combustible liquids shall be subdivided as follows:

(a) Class II liquids shall include those having flash points at or above 100°F (37.8°C) and below 140°F (60°C).

(b) Class IIIA liquids shall include those having flash points at or above 140°F (60°C) and below 200°F (93°C).

(c) Class IIIB liquids shall include those having flash points at or above 200°F (93°C).

Conductor, Bonding. A conductor intended to be used for potential equalization between grounded metal bodies and the lightning protection system.

Conductor, Main. A conductor intended to be used to carry lightning currents between strike termination devices and ground terminals. For catenary systems, the overhead ground wire is both a strike termination device and a main conductor.

Copper-Clad Steel. Steel with a coating of copper bonded to it.

Explosive Materials. Materials, including explosives, blasting agents, and detonators, that are authorized for transportation by the Department of Transportation or the Department of Defense as explosive materials.

Fastener. An attachment device used to secure the conductor to the structure.

Flame Protection. Self-closing gauge hatches, vapor seals, pressure-vacuum breather valves, flame arresters, or other reasonably effective means to minimize the possibility of flame entering the vapor space of a tank.

Flammable Air-Vapor Mixtures. Flammable vapors mixed with air in proportions that will cause the mixture to burn rapidly when ignited. The combustion range for ordinary petroleum products, such as gasoline, is from about $1^1/_2$ to $7^1/_2$ percent of vapor by volume, the remainder being air.

Flammable Vapors. The vapors given off from a flammable or combustible liquid at or above its flash point.

Flash Point. The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitable mixture with air that is near the surface of the liquid within the vessel, as specified by appropriate test procedure and apparatus.

Gastight. Structures so constructed that gas or air cannot enter or leave the structure except through vents or piping provided for the purpose.

Ground Terminal.* The portion of a lightning protection system, such as a ground rod, ground plate, or ground conductor, that is installed for the purpose of providing electrical contact with the earth. *[See Figure A-2-2(f).]*

Grounded. Connected to earth or to some conducting body that is connected to earth.

High-Rise Building. For the purposes of this standard, a structure exceeding 75 ft (23 m) in height.

Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Listed.* Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets identified standards or has been tested and found suitable for a specified purpose.

Loop Conductor. A conductor encircling a structure that is used to interconnect ground terminals, main conductors, or other grounded bodies.

Metal-Clad Structure. A structure with sides or roof, or both, covered with metal.

Metal-Framed Structure. A structure with electrically continuous structural members of sufficient size to provide an electrical path equivalent to that of the lightning conductors covered in this standard.

Shall. Indicates a mandatory requirement.

Should. Indicates a recommendation or that which is advised but not required.

Sideflash.* An electrical spark caused by differences of potential that occurs between conductive metal bodies or between such metal bodies and a component of the lightning protection system or ground. *[See Figure A-2-2(g).]*

Spark Gap. As used in this standard, any short air space between two conductors that are electrically insulated from or remotely electrically connected to each other.

Stack, Heavy-Duty. A smoke or vent stack with the cross-sectional area of the flue greater than 500 in.^{2}(0.3 m^2) and the height greater than 75 ft (23 m).

Strike Termination Device. A component of a lightning protection system that is intended to intercept lightning flashes and connect them to a path to ground. Strike termination devices include air terminals, metal masts, permanent metal parts of structures as described in Section 3-9, and overhead ground wires installed in catenary lightning protection systems.

Striking Distance. The distance over which the final breakdown of the initial stroke occurs.

Surge Arrester. A protective device used for limiting surge voltages by discharging or bypassing surge current. A surge arrester can also prevent continued flow of follow current while remaining capable of discharging or bypassing surge current.

Vapor Openings. Openings through a tank shell or roof that are above the surface of the stored liquid. Such openings might be provided for tank breathing, tank gauging, fire fighting, or other operating purposes.

Watercraft. For the purpose of this document, all forms of boats and vessels up to 300 gross tons (272 metric tons) used for pleasure or commercial purposes, but excluding seaplanes, hovercraft, vessels with a cargo of flammable liquids, and submersible vessels.

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

2-3 Metric Units of Measurement. Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI). If a value for measurement as given in this standard is followed by an equivalent value in other units, the first stated shall be regarded as the requirement. A given equivalent value might be approximate.

Chapter 3 Protection for Ordinary Structures

3-1 General.

3-1.1 An ordinary structure shall be any structure that is used for ordinary purposes whether commercial, industrial, farm, institutional, or residential. Ordinary structures not exceeding 75 ft (23 m) in height shall be protected with Class I materials as shown in Table 3-1.1(a). Ordinary structures greater than 75 ft (23 m) in height shall be protected with Class II materials as shown in Table 3-1.1(b). If part of a structure is over 75 ft (23 m) in height (e.g., steeple) and the remaining portion does not exceed 75 ft (23 m) in height, the requirements for Class II air terminals and conductors shall apply only to that portion exceeding 75 ft (23 m) in height. Class II conductors from the higher portion shall be extended to ground and shall be interconnected with the balance of the system.

3-1.2 Roof Types and Pitch. For the purpose of this standard, roof types and pitches shall be as shown in Figures 3-1.2(a) and 3-1.2(b).

3-2 Materials. Protection systems shall be made of materials that are resistant to corrosion or acceptably protected against corrosion. Combinations of materials that form electrolytic couples of such a nature that in the presence of moisture corrosion is accelerated shall not be used. One or more of the following materials shall be used:

(a) *Copper.* Where copper is used, it shall be of the grade ordinarily required for commercial electrical work, generally designated as being of 95-percent conductivity when annealed.

(b) *Copper Alloys.* Where alloys of copper are used, they shall be as substantially resistant to corrosion as copper under similar conditions.

(c) *Aluminum.* Where aluminum is used, care shall be taken not to use it where contact could be made with the earth or anywhere it could rapidly deteriorate. Conductors shall be of electrical grade aluminum.

3-2.1 Copper lightning protection materials shall not be installed on aluminum roofing, siding, or other aluminum surfaces.

3-2.2 Aluminum lightning protection materials shall not be installed on copper surfaces.

3-3 Corrosion Protection. Precautions shall be taken to provide the necessary protection against any potential deterioration of any lightning protection component due to local conditions. Copper components installed within 24 in. (600 mm) of the top of a chimney or vent emitting corrosive gases shall be protected by a hot-dipped lead coating or equivalent.

Table 3-1.1(a) Minimum Class I Material Requirements

Type of Conductor		Copper Standard	Copper Metric	Aluminum Standard	Aluminum Metric
Air Terminal, Solid	Diameter	3/8 in.	9.5 mm	1/2 in.	12.7 mm
Air Terminal, Tubular	Diameter	5/8 in.	15.9 mm	5/8 in.	15.9 mm
	Wall Thickness	0.033 in.	0.8 mm	0.064 in.	1.6 mm
Main Conductor, Cable	Size ea. Strand	17 AWG		14 AWG	
	Wgt. per Length	187 lb/1000 ft	278 g/m	95 lb/1000 ft	141 g/m
	Cross Sect. Area	57,400 CM	29 mm^2	98,600 CM	50 mm^2
Main Conductor,	Thickness	0.051 in.	1.30 mm	0.064 in.	1.63 mm
Solid Strip	Width	1 in.	25.4 mm	1 in.	25.4 mm
Bonding Conductor, Cable	Size ea. Strand	17 AWG		14 AWG	
(solid or stranded)	Cross Sect. Area	26,240 CM		41,100 CM	
Bonding Conductor,	Thickness	0.051 in.	1.30 mm	0.064 in.	1.63 mm
Solid Strip	Width	1/2 in.	12.7 mm	1/2 in.	12.7 mm

Table 3-1.1(b) Minimum Class II Material Requirements

Type of Conductor		Copper Standard	Copper Metric	Aluminum Standard	Aluminum Metric
Air Terminal, Solid	Diameter	1/2 in.	12.7 mm	5/8 in.	15.9 mm
Main Conductor, Cable	Size ea. Strand	15 AWG		13 AWG	
	Wgt. per Length	375 lb/1000 ft	558 g/m	190 lb/1000 ft	283 g/m
	Cross Sect. Area	115,000 CM	58 mm^2	192,000 CM	97 mm^2
Bonding Conductor, Cable	Size ea. Strand	17 AWG		14 AWG	
(solid or stranded)	Cross Sect. Area	26,240 CM		41,100 CM	
Bonding Conductor,	Thickness	0.051 in.	1.30 mm	0.064 in.	1.63 mm
Solid Strip	Width	1/2 in.	12.7 mm	1/2 in.	12.7 mm

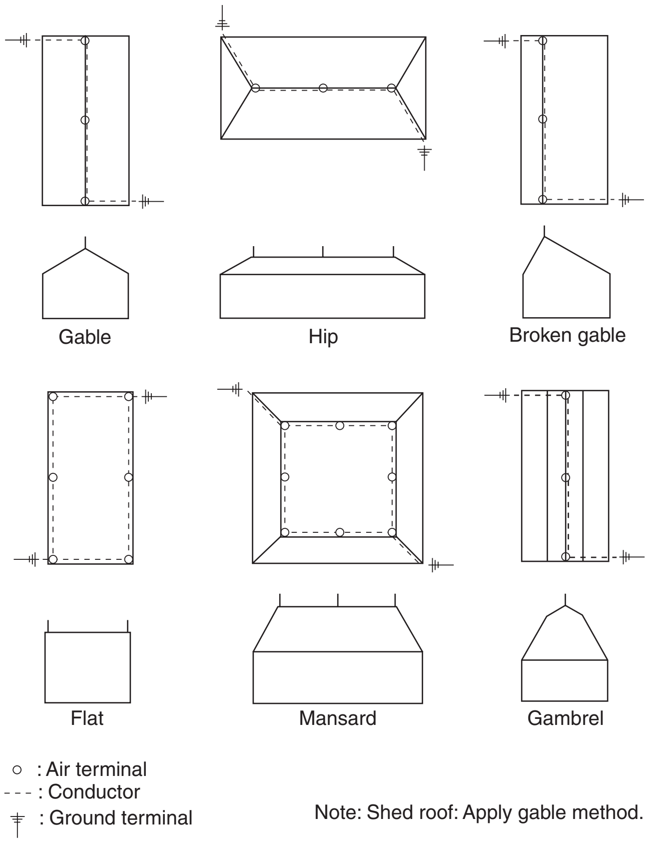


Figure 3-1.2(a) Roof types: protection methods (drawings are top and end views of each roof type).

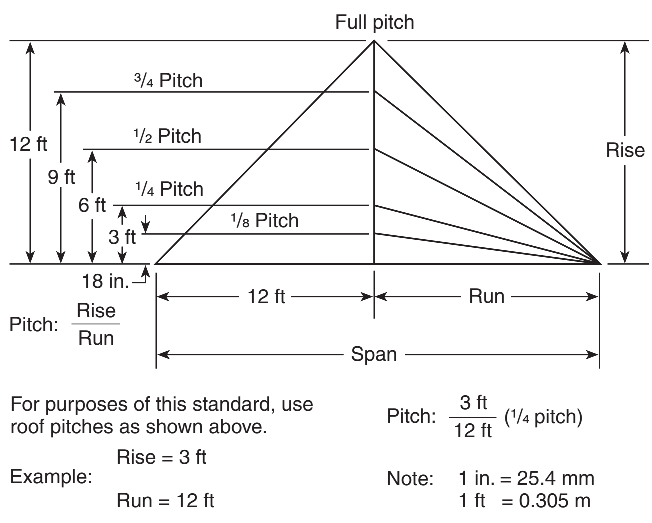


Figure 3-1.2(b) Roof pitch.

3-4 Mechanical Damage or Displacement. Any part of a lightning protection system that is subject to mechanical damage or displacement shall be protected with a protective molding or covering. If metal pipe or tubing is used around the conductor, the conductor shall be electrically connected to the pipe or tubing at both ends.

3-5 Use of Aluminum. Aluminum systems shall be installed in accordance with other applicable sections and with the following:

(a) Aluminum lightning protection equipment shall not be installed on copper roofing materials or other copper surfaces, or where exposed to the runoff from copper surfaces.

(b) Aluminum materials shall not be used where they come into direct contact with earth. Fittings used for the connection of aluminum-down conductors to copper or copper-clad grounding equipment shall be of the bimetallic type. Bimetallic connectors shall be installed not less than 18 in. (457 mm) above earth level.

(c) Connectors and fittings shall be suitable for use with the conductor and the surfaces on which they are installed. Bimetallic connectors and fittings shall be used for splicing or bonding dissimilar metals.

(d) An aluminum conductor shall not be attached to a surface coated with alkaline-base paint, embedded in concrete or masonry, or installed in a location subject to excessive moisture.

3-6 Strike Termination Devices. Strike termination devices shall be provided for all parts of a structure that are likely to be damaged by direct lightning flashes. Metal parts of a structure that are exposed to direct lightning flashes and that have a metal thickness of $^{3}/_{16}$ in. (4.8 mm) or greater shall only require connection to the lightning protection system. Such connections shall provide a minimum of two paths to ground. Strike termination devices shall not be required for those parts of a structure located within a zone of protection.

3-6.1 Air Terminal Height. The tip of an air terminal shall be not less than 10 in. (254 mm) above the object or area it is to protect. (*See Figure 3-6.1.*)

3-6.2 Air Terminal Support. Air terminals shall be secured against overturning by attachment to the object to be protected or by means of braces that shall be permanently and rigidly attached to the building. An air terminal exceeding 24 in. (600 mm) in height shall be supported at a point not less than one-half its height.

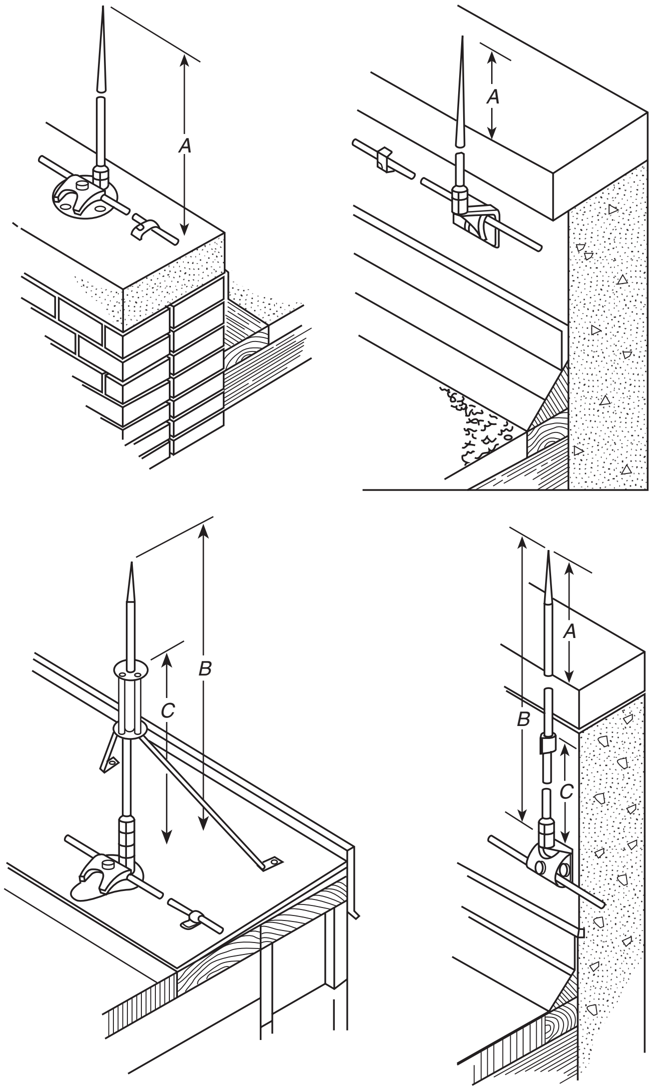
3-6.3 Ornaments. An ornament or decoration on a freestanding, unbraced air terminal shall not present, in any plane, a wind-resistance area in excess of 20 in.^{2} (0.01 m^2). This shall permit the use of an ornamental ball 5 in. (127 mm) in diameter.

3-7 Zones of Protection. To determine the zone of protection, the geometry of the structure shall be considered. (*See 3-7.1 through 3-7.3.*)

3-7.1 For flat or gently sloping roofs, dormers, domed roofs, and roofs with ridges, wells, chimneys, or vents, the zone of protection shall include the roof and appurtenances where protected in accordance with Section 3-8.

3-7.2 For structures with multiple-level roofs no more than 50 ft (15 m) in height, the zone of protection shall include areas as identified in 3-7.2.1 and 3-7.2.2. The zone of protection shall form a cone having an apex at the highest point of the strike termination device, with walls forming approximately a 45-degree or 63-degree angle from the vertical.

3-7.2.1 Structures that do not exceed 25 ft (7.6 m) above earth are considered to protect lower portions of a structure located in a one-to-two zone of protection as shown in Figures 3-7.2.1(a) and 3-7.2.1(b).



A: 10 in. (254 mm). See 3-6.1.
24 in. (600 mm). See 3-6.2.
B: Air terminals over 24 in. (600 mm) high shall be supported.
C: Air terminal supports shall be located at a point not less than one-half the height of the air terminal.

Figure 3-6.1 Air terminal height.

3-7.2.2 Structures that do not exceed 50 ft (15.24 m) above earth are considered to protect lower portions of a structure located within a one-to-one zone of protection as shown in Figures 3-7.2.2(a) and 3-7.2.2(b).

3-7.3 Rolling Sphere Model.

3-7.3.1 The zone of protection shall include the space not intruded by a rolling sphere having a radius of 150 ft (46 m). When the sphere is tangent to earth and resting against a strike termination device, all space in the vertical plane between the two points of contact and under the sphere are in the zone of protection. A zone of protection is also formed when such a sphere is resting on two or more strike termination devices and shall include the space in the vertical plane under the sphere and between those devices, as shown in Figure 3-7.3.1. All possible placements of the sphere must be considered when determining the zone of protection using the rolling sphere model.

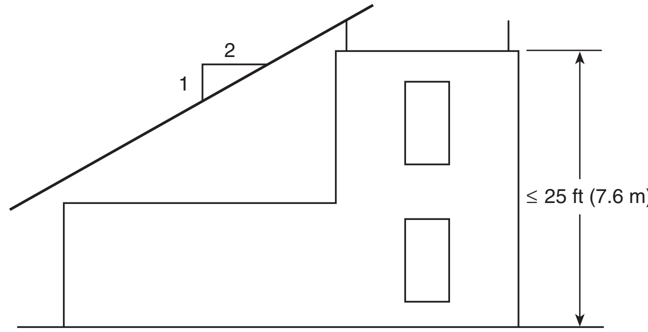


Figure 3-7.2.1(a) Lower roof protection for flat roof buildings 25 ft (7.6 m) or less in height.

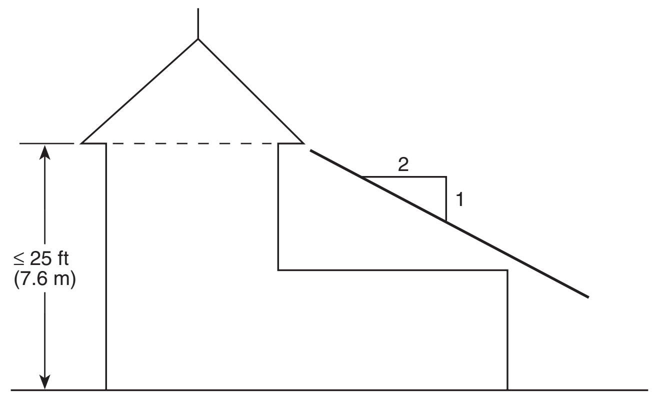


Figure 3-7.2.1(b) Lower roof protection provided by pitched roof buildings 25 ft (7.6 m) or less in height.

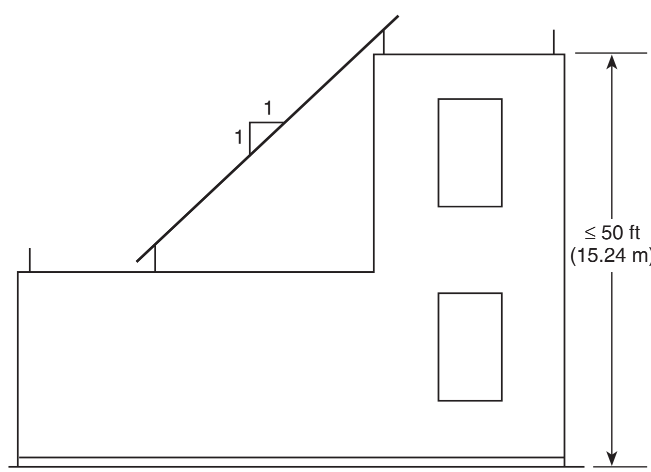


Figure 3-7.2.2(a) Lower roof protection for buildings 50 ft (15.24 m) or less in height.

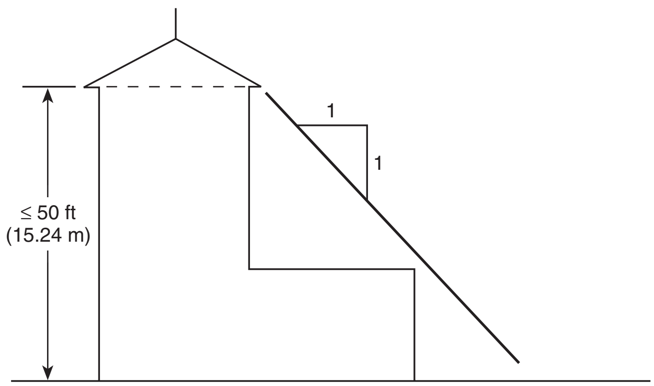


Figure 3-7.2.2(b) Lower roof protection provided by pitched roof buildings 50 ft (15.24 m) or less in height.

3-7.3.2 For structure heights exceeding 150 ft (46 m) above earth or above a lower strike termination device, the zone of protection is considered to be the space in the vertical plane between the points of contact and under the sphere when the sphere is resting against a vertical surface of the structure and the lower strike termination device or earth. The zone of protection shall be limited to the space above the horizontal plane of the lowest terminal unless it can be extended by further analysis, such as in rolling the sphere to be tangent to earth.

3-7.3.3 Figure 3-7.3.3 provides a graphic representation of the 150-ft (46-m) geometric model for structures of selected heights up to 150 ft (46 m), as shown in Figure 3-7.3.3. Based on the height of the strike termination device for a protected structure being 25 ft (7.6 m), 50 ft (15 m), 75 ft (23 m), 100 ft (30 m), or 150 ft (46 m) aboveground, reference to the appropriate curve shows the anticipated zone of protection for objects and roofs at lower elevations. The graph shows the protected distance ("horizontal distance") as measured radially from the protected structure. The horizontal distance thus determined shall apply only at the horizontal plane of the "height protected."

3-7.3.4 Under the rolling sphere model, the horizontal protected distance found geometrically by Figure 3-7.3.3 ("horizontal distance, ft") also shall be permitted to be calculated using the following formula:

$$d = \sqrt{h_1(300 - h_1)} - \sqrt{h_2(300 - h_2)}$$

where:
d = horizontal distance (ft)
h_1 = height of the higher roof (ft)
h_2 = height of the lower roof (top of the object) (ft)

Use of this formula is based on a 150-ft (46-m) striking distance.

For the formula to be valid, the sphere must be tangent to either the lower roof or in contact with the earth, and in contact with the vertical side of the higher portion of the structure. In addition, the difference in heights between the upper and lower roofs or earth must be 150 ft (46 m) or less.

3-8 Strike Termination Devices on Roofs. Pitched roofs shall be defined as roofs having a span of 40 ft (12 m) or less and a pitch $^1/_8$ or greater; and roofs having a span of more than 40 ft (12 m) and a pitch $^1/_4$ or greater. All other roofs shall be considered flat or gently sloping. (*See Figure 3-8.*)

3-8.1 Strike termination devices shall be placed at or within 2 ft (0.6 m) of ridge ends on pitched roofs or at edges and outside corners of flat or gently sloping roofs. Strike termination devices shall be placed on ridges of pitched roofs and around the perimeter of flat or gently sloping roofs at intervals not exceeding 20 ft (6 m). Strike termination devices 24 in. (600 mm) or more above the object or area to be protected shall be permitted to be placed at intervals not exceeding 25 ft (7.6 m). *[See Figures 3-8, 3-8.1.2(a), and 3-8.1.2(b).]*

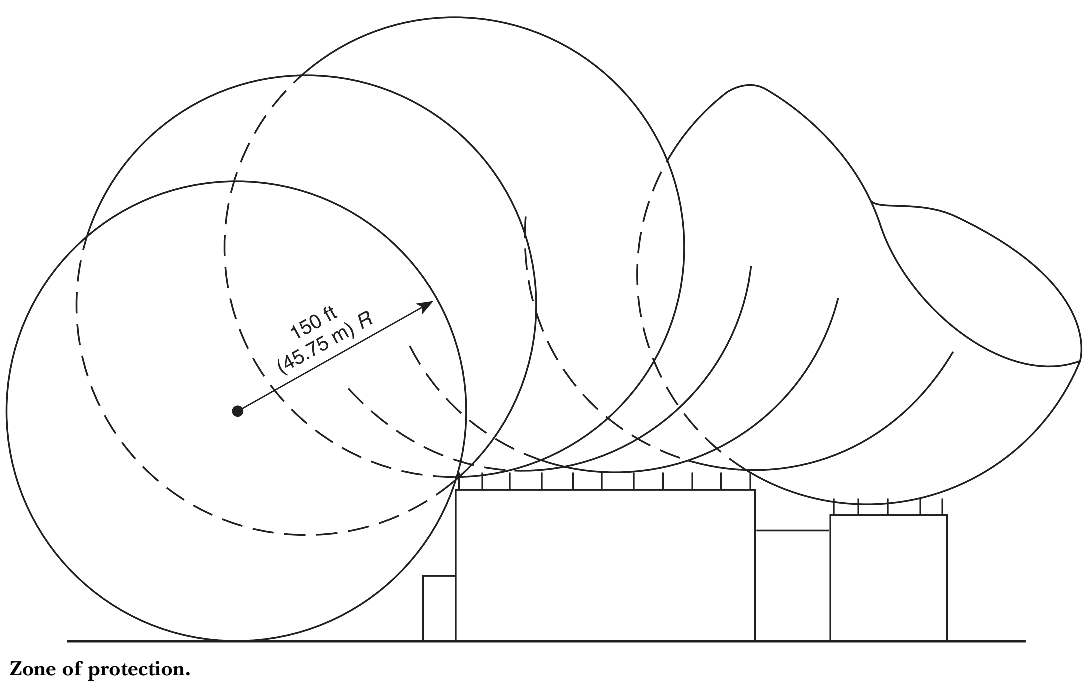
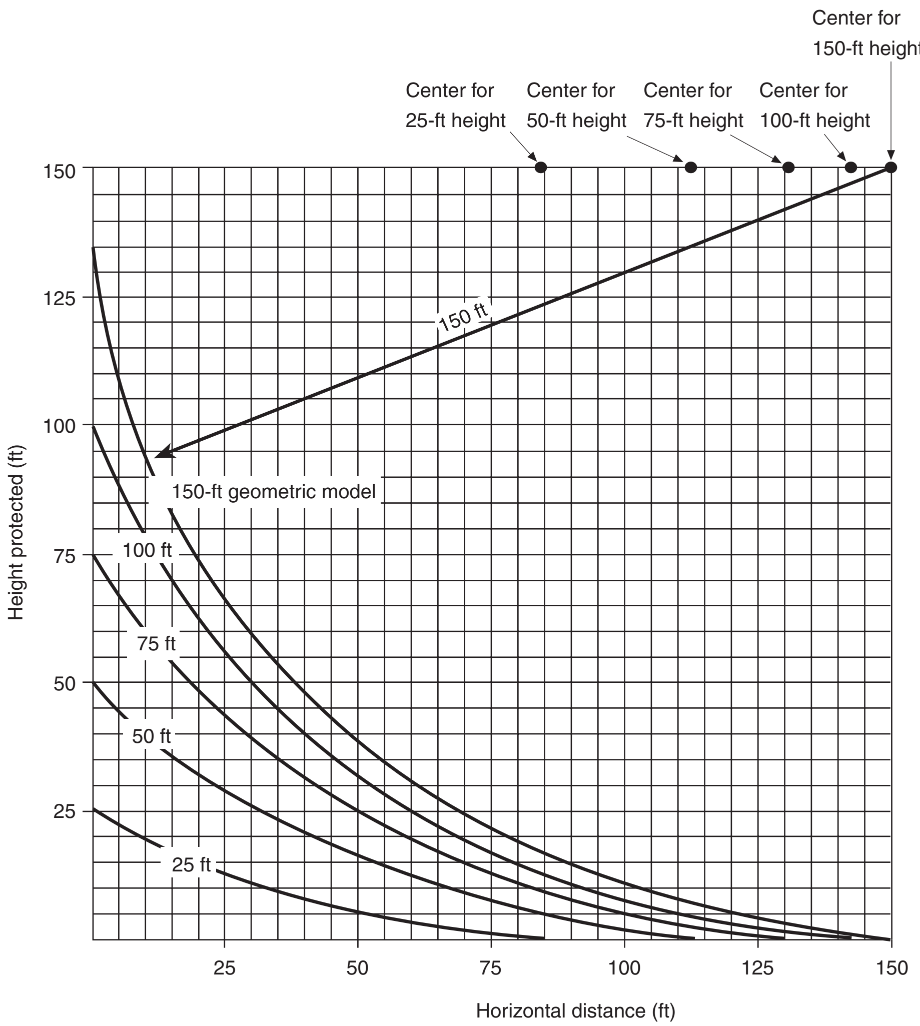


Figure 3-7.3.1 Zone of protection.



Note: 1 ft = 0.305 m

Figure 3-7.3.3 Zone of protection.

3-8.1.1 Pitched Roof Area. A pitched roof with eaves height of 50 ft (15 m) or less above grade shall require protection for the ridge only when there is no horizontal portion of the building that extends beyond the eaves, other than a gutter. Pitched roofs with eaves height over 50 ft (15 m) shall have strike termination devices located according to the 150-ft (46-m) geometric model. (*See Figures 3-7.3.1 and 3-7.3.3.*)

3-8.1.2 Flat or Gently Sloping Roof Area. Flat or gently sloping roofs that exceed 50 ft (15 m) in width or length shall have additional strike termination devices located at intervals not to exceed 50 ft (15 m) on the flat or gently sloping areas. *[See Figures 3-8.1.2(a) and 3-8.1.2(b).]*

3-8.2* Dormers. Dormers as high or higher than the main roof shall be protected with strike termination devices, conductors, and grounds as required. Dormers and projections below the main ridge shall require protection only on those areas extending outside a zone of protection.

3-8.3 Roofs with Intermediate Ridges. Strike termination devices shall be located along the outermost ridges of buildings that have a series of intermediate ridges at the same intervals as required by Section 3-8. Strike termination devices shall be located on the intermediate ridges in accordance with the requirements for the spacing of strike termination devices on flat or gently sloping roofs. If any intermediate ridge is higher than the outermost ridges, it shall be treated as a main ridge and protected according to Section 3-8.

3-8.4 Flat or Gently Sloping Roofs with Irregular Perimeters. Structures that have exterior wall designs that result in irregular roof perimeters shall be treated on an individual basis. In many cases, the outermost projections form an "imaginary" roof edge that is used to locate the strike termination devices in accordance with Section 3-8. In all cases, however, strike termination devices shall be located in accordance with Section 3-8 through 3-8.7. [*See Figure 3-8.4(a).*]

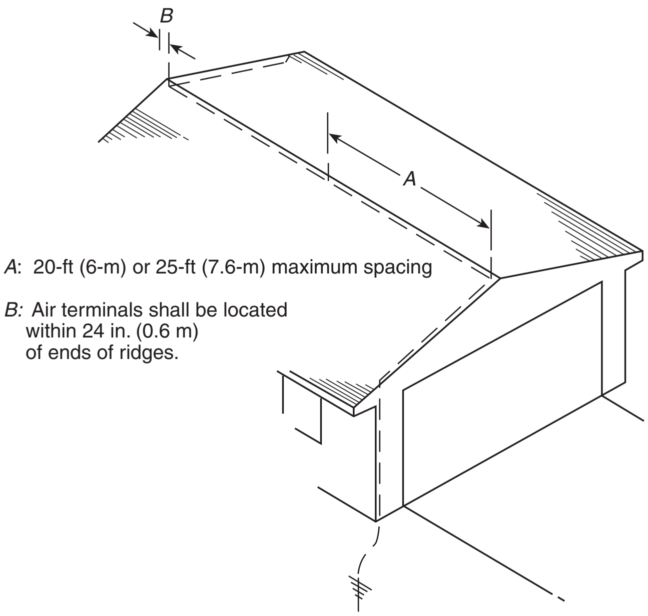


Figure 3-8 Air terminals on pitched roof.

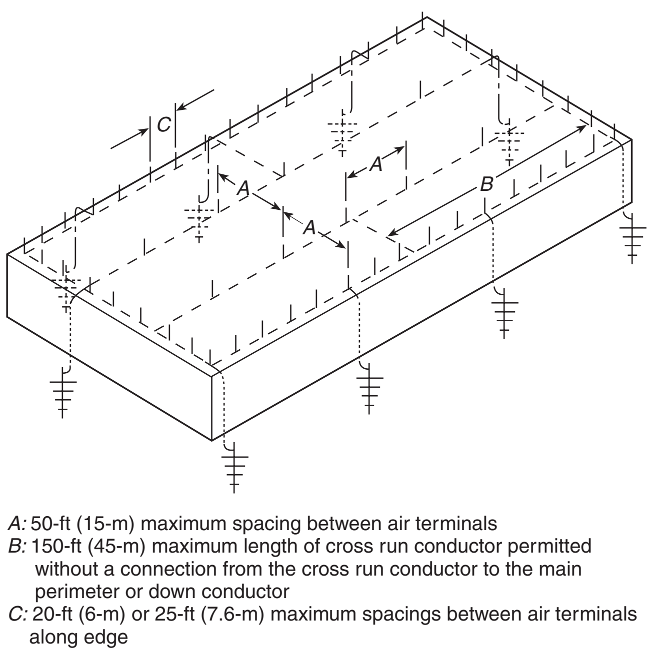


Figure 3-8.1.2(a) Air terminals on flat roof.

Strike termination devices installed on vertical roof members shall be permitted to use a single main sized cable to connect to a main roof conductor. The main roof conductor shall be run adjacent to the vertical roof members so that the single cable from the strike termination device is as short as possible and in no case longer than 16 ft (4.9 m). The connection of the single cable to the down conductor shall be made with a tee splice. [*See Figure 3-8.4(b).*]

3-8.5 Open Areas in Flat Roofs. The perimeter of open areas, such as light or mechanical wells, shall be protected if the open area perimeter exceeds 300 ft (92 m), provided both rectangular dimensions exceed 50 ft (15 m).

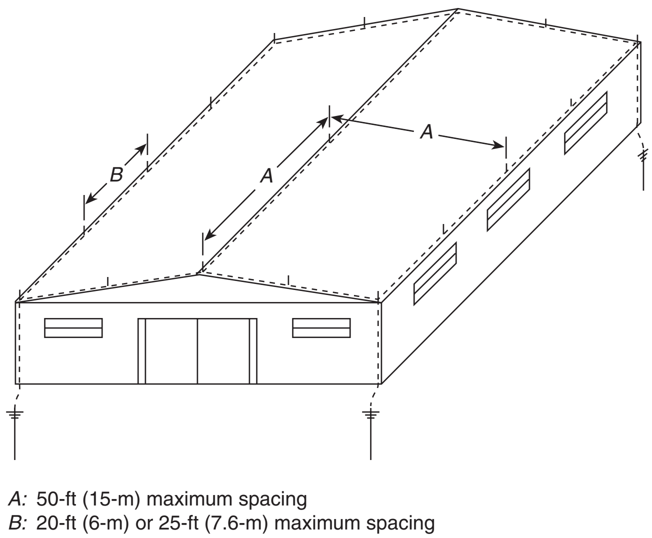


Figure 3-8.1.2(b) Air terminals on gently sloping roof.

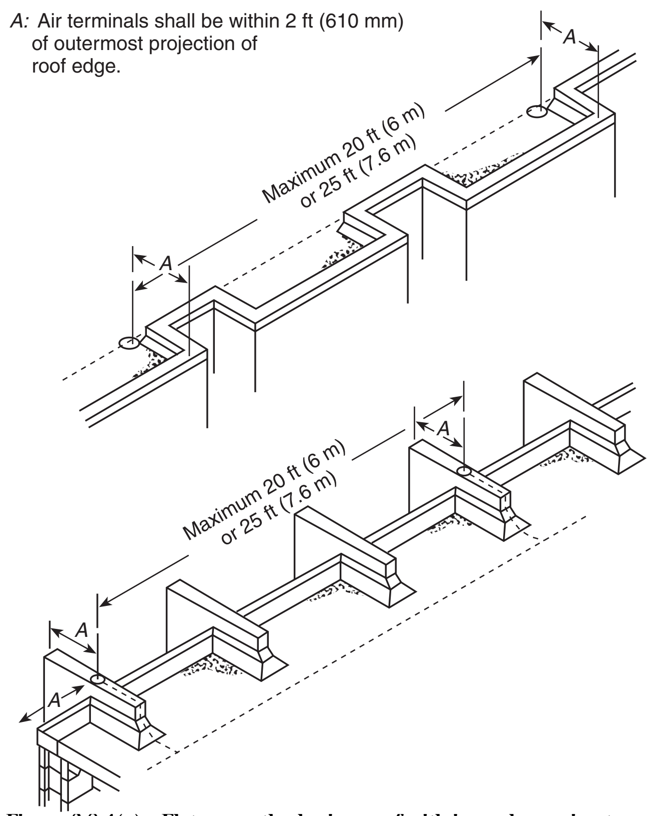


Figure 3-8.4(a) Flat or gently sloping roof with irregular perimeter.

3-8.6 Domed or Rounded Roofs. Strike termination devices shall be located as required so that no portion of the structure is located outside a zone of protection, based on a striking distance of 150 ft (45 m), as set forth in Section 3-8.

3-8.7 Chimneys and Vents. Strike termination devices shall be required on all chimneys and vents that are not located within a zone of protection, including metal chimneys having a metal thickness of less than $^3/_{16}$ in. (4.8 mm). Chimneys or vents with a metal thickness of $^3/_{16}$ in. (4.8 mm) or more shall require only a connection to the lightning protection system.

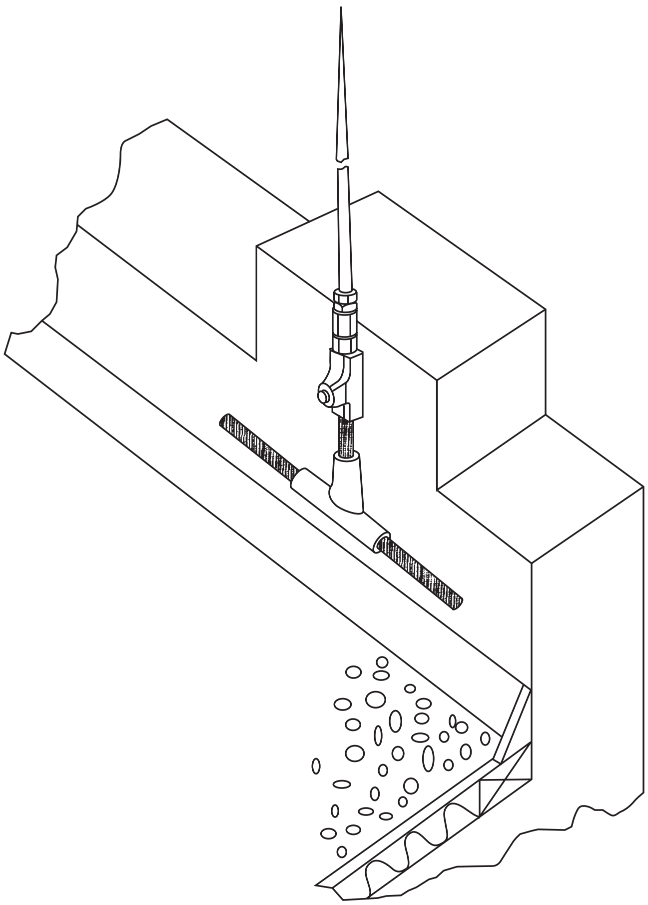


Figure 3-8.4(b) Irregular roof perimeter.

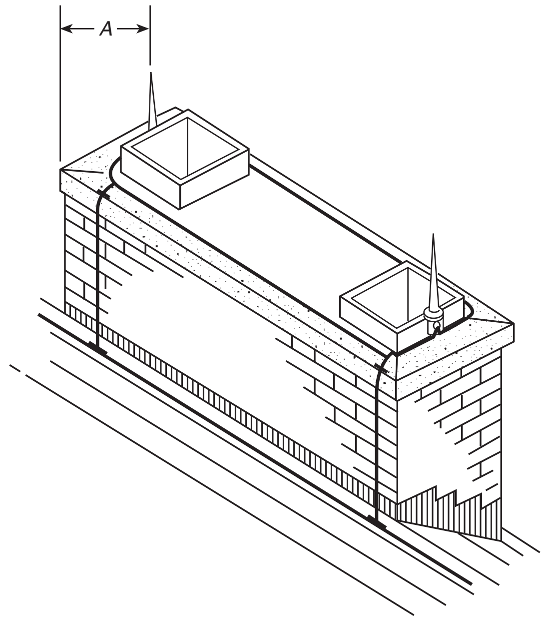


Figure 3-8.7 Air terminals on chimney.

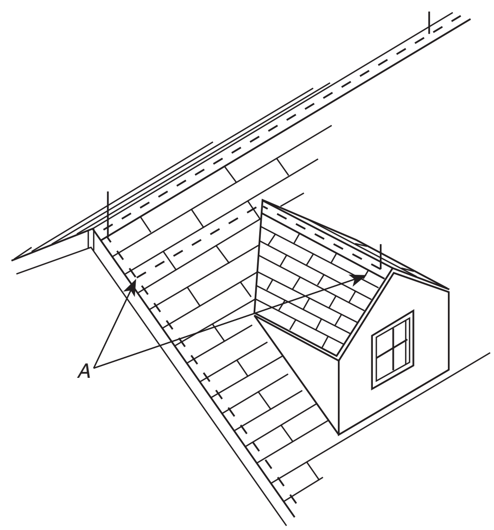


Figure 3-9.2 Dead end.

Such a connection shall be made using a main size lightning conductor and a bonding device having a surface contact area of not less than 3 in.^{2} (1940 mm^2), and shall provide two or more paths to ground as is required for strike termination devices. Required strike termination devices shall be installed on chimneys and vents so that the distance from a strike termination device to an outside corner or the distance perpendicular to an outside edge shall be not greater than 2 ft (0.6 m). (*See Figure 3-8.7.*) Where only one strike termination device is required on a chimney or vent, at least one main sized conductor shall connect the strike termination device to a main conductor at the location where the chimney or vent meets the roof surface and provides two or more paths to ground from that location in accordance with Section 3-9 and 3-9.2.

3-9 Conductors. Main conductors shall interconnect all strike termination devices and shall form two or more paths from each strike termination device downward, horizontally, or rising at no more than $^1/_4$ pitch to connections with ground terminals, except as permitted by 3-9.1 and 3-9.2.

3-9.1 One-Way Path. Strike termination devices on a lower roof level that are interconnected by a conductor run from a higher roof level shall only require one horizontal or downward path to ground provided the lower level roof conductor run does not exceed 40 ft (12 m).

3-9.2 Dead Ends. Strike termination devices shall be permitted to be "dead ended" with only one path to a main conductor on roofs below the main protected level provided the conductor run from the strike termination device to a main conductor is not more than 16 ft (4.9 m) in total length and maintains a horizontal or downward coursing. (*See Figure 3-9.2.*)

3-9.3 Substitution of Metals. Metal parts of a structure, such as eave troughs, down spouts, ladders, chutes, or other metal parts, shall not be substituted for the main lightning conductor. Likewise, metal roofing or siding having a thickness of less than $^3/_{16}$ in. (4.8 mm) shall not be substituted for main lightning conductors.

3-9.4 "U" or "V" Pockets. Conductors shall maintain a horizontal or downward coursing free from "U" or "V" (down and up) pockets. Such pockets, often formed at low-positioned chimneys, dormers, or other projections on sloped roofs or at parapet walls, shall be provided with a down conductor from the base of the pocket to ground or to an adjacent down-lead conductor. (*See Figure 3-9.4.*)

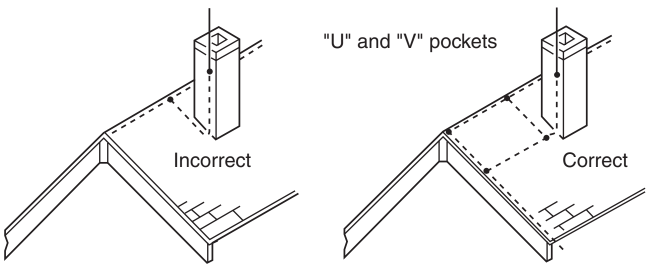


Figure 3-9.4 Pockets.

3-9.5 Conductor Bends. No bend of a conductor shall form an included angle of less than 90 degrees, nor shall it have a radius of bend less than 8 in. (203 mm). (*See Figure 3-9.5.*)

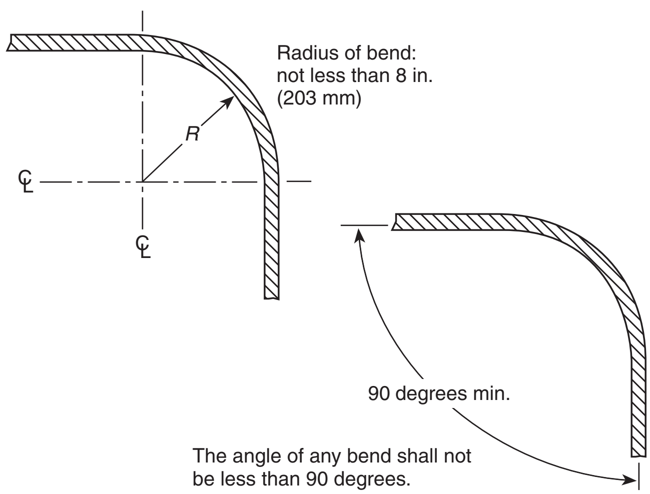


Figure 3-9.5 Conductor bends.

3-9.6 Conductor Supports. Conductors shall be permitted to be coursed through air without support for a distance of 3 ft (0.9 m) or less. Conductors that must be coursed through air for longer distances shall be provided with a positive means of support that will prevent damage or displacement of the conductor.

3-9.7 Roof Conductors. Roof conductors shall be coursed along ridges of gable, gambrel, and hip roofs; around the perimeter of flat roofs; behind or on top of parapets; and across flat or gently sloping roof areas as required to interconnect all strike termination devices. Conductors shall be coursed through or around obstructions (e.g., cupolas, ventilators, etc.) in a horizontal plane with the main conductor.

3-9.8 Cross-Run Conductors. Cross-run conductors (main conductors) shall be required to interconnect the strike termination devices on flat or gently sloping roofs that exceed 50 ft (15 m) in width. For example, roofs from 50 ft to 100 ft (15 m to 30 m) in width shall require one cross-run conductor, roofs 100 ft to 150 ft (30 m to 46 m) in width shall require two cross-run conductors, and so on. Cross-run conductors shall be connected to the main perimeter cable at intervals not exceeding 150 ft (46 m). *[See Figure 3-8.1.2(a).]*

3-9.9 Down Conductors. Down conductors shall be as widely separated as practicable. Their location shall depend on such considerations as the following:

(a) Placement of strike termination devices

(b) Most direct coursing of conductors

(c) Earth conditions

(d) Security against displacement

(e) Location of large metallic bodies

(f) Location of underground metallic piping systems

3-9.10 Number of Down Conductors. At least two down conductors shall be provided on any kind of structure, including steeples. Structures exceeding 250 ft (76 m) in perimeter shall have a down conductor for every 100 ft (30 m) of perimeter or fraction thereof. The total number of down conductors on structures having flat or gently sloping roofs shall be such that the average distance between all down conductors does not exceed 100 ft (30 m). Irregular-shaped structures could require additional down conductors in order to provide a two-way path from each strike termination device. For a flat or gently sloping roof structure, only the perimeter of the roof areas requiring protection shall be measured. When determining the perimeter of a pitched roof structure, the horizontal projection (footprint) of the protected roof shall be measured. Lower roofs or projections that are located within a zone of protection shall not be required to be included in the perimeter measurement. (*See Figure 3-9.10.*)

3-9.11 Protecting Down Conductors. Down conductors located in runways, driveways, school playgrounds, cattle yards, public walks, or other similar locations shall be guarded to prevent physical damage or displacement. If the conductor is run through ferrous metal tubing, the conductor shall be bonded to the top and bottom of the tubing. The down conductor shall be protected for a minimum distance of 6 ft (1.8 m) above grade level.

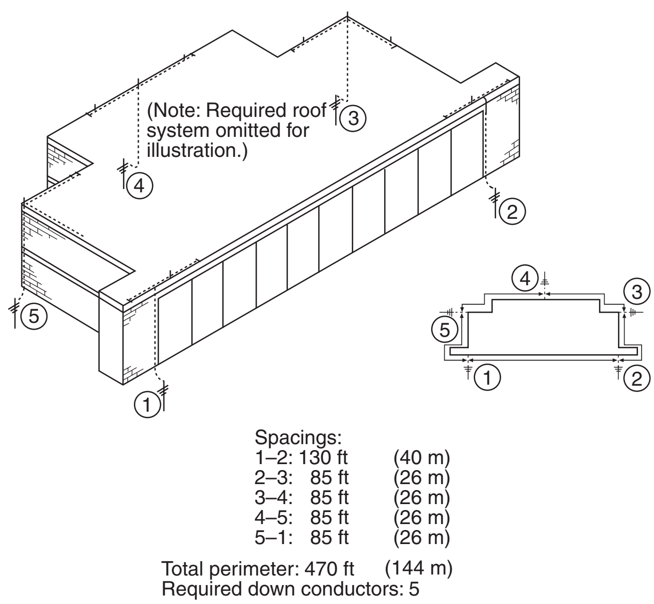


Figure 3-9.10 Quantity of down conductors.

3-9.12 Down Conductor Entering Corrosive Soil. Down conductors entering corrosive soil shall be protected against corrosion by a protective covering beginning at a point 3 ft (0.9 m) above grade level and extending for its entire length below grade.

3-9.13 Down Conductors and Structural Columns. Down conductors coursed on or in reinforced concrete columns or on structural steel columns shall be connected to the reinforcing steel or the structural steel member at its upper and lower extremities. In the case of long vertical members, an additional connection shall be made at intervals not exceeding 200 ft (60 m). Such connections shall be made using listed clamps or listed bonding plates or by welding or brazing. The use of PVC conduit or other nonmetallic chase shall not negate the need for these interconnections unless sufficient separation is provided to satisfy the bonding requirements of Sections 3-19, 3-20, and 3-21. Where these bonding requirements are not satisfied, provisions shall be made to ensure the required interconnection of these parallel vertical paths.

3-10 Conductor Fasteners. Conductors shall be securely fastened to the structure upon which they are placed at intervals not exceeding 3 ft (1 m). Attached by nails, screws, bolts, or adhesives as necessary, 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. No combination of materials shall be used that will form an electrolytic couple of such a nature that, in the presence of moisture, corrosion will be accelerated.

3-11 Masonry Anchors. Masonry anchors used to secure lightning protection materials shall have a minimum outside diameter of $^{1}/_{4}$ in. (6.4 mm) and shall be set with care. Holes made to receive the body of the anchor shall be of the correct size, made with the proper tools, and preferably made in the brick, stone, or other masonry unit rather than in mortar joints. When the anchors are installed, the fit shall be tight against moisture thus reducing the possibility of damage due to freezing.

3-12 Connector Fittings. Connector fittings shall be used at all “end-to-end,” “tee,” or “Y” splices of lightning conductors. They shall be attached so as to withstand a pull test of 200 lb (890 N). Fittings used for required connections to metal bodies in or on a structure shall be secured to the metal body by bolting, brazing, welding, or using high-compression connectors listed for the purpose. Conductor connections shall be of the bolted, welded, high compression, or crimp-type. Crimp-type connections shall not be used with Class II conductors.

3-13 Ground Terminals. Each down conductor shall terminate at a ground terminal dedicated to the lightning protection system. The design, size, depth, and number of ground terminals used shall comply with 3-13.1 through 3-13.4.

3-13.1* Ground Rods. Ground rods shall be not less than $^{1}/_{2}$ in. (12.7 mm) in diameter and 8 ft (2.4 m) long. Rods shall be copper-clad steel, solid copper, hot-dipped galvanized steel, or stainless steel. Rods shall be free of paint or other nonconductive coatings.

Electrical system and telecommunication grounding electrodes shall not be used in lieu of lightning ground rods. This provision shall not prohibit the required bonding together of grounding electrodes of different systems.

3-13.1.1 Ground Rod Terminations. The down conductor shall be attached to the ground rod by bolting, brazing, welding, or using high-compression connectors listed for the purpose. Clamps shall be suitable for direct soil burial.

3-13.1.2 Deep Moist Clay Soil. The lightning conductors or ground rods shall extend vertically not less than 10 ft (3 m) into the earth. The earth shall be compacted and made tight against the length of the conductor or ground rod. *(See Figure 3-13.1.2.)*

3-13.1.3 Sandy or Gravelly Soil. In sand or gravel, two or more ground rods, at not less than 10-ft (3-m) spacings, shall be driven vertically to a minimum depth of 10 ft (3 m) below grade. (*See Figure 3-13.1.3.*)

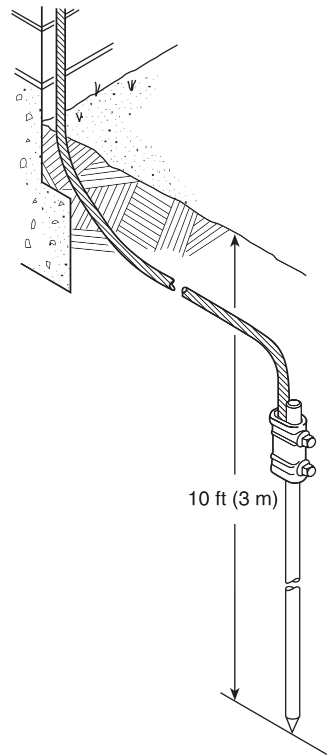


Figure 3-13.1.2 Grounding in moist clay-type soil.

3-13.1.4 Shallow Topsoil. Where bedrock is near the surface, the conductor shall be laid in trenches extending away from the building at each down conductor. These trenches shall be not less than 12 ft (3.7 m) in length and from 1 ft to 2 ft (0.3 m to 0.6 m) in depth in clay soil. In sandy or gravelly soil, the trench shall be not less than 24 ft (7.5 m) in length and 2 ft (0.6 m) in depth. If these methods prove impractical, it shall be permitted to carry the lightning protection cable in trenches of a depth specified above or, if this is impossible, directly on bedrock a minimum distance of 2 ft (0.6 m) from the foundation or exterior footing. The cable shall terminate by attachment to a buried copper ground plate at least 0.032 in. (0.8 mm) thick and having a minimum surface area of 2 ft^2 (0.18 m^2).

3-13.1.5 Soil Less than One Foot [1 ft (0.3 m)] Deep. If the soil is less than 1 ft (0.3 m) in depth, down conductors shall be connected to a loop conductor installed in a trench or in rock crevices around the structure. The loop conductor shall be not smaller than the equivalent of a main size lightning conductor. Optional plate electrodes shall be permitted to be attached to the loop conductor to enhance its earth contact where the measured grounding resistance is found to be too high to provide effective grounding. (*See Figure 3-13.1.5.*)

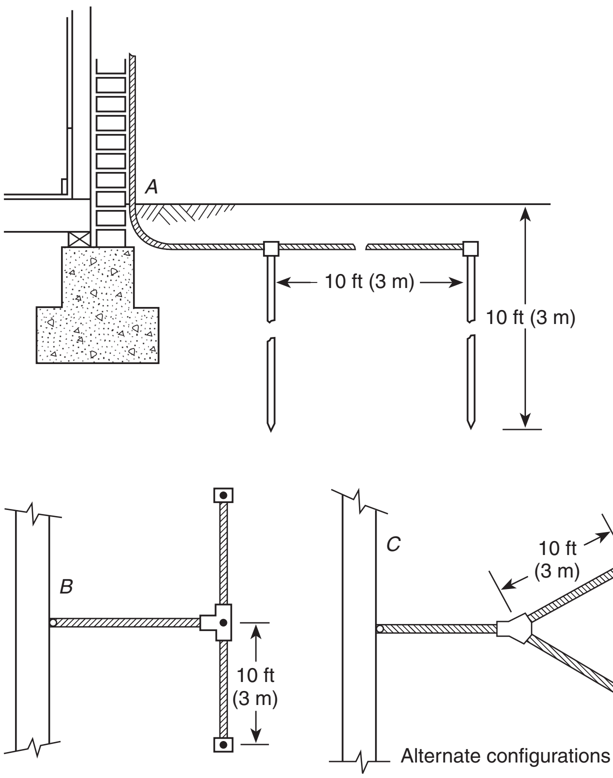


Figure 3-13.1.3 Grounding in sandy or gravelly soil.

3-13.2 Concrete Encased Electrodes.

3-13.2.1 Concrete encased electrodes shall only be used in new construction. The electrode shall be located near the bottom of a concrete foundation or footing that is in direct contact with the earth and shall be encased by not less than 2 in. (50.8 mm) of concrete. The encased electrode shall consist of the following:

(a) Not less than 20 ft (6.1 m) of bare copper main size conductor, or

(b) An electrode consisting of at least 20 ft (6.1 m) of one or more steel reinforcing bars or rods not less than $^1/_2$ in. (12.7 mm) in diameter that have been effectively bonded together by either welding or overlapping 20 diameters and securely wire-tying.

3-13.2.2 Concrete Encased Electrode Terminations. The down conductor(s) shall be permanently attached to the concrete encased electrode system by bolting, brazing, welding, or using high-compression connectors listed for the purpose.

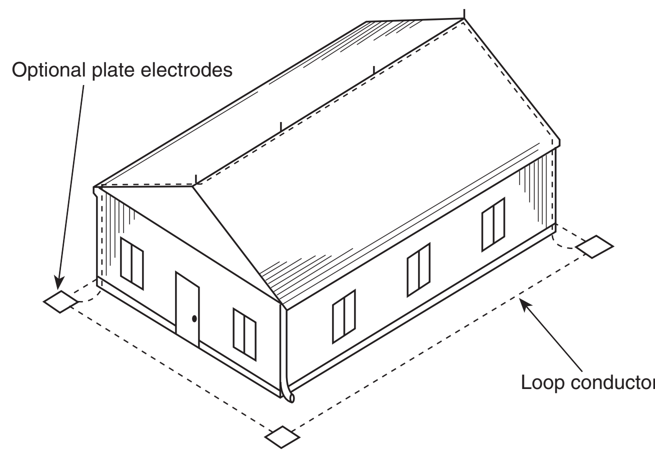


Figure 3-13.1.5 Grounding in soil less than 1 ft (0.3 m) deep.

3-13.3 Ground Ring Electrode.

3-13.3.1 A ground ring electrode encircling a structure shall be in direct contact with earth at a depth of not less than $2^1/_2$ ft (762 mm) or encased in a concrete footing in accordance with 3-13.2. The encased electrode shall consist of not less than 20 continuous ft (6.1 m) of bare copper main size conductor.

3-13.3.2 Ground Ring Electrode Terminations. The down conductor(s) shall be permanently attached to the ground ring electrode by bolting, brazing, welding, or using high-compression connectors listed for the purpose. Clamps shall be suitable for direct burial.

3-13.4 Combinations. Combinations of the grounding terminals in Section 3-13 shall be permitted.

3-14 Common Grounding.

3-14.1 General. All grounding media in or on a structure shall be interconnected to provide a common ground potential. This shall include lightning protection, electric service, telephone and antenna system grounds, as well as underground metallic piping systems. Underground metallic piping systems shall include water service, well casings located within 25 ft (7.6 m) 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. Main size lightning conductors shall be used for interconnecting these grounding systems to the lightning protection system.

3-14.2 Common Ground Bondings. If electric, Community Antenna Television (CATV), data, telephone, or other systems are bonded to a metallic water pipe, only one connection from the lightning protection system to the water pipe system shall be required provided that the water pipe is electrically continuous between all systems. If the water pipe is not electrically continuous due to the use of plastic pipe sections or other reasons, the nonconductive sections shall be bridged with main size conductors or the connection shall be made at a point where electrical continuity is ensured.

3-15 Concealed Systems.

3-15.1 General. Requirements covering exposed systems also shall apply to concealed systems, except conductors shall be permitted to be coursed under roofing materials; under roof framing; behind exterior wall facing; between wall studding; in conduit chases; or embedded directly in concrete or masonry construction. If a conductor is run in metal conduit, it shall be bonded to the conduit at the point where it enters the conduit and at the point where it emerges from the conduit and at all locations where the conduit is not electrically continuous.

3-15.2 Masonry Chimneys. Chimney strike termination devices and conductors shall be permitted to be concealed within masonry chimneys or to be attached to the exterior of masonry chimneys and routed through the structure to concealed main conductors.

3-15.3 Concealment in Steel Reinforced Concrete. Conductors or other components of the lightning protection system concealed in steel reinforced concrete units shall be connected to the reinforcing steel. Concealed down conductors shall be connected to the vertical reinforcing steel in accordance with 3-9.13. Roof conductors or other concealed horizontal conductor runs shall be connected to the reinforcing steel at intervals not exceeding 100 ft (30 m).

3-15.4 Ground Terminals. Ground terminals for concealed systems shall comply with Section 3-13. Ground terminals located under basement slabs or in crawl spaces shall be installed as near as practicable to the outside perimeter of the structure. Where rod or cable conductors are used for ground terminals, they shall be in contact with the earth for a minimum of 10 ft (3 m) and shall extend to a depth of not less than 10 ft (3 m) below finished grade, except as permitted by 3-13.3 and 3-13.4.

3-16 Structural Steel Systems.

3-16.1 General. The structural steel framework of a structure shall be permitted to be utilized as the main conductor of a lightning protection system if it is electrically continuous or is made electrically continuous.

3-16.2 Strike Termination Devices. Strike termination devices shall be connected to the structural steel framing by direct connection, by use of individual conductors routed through the roof or parapet walls to the steel framework, or by use of an exterior conductor that interconnects all strike termination devices and that is connected to the steel framework. Where such an exterior conductor is used, it shall be connected to the steel framework of the structure at intervals not exceeding 100 ft (30 m).

3-16.3 Connections to Framework. Conductors shall be connected to areas of the structural steel framework, which have been cleaned to base metal, by use of bonding plates having a surface contact area of not less than 8 in.^{2} (5200 mm^2) or by welding or brazing. Drilling and tapping the steel column to accept a threaded connector also shall be an acceptable method. The threaded device shall be installed with five threads fully engaged and secured with a jam-nut. The threaded portion of the connector shall be not less than $^1/_2$ in. (12.7 mm) in diameter. Bonding plates shall have bolt-pressure cable connectors and shall be bolted, welded, or brazed securely to the structural steel framework so as to maintain electrical continuity. Where rust-protective paint or coating is removed, the base steel shall be protected with a conductive, corrosion-inhibiting coating.

3-16.4 Ground Terminals. Ground terminals shall be connected to approximately every other steel column around the perimeter of the structure at intervals averaging not more than 60 ft (18 m). Connections shall be made near the base of the column in accordance with the requirements in 3-16.3.

3-16.5 Bonding Connections. Where metal bodies located within a steel-framed structure are inherently bonded to the structure through the construction, separate bonding connections shall not be required.

3-17 Metal Antenna Masts and Supports. Metal antenna masts or supports located on a protected structure shall be connected to the lightning protection system using main size conductors and listed fittings unless they are within a zone of protection.

3-18* Surge Suppression. Devices suitable for the protection of the structure shall be installed on electric and telephone service entrances and on radio and television antenna lead-ins.

3-19 Metal Bodies. Metal bodies, located outside or inside a structure, that contribute to lightning hazards because they are grounded or assist in providing a path to ground for lightning currents shall be bonded to the lightning protection system in accordance with Sections 3-19, 3-20, and 3-21. *(See Appendix J for a technical discussion of lightning-protection potential-equalization bonding.)*

3-19.1 General. In determining the necessity of bonding a metal body to a lightning protection system, the following factors shall be considered:

(a) Bonding shall only be required if there is likely to be a sideflash between the lightning protection system and another grounded metal body.

(b) The influence of a nongrounded metal body, such as a metal window frame in a nonconductive medium, is limited to its effectiveness as a short circuit conductor if a sideflash occurs and, therefore, shall not necessarily require bonding to the lightning protection system.

(c) Bonding distance requirements depend on a technical evaluation of the number of down conductors and their location, the interconnection of other grounded systems, the proximity of grounded metal bodies to the down conductors, and the flashover medium (i.e., air or solid materials).

(d) Metal bodies located in a steel-framed structure that are inherently bonded through construction do not require further bonding.

3-19.2 Materials. Horizontal loop conductors used for the interconnection of lightning protection system downlead conductors, ground terminals, or other grounded media shall be sized no smaller than that required for the main lightning conductor. *[See Tables 3-1.1(a) and 3-1.1(b).]*

Conductors used for the bonding of grounded metal bodies or isolated metal bodies requiring connection to the lightning protection system shall be sized in accordance with bonding conductor requirements in Tables 3-1.1(a) and 3-1.1(b).

3-20 Potential Equalization.

3-20.1* Ground-Level Potential Equalization. All grounded media in and on a structure shall be connected to the lightning protection system within 12 ft (3.6 m) of the base of the structure in accordance with Section 3-14.

For structures exceeding 60 ft (18 m) in height, the interconnection of the lightning protection system ground terminals and other grounded media shall be in the form of a ground loop conductor.

3-20.2* Roof-Level Potential Equalization. For structures exceeding 60 ft (18 m) in height, all grounded media in or on the structure shall be interconnected within 12 ft (3.6 m) of the main roof level.

3-20.3 Intermediate-Level Potential Equalization. Intermediate-level potential equalization is accomplished by the interconnection of the lightning protection system down conductors and other grounded media at the intermediate levels between the roof and the base of a structure in accordance with the following:

(a) *Steel-Framed Structures.* Intermediate-loop conductors are not required for steel-framed structures where the framing is electrically continuous.

(b) *Reinforced Concrete Structures where the Reinforcement Is Interconnected and Grounded in Accordance with 3-15.3.* The lightning protection system down conductors and other grounded media shall be interconnected with a loop conductor at intermediate levels not exceeding 200 ft (60 m).

(c) *Other Structures.* The lightning protection down conductors and other grounded media shall be interconnected with a loop conductor at intermediate levels not exceeding 60 ft (18 m).

3-21 Bonding of Metal Bodies.

3-21.1 Long, Vertical Metal Bodies. Long, vertical metal bodies shall be bonded in accordance with the following:

(a) *Steel-Framed Structures.* Grounded and ungrounded metal bodies exceeding 60 ft (18 m) in vertical length shall be bonded to structural steel members as near as practical to their extremities unless inherently bonded through construction at these locations.

(b) *Reinforced Concrete Structures where the Reinforcement Is Interconnected and Grounded in Accordance with 3-15.3.* Grounded and ungrounded metal bodies exceeding 60 ft (18 m) in vertical length shall be bonded to the lightning protection system as near as practical to their extremities unless inherently bonded through construction at these locations.

(c) *Other Structures.* Bonding of grounded or ungrounded long, vertical metal bodies shall be determined by 3-21.2 and 3-21.3, respectively.

3-21.2 Grounded Metal Bodies. This section covers the bonding of grounded metal bodies not covered in 3-21.1. Where grounded metal bodies have been connected to the lightning protection system at only one extremity, the following formula shall be used to determine if additional bonding is required. Branches of grounded metal bodies connected to the lightning protection system at their extremities shall require bonding to the lightning protection system in accordance with the following formula if they change vertical direction more than 12 ft (3.6 m).

NOTE: Where such bonding has been accomplished either inherently through construction or by physical contact between electrically conductive materials, no additional bonding connection shall be required.

(a) *Structures over 40 ft (12 m) in Height.* Grounded metal bodies shall be bonded to the lightning protection system where located within a calculated bonding distance, D, as determined by the following formula:

$$D = \frac{h}{6n} \cdot K_m$$

Here, h is the vertical distance between the bond being considered and the nearest lightning protection system bond.

The value of n is related to the number of down conductors that are spaced at least 25 ft (7.6 m) apart and located within a zone of 100 ft (30 m) from the bond in question and shall be calculated as follows:

Where bonding is required within 60 ft (18 m) from the top of any structure,

$n = 1$ where there is only one down conductor in this zone

$n = 1.5$ where there are only two down conductors in this zone

$n = 2.25$ where there are three or more down conductors in this zone

$K_m = 1$ if the flashover is through air, or 0.50 if through dense material such as concrete, brick, wood and so forth.

Where bonding is required below a level 60 ft (18 m) from the top of a structure, n is the total number of down conductors in the lightning protection system.

(b) *Structures 40 ft (12 m) and Less in Height.* Grounded metal bodies shall be bonded to the lightning protection system where located within a calculated bonding distance, D, as determined by the following formula:

$$D = \frac{h}{6n} \cdot K_m$$

Here, h is either the height of the building or the vertical distance from the nearest bonding connection from the grounded metal body to the lightning protection system and the point on the down conductor where the bonding connection is being considered.

The value of n is related to the number of down conductors that are spaced at least 25 ft (7.6 m) apart and located within a zone of 100 ft (30 m) from the bond in question and shall be calculated as follows:

$n = 1$ where there is only one down conductor in this zone

$n = 1.5$ where there are only two down conductors in this zone

$n = 2.25$ where there are three or more down conductors in this zone

$K_m = 1$ if the flashover is through air, or 0.50 if through dense material such as concrete, brick, wood, and so forth

3-21.3* Isolated (Nongrounded) Metallic Bodies. An isolated metallic body, such as a metal window frame in a nonconducting medium, that is located close to a lightning conductor and to a grounded metal body will influence bonding requirements only if the total of the isolated distances between the lightning conductor and the isolated metal body, and between the isolated metal body and the grounded metal body is equal to or less than the calculated bonding distance. (*See Figure 3-21.3.*)

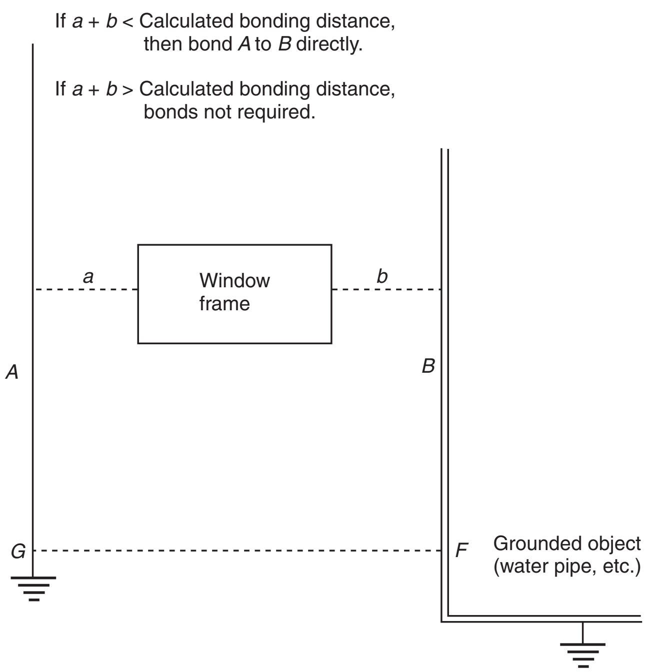


Figure 3-21.3 Effect of isolated (nongrounded) metallic bodies, such as a window frame, in nonconductive media.

A bonding connection shall be required when the total of the shortest distance between the lightning conductor and the isolated metal body, and the shortest distance between the isolated metal body and the grounded metal body is equal to or less than the bonding distance as calculated in accordance with 3-21.2. Bondings shall be made between the lightning protection system and the grounded metal body and shall not need to run through or be connected to the isolated metal body.

Chapter 4 Protection for Miscellaneous Structures and Special Occupancies

4-1 General. Special consideration shall be given to the miscellaneous structures and special occupancies covered in this chapter. All requirements of Chapter 3 shall apply except as modified.

4-2 Masts, Spires, Flagpoles. These slender structures shall require one strike termination device, down conductor, and ground terminal. Electrically continuous metal structures shall require only bonding to ground terminals.

4-3 Grain-, Coal-, and Coke-Handling and Processing Structures. Provisions shall be made for the settling and rising of wood frame elevators as grain, coal, and coke is loaded and unloaded.

4-4 Metal Towers and Tanks. Metal towers and tanks constructed so as to receive a stroke of lightning without damage shall require only bonding to ground terminals as required in Chapter 3, except as provided in Chapter 6.

4-5 Air-Inflated Structures. Air-inflated structures shall be protected with a mast-type or catenary lightning protection system in accordance with Chapter 6, or with a lightning protection system in accordance with Chapter 3.

4-6 Concrete Tanks and Silos. Lightning protection systems for concrete (including prestressed concrete) tanks containing flammable vapors, flammable gases, and liquids that can produce flammable vapors; and concrete silos containing materials susceptible to dust explosions shall be provided with either external conductors or with conductors embedded in the concrete in accordance with Chapters 3 or 6.

4-7 Guyed Structures. Each metal guy cable shall be bonded at its lower end with a main size conductor to all other guy cables sharing a common anchor point, and grounded at the anchor point. Anchor plates shall be bonded to the anchor ground point. Multiple guy cables shall be permitted to be connected to a common point with a single continuous conductor to the ground and the anchor plate bonding conductor attached to that main conductor.

Each metal guy cable shall be bonded at its upper end to the structure it supports if it is constructed of a conductive material, and to the lightning protection system loop conductor or down conductors.

Chapter 5 Protection for Heavy-Duty Stacks

5-1 General. A smoke or vent stack shall be classified as heavy duty if the cross-sectional area of the flue is greater than 500 in.^{2} (0.3 m^2) and the height is greater than 75 ft (23 m). (*See Figure 5-1.*)

5-2 Materials.

5-2.1 General. Materials shall be Class II as shown in Table 3-1.1(b), and as described in this chapter.

5-2.2 Corrosion Protection. Copper and bronze materials used on the upper 25 ft (7.6 m) of a stack shall have a continuous covering of lead having minimum thickness of $^1/_{16}$ in. (1.6 mm) to resist corrosion by flue gases. Such materials shall include conductors, strike termination devices, connectors, splicers, and cable holders. Stacks that extend through a roof less than 25 ft (7.6 m) shall have a lead covering only on those materials above the roof level.

5-3 Strike Termination Devices. Strike termination devices shall be made of solid copper, stainless steel, or Monel Metal. They shall be located uniformly around the top of cylindrical stacks at intervals not exceeding 8 ft (2.4 m). On square or rectangular stacks, strike termination devices shall be located not more than 24 in. (600 mm) from the corners and shall be spaced not more than 8 ft (2.4 m) apart around the perimeter.

5-3.1 Air Terminal Heights. The height of air terminals above the stacks shall be not less than 18 in. (460 mm) nor more than 30 in. (760 mm). They shall be at least $^5/_8$ in. (15 mm) in diameter, exclusive of the corrosion protection. Top-mounted air terminals shall not extend more than 18 in. (460 mm) above the top of the stack.

5-3.2 Air Terminal Mountings. Air terminals shall be properly secured to the stack and shall be connected together at their lower end with a conductor forming a closed loop around the stack. Side-mounted air terminals shall be secured to the stack at not less than two locations. An anchored base connector shall be considered as one location.

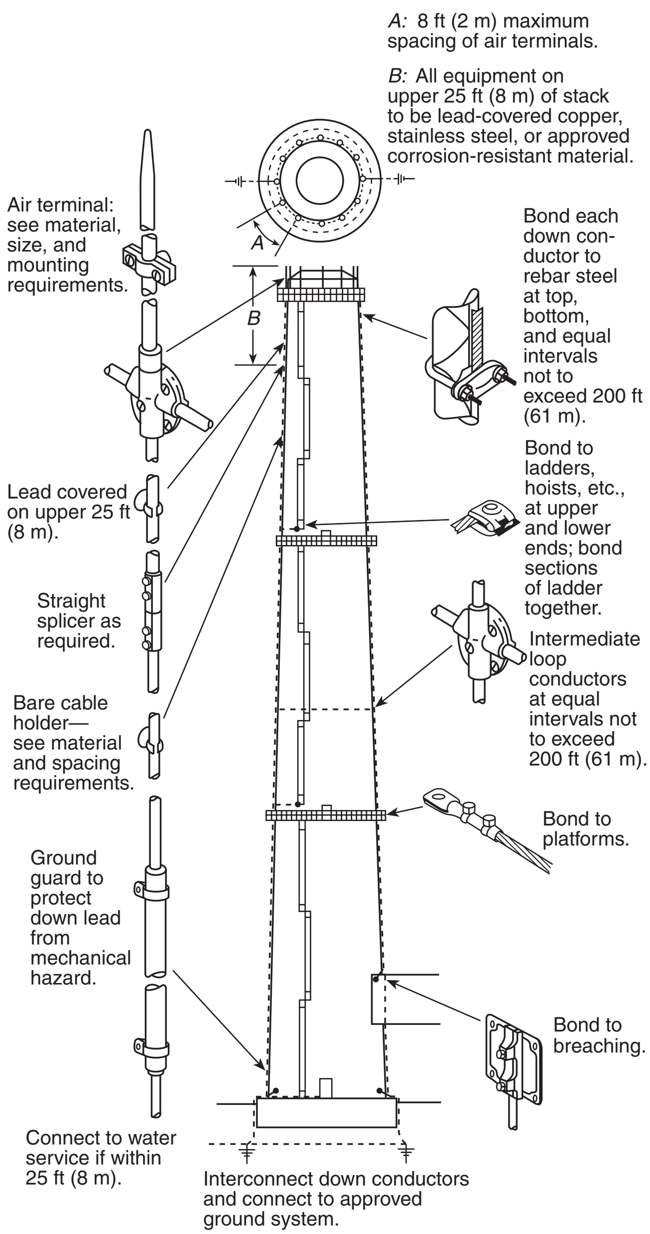


Figure 5-1 Heavy-duty stack.

5-3.3 Steel Hoods. An electrically continuous steel hood covering the stack lining and column having a metal thickness of not less than $^{3}/_{16}$ in. (4.8 mm), shall be permitted to serve as the strike termination device. The hood serves as a top loop conductor and shall be connected to each down conductor using a connection plate of not less than 8 in.^{2}(5200 mm^{2}) securely bolted or welded to the hood.

5-4 Conductors.

5-4.1 General. Conductors shall be copper, weighing not less than 375 lb per 1000 ft (558 g per m) without the lead covering. The size of any wire in the conductor shall be not less than 15 AWG.

5-4.2 Down Conductors. Not less than two down conductors shall be provided. They shall be located on opposite sides of the stack and lead from the loop conductor at the top to ground terminals. Down conductors shall be interconnected within 12 ft (3.6 m) of the base by a loop conductor, preferably below grade. The down conductor also shall be interconnected with a loop conductor at approximately equal intervals not to exceed 200 ft (67 m). Down conductors shall be protected from physical damage or displacement for a distance of not less than 8 ft (2.4 m) above grade.

5-5 Fasteners. Fasteners shall be of copper, bronze, or stainless steel. They shall be anchored firmly to the stack by masonry anchors or lay-in attachments. The threaded shank of fasteners shall be not less than $^{1}/_{2}$-in. (13-mm) diameter for air terminals and $^{3}/_{8}$-in. (10-mm) diameter for conductors. Vertical conductors shall be fastened at intervals not exceeding 4 ft (1.2 m) and horizontal conductors shall be fastened at intervals not exceeding 2 ft (0.6 m).

5-6 Splices. Splices in conductors shall be as few as practicable and shall be attached so as to withstand a pull test of 200 lb (890 N). All connections and splices shall be by bolting, brazing, welding, or high-compression connectors listed for the purpose. All connectors and splicers shall make contact with the conductor for a distance not less than $1^{1}/_{2}$ in. (38 mm), measured parallel to the axis of the conductor.

5-7 Reinforced Concrete Stacks. All reinforcing steel shall be made electrically continuous and bonded to each down conductor within 12 ft (3.6 m) of the top and base of the stack, and at approximately equal intervals not to exceed 200 ft (67 m). Tying or clipping of reinforcing steel shall be an acceptable means of ensuring continuity. Clamps or welding shall be used for all connections to the reinforcing steel and to the down conductors.

5-8 Bonding of Metal Bodies. Bonding of metal bodies on a heavy-duty stack shall comply with the requirements of Sections 3-19, 3-20, and 3-21, and as described herein.

5-8.1 Potential Equalization. Potential equalization shall be accomplished by the following:

(a) *Ground Level of Stack.* All interior and exterior grounded media shall be interconnected by a loop conductor within 12 ft (3.6 m) of the base of the stack. This shall include, but not be limited to, lightning protection down conductors, conduit, piping, elevators, ladders, and breeching steel and reinforcing steel.

(b) *Top Level of Stack.* All interior and exterior grounded media shall be interconnected within 12 ft (3.6 m) of the top of the stack.

(c) *Intermediate Levels of Stack.* All interior and exterior vertical grounded media shall be interconnected at approximately equal intervals not to exceed 200 ft (67 m).

5-8.2 Isolated (Nongrounded) Protruding Metal Bodies. Isolated (nongrounded) protruding metal bodies shall be bonded in accordance with the following:

(a) Isolated protruding metal bodies 150 ft (50 m) or more above the base and on the exterior of a stack are subject to a direct strike and shall be interconnected to the lightning protection system. Isolated protruding metal bodies shall include, but not be limited to, rest platforms, jib hoists, and other metal bodies protruding 18 in. (460 mm) or more from the column wall.

(b) Isolated metal bodies on the interior of a reinforced steel stack or within the zone of protection on the exterior shall not be required to be connected to the lightning protection system.

5-9* Grounding. A ground terminal suitable for the soil conditions encountered shall be provided for each down conductor. Ground terminals shall be in accordance with Section 3-13, except ground rods shall be a copper-clad or stainless steel rod having a diameter of not less than $^{5}/_{8}$ in. (15.9 mm) and shall be at least 10 ft (3 m) in length.

5-10 Metal Stacks. Heavy-duty metal stacks having a metal thickness of $^{3}/_{16}$ in. (4.8 mm) or greater shall not require air terminals or down conductors. They shall be grounded by means of at least two ground terminals located on opposite sides of the stack. If the stack is an adjunct of a building or located within the sideflash distance, as determined by Sections 3-19, 3-20, and 3-21, it shall be interconnected to the lightning protection on the building. If the stack is located within the perimeter of a protected building, two connections shall be made between the stack conductors and the nearest main building lightning conductors at or about the roof level.

5-11 Metal Guy Wires and Cables. Metal guy wires and cables used to support stacks shall be grounded at their lower ends.

Chapter 6 Protection for Structures Containing Flammable Vapors, Flammable Gases, or Liquids that Can Give Off Flammable Vapors

6-1 Reduction of Damage.

6-1.1* This chapter shall apply to the protection of structures containing flammable vapors, flammable gases, or liquids that can give off flammable vapors. For the purpose of this chapter, the term "structure" shall apply to the vessel, tank, or other container where this material is contained.

6-1.2 Certain types of structures used for the storage of liquids that can produce flammable vapors or used to store flammable gases are essentially self-protecting against damage from lightning strokes and shall need no additional protection. Metallic structures that are electrically continuous, tightly sealed to prevent the escape of liquids, vapors, or gases, and of adequate thickness to withstand direct strokes in accordance with 6-3.2 shall be considered to be inherently self-protecting. Protection of other structures can be achieved by the use of air terminals, masts, overhead ground wires, or other types of protective devices.

6-1.3 Chapters 3 through 5 of this standard give requirements for the protection of buildings and miscellaneous property against lightning damage. Because of the nature of the contents of the structures considered in this chapter, extra precautions shall be taken. In these structures, a spark that would otherwise cause little or no damage might ignite the flammable contents and result in a fire or explosion.

6-2 Fundamental Principles of Protection. Protection of these structures and their contents from lightning damage shall require adherence to the following principles:

(a) Liquids that can give off flammable vapors shall be stored in essentially gastight structures.

(b) Openings where flammable concentrations of vapor or gas can escape to the atmosphere shall be closed or otherwise protected against the entrance of flame.

(c) Structures and all appurtenances (e.g., gauge hatches, vent valves) shall be maintained in good operating condition.

(d) Flammable air-vapor mixtures shall be prevented, to the greatest possible extent, from accumulating outside of such structures.

(e) Potential spark gaps between metallic conductors shall be avoided at points where flammable vapors can escape or accumulate.

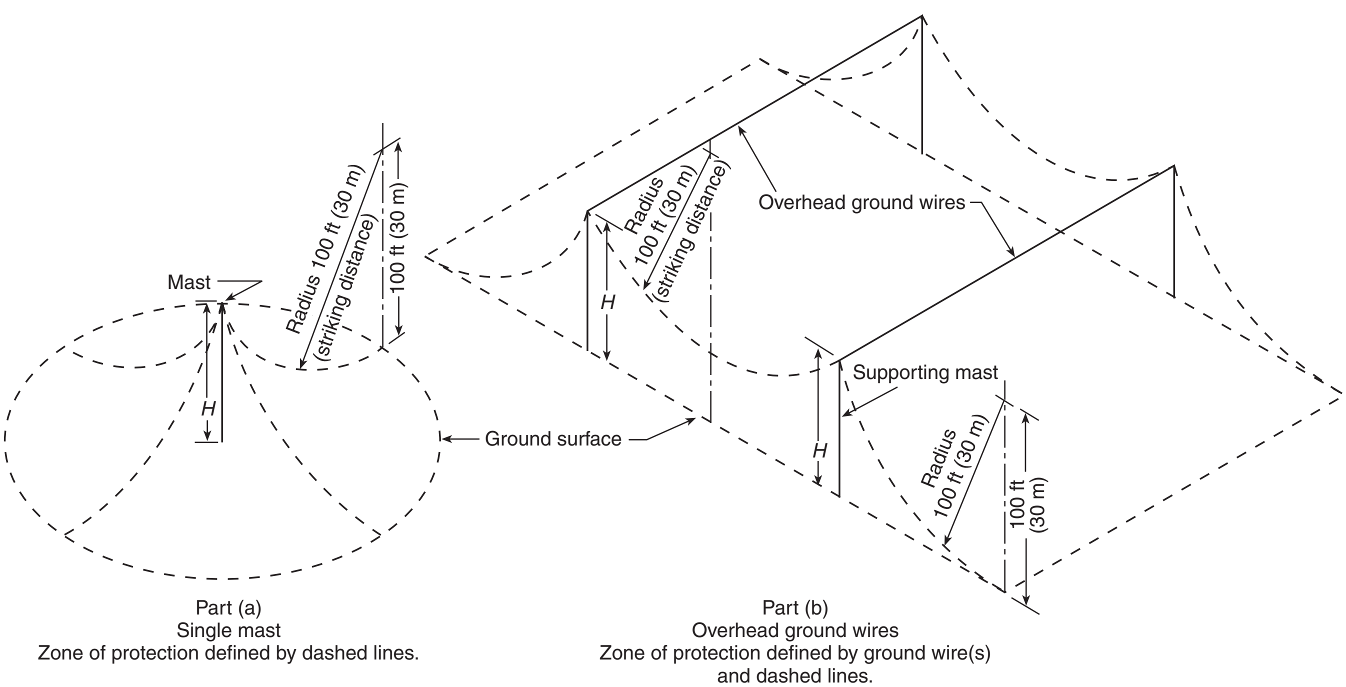


Figure 6-3.3.1(a) Single mast zone of protection [part a] and overhead ground wires [part b].

6-3 Protective Measures.

6-3.1 Materials and Installation. Conductors, strike termination devices, and grounding connections shall be selected and installed in accordance with the requirements of Chapter 3 and as described in this chapter. Overhead ground wires shall be noncorrosive for the conditions existing at the site. The overhead ground wire selected shall be sized to be equivalent in cross-sectional area to a main conductor and shall be self-supporting with minimum sag under all conditions. The overhead ground wire shall be constructed of aluminum, copper, stainless steel, or protected steel such as copper-clad, aluminum-clad, lead-clad, or galvanized steel.

6-3.2 Sheet Steel. Sheet steel less than $^3/_{16}$ in. (4.8 mm) in thickness might be punctured by severe strokes and shall not be relied upon as protection from direct lightning strokes.

6-3.3 Rods, Masts, and Overhead Ground Wires.

6-3.3.1 The zone of protection of a lightning protection mast shall be based on the striking distance of the lightning stroke, that is the distance over which final breakdown of the initial stroke to ground, or to a grounded object, occurs. Since the lightning stroke can strike any grounded object within the striking distance of the point from which final breakdown to ground occurs, the zone of protection shall be defined by a circular arc concave upward. [*See Figure 6-3.3.1(a), part (a).*] The radius of the arc is the striking distance, and the arc shall pass through the tip of the mast and be tangent to the ground. Where more than one mast is used, the arc shall pass through the tips of adjacent masts. [*See Figure 6-3.3.1(a), part (b) and Figure 6-3.3.1(b).*]

The striking distance is related to the peak stroke current and thus to the severity of the lightning stroke; the greater the severity of the stroke, the greater the striking distance. In the vast majority of cases, the striking distance exceeds 100 ft (30 m). Accordingly, the zone based on a striking distance of 100 ft (30 m) is considered to be adequately protected.

The zone of protection afforded by any configuration of masts or other elevated, conductive grounded objects can readily be determined graphically. Increasing the height of a mast above the striking distance will not increase the zone of protection.

6-3.3.2 The zone of protection of an overhead ground wire shall be based on a striking distance of 100 ft (30 m) and defined by 100-ft (30-m) radius arcs concave upward. [*See Figure 6-3.3.1(a), part (b).*] The supporting masts shall have a clearance from the protected structure in accordance with 6-3.3.3.

6-3.3.3* To prevent sideflashes, the minimum distance between a mast or overhead ground wire and the structure to be protected shall be not less than the bonding distance or sideflash distance. Sideflash distance from a mast can be calculated from the following formula:

$$D = \frac{h}{6}$$

where:
h = height of structure (or object under consideration)

Sideflash distance from a catenary can be calculated as

$$D = \frac{l}{6n}$$

where:
l = length of lightning protection conductor between its grounded point and the point under consideration

n = 1 where there is a single overhead ground wire that exceeds 200 ft (67 m) in horizontal length

n = 1.5 where there is a single overhead wire or more than one wire interconnected above the structure to be protected, such that only two down conductors are located greater than 20 ft (6 m)and less then 100 ft (30 m) apart

n = 2.25 where there are more than two down conductors spaced more than 25 ft (7.6 m) apart within a 100-ft (30-m) wide area that are interconnected above the structure being protected

The masts or overhead ground wires shall be grounded and interconnected with the grounding system of the structure to be protected. The grounding requirements of Chapter 3 shall apply.

6-3.3.4 Masts of wood, used either separately or with ground wires, shall have an air terminal extending at least 2 ft (0.6 m) above the top of the pole, securely attached to the pole (*see Figure 6-3.3.4*), and connected to the grounding system. As an alternative, an overhead ground wire or a down conductor, extending above or across the top of the pole, can be used. In the case of an overhead ground-wire system, the pole guy wire shall be permitted to be used as the down conductor. (*See Figure 6-3.3.4.*) For metallic masts, the air terminal and the down conductor shall not be required.

6-4 Protection of Specific Classes of Structures.

6-4.1 Aboveground Tanks at Atmospheric Pressure Containing Flammable Vapors or Liquids that Can Give Off Flammable Vapors.

6-4.1.1 Fixed Roof Tanks. Metallic tanks with steel roofs of riveted, bolted, or welded construction, with or without supporting members that are used for the storage of liquids which give off flammable vapors at atmospheric pressure shall be considered to be protected against lightning (inherently self-protecting) if the following requirements are met:

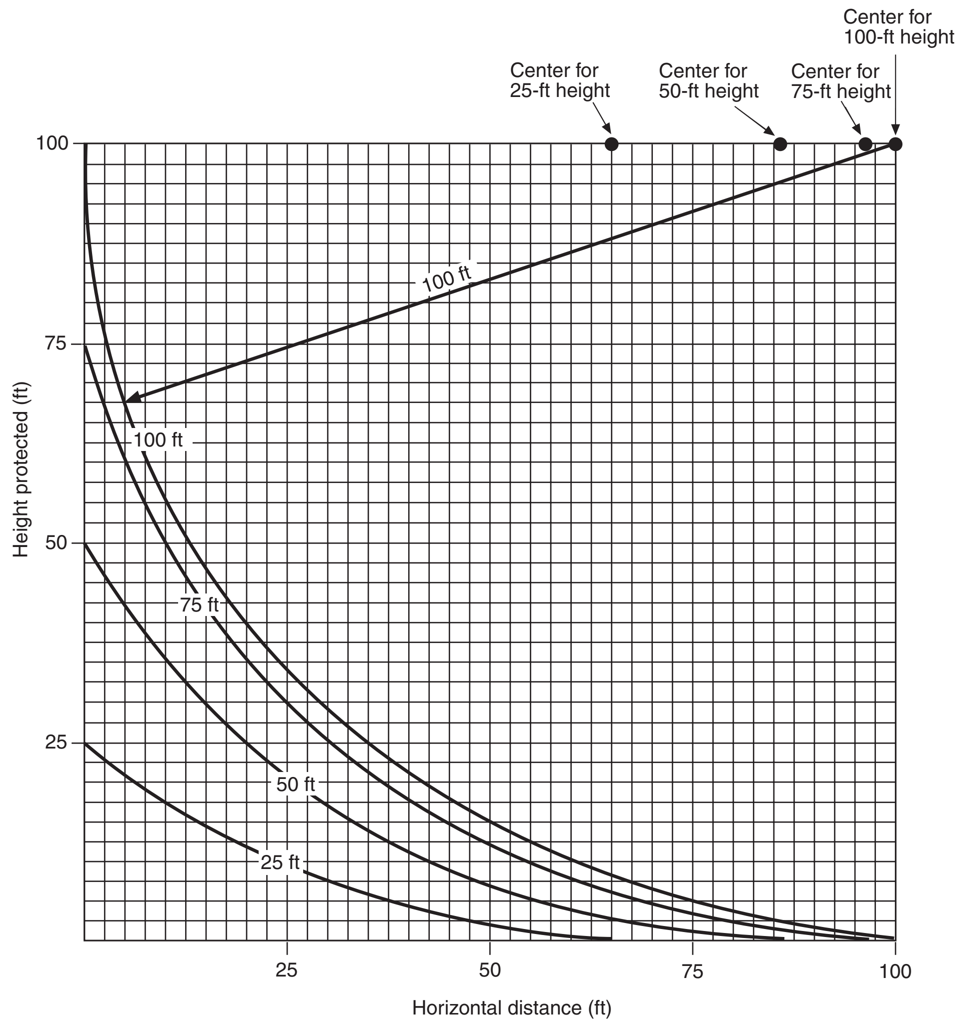
(a) All joints between metallic plates shall be riveted, bolted, or welded.

(b) All pipes entering the tank shall be metallically connected to the tank at the point of entrance.

(c) All vapor or gas openings shall be closed or provided with flame protection in locations where the stored stock might produce a flammable air-vapor mixture under storage conditions.

(d) The roof shall have a minimum thickness of $^3/_{16}$ in. (4.8 mm).

(e) The roof shall be welded, bolted, or riveted to the shell.



Note: The distance can be determined analytically for a 100-ft (30-m) striking distance with the following equation:

$$d = \sqrt{h_1 (200 - h_1)} - \sqrt{h_2 (200 - h_2)}$$

where: d = horizontal distance (ft)
h_1 = height of higher mast (ft)
h_2 = height of lower mast (ft)

SI units: 1 ft = 0.305 m

Figure 6-3.3.1(b) Zone of protection—100-ft (30-m) striking distance.

6-4.1.2 Floating Roof Tanks.

(a) *General.* Fires have occurred when lightning has struck the rims of open-top floating roof tanks where the roofs were quite high and the contents volatile. Similar above-the-seal fires have occurred when direct lightning strokes to the rims of floating roof tanks have ignited flammable vapors within the open shells. These have occurred where roofs were low. The resulting seal fires have been at small leakage points in the seal. An effective defense against ignition by a direct stroke is a tight seal.

Fires have also occurred in the seal space of open-top floating roof tanks as a result of discharges caused by lightning. These have occurred most frequently in tanks having floating roofs and seals with vapor spaces below the flexible membranes. Similar vapor spaces will be formed where tanks are fitted with secondary seals in compliance with environmental regulations. Ignition can be from a direct stroke or from the sudden discharge of an induced (bound) charge on the floating roof, released when the charge on a cloud discharges to ground or to another cloud.

(b) *Protection.* Where floating roofs utilize hangers located within a vapor space, the roof shall be electrically bonded to the shoes of the seal through the most direct electrical path at intervals not greater than 10 ft (3 m) on the circumference of the tank. These shunts shall consist of flexible Type 302, 28-gauge [$^1/_{64}$ in. × 2 in. (0.4 mm × 51 mm)] wide stainless steel straps or the equivalent in current-carrying capacity and corrosion resistance. The metallic shoe shall be maintained in contact with the shell and without openings (such as corrosion holes) through the shoe. Tanks without a vapor space at the seal do not require shunts at the seal. Where metallic weather shields cover the seal, they shall maintain contact with the shell.

Where a floating roof is equipped with both primary and secondary seals, the space between the two seals might contain a vapor-air mixture within the flammable range. If the design of such a seal system incorporates electrically conductive materials and a spark gap exists within that space or could be created by roof movement, shunts shall be installed so that they directly contact the tank shell above the secondary seal. The shunts shall be spaced at intervals not greater than 10 ft (3 m) and shall be constructed so that metallic contact is maintained between the floating roof and the tank shell in all operational positions of the floating roof.

6-4.1.3 Metallic Tanks with Nonmetallic Roofs. Metallic tanks with wooden or other nonmetallic roofs shall not be considered to be self-protecting, even if the roof is essentially gastight and sheathed with thin metal and with all gas openings provided with flame protection. Such tanks shall be provided with strike termination devices. Such strike termination devices shall be bonded to each other, to the metallic sheathing, if any, and to the tank shell. Isolated metal parts shall be bonded as required by Section 3-19. Any of the following strike termination devices shall be permitted to be used: conducting masts, overhead ground wires, or a combination of masts and overhead ground wires.

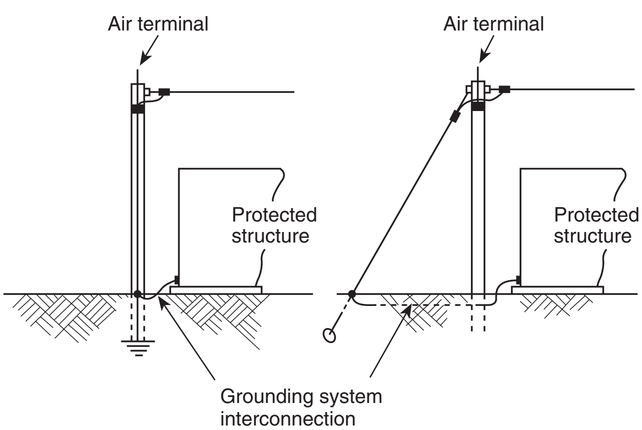


Figure 6-3.3.4 Alternate grounding method for overhead ground-wire protection.

6-4.1.4 Grounding Tanks. Tanks shall be grounded to conduct away the current of direct strokes and to avoid the buildup and potential that can cause sparks to ground. A metal tank shall be grounded by one of the following methods:

(a) A tank is connected without insulated joints to a grounded metallic piping system.

(b) A vertical cylindrical tank rests on earth or concrete and is at least 20 ft (6 m) in diameter, or rests on bituminous pavement and is at least 50 ft (15 m) in diameter.

(c) A tank is bonded to ground through a minimum of two ground terminals, as described in Section 3-13, at maximum 100-ft (30-m) intervals along the perimeter of the tank. This also shall apply to tanks with an insulating membrane beneath the tank.

6-4.2 Earthen Containers at Atmospheric Pressure Containing Flammable Vapors or Liquids that Can Give Off Flammable Vapors. Lined or unlined earthen containers with combustible roofs that enclose flammable vapors or liquids which can give off flammable vapors shall be protected by air terminals, separate masts, overhead ground wires, or a combination of these devices.

6-4.3 Aboveground nonmetallic tanks shall be protected as described in 6-3.3.

Chapter 7 Protection for Watercraft

7-1 General. The intent of this chapter shall be to provide lightning protection requirements for watercraft while in water. Lightning protection systems installed on watercraft shall be installed in accordance with the provisions of this chapter.

7-1.1 A lightning protection system installed in accordance with the requirements of this chapter shall offer no protection for a watercraft that is out of the water.

7-1.2 Personnel on small watercraft shall exit the water as quickly as practical when an approaching thunderstorm is noticed. (*See Appendix C for information on personnel safety.*)

7-1.3 A lightning protection system shall not be intended to afford protection if any part of the watercraft contacts a power line or other voltage source while in water or on shore.

7-2 Materials.

7-2.1 The materials used in the lightning protection system shall be resistant to corrosion. The use of combinations of metals that form detrimental galvanic couples shall be avoided.

7-2.2 In those cases where it is impractical to avoid a junction of dissimilar metals, the corrosion effect shall be permitted to be reduced by the use of suitable plating or special connectors, such as stainless steel connectors used between aluminum and copper alloys.

Exception: Except for the use of conducting materials that are part of the structure of the watercraft, such as aluminum masts, only copper shall be used in a lightning conductor system. All copper conductors shall be the grade ordinarily required for commercial electrical work, which generally is designated as providing 98-percent conductivity where annealed.

7-2.3* Copper Conductors. Copper cable conductors shall be of a diameter not less than No. 4 AWG (41,740 CM) for the main down conductor, not less than No. 6 AWG for two parallel paths, or No. 8 AWG for more than two paths (such as those to shrouds and stay connections on sailboats). The thickness of any copper ribbon or strip (except for grounding plates and strips as discussed in 7-5.1) shall not be less than No. 20 AWG. Where other materials are used, the gauge shall be such as to provide conductivity equal to or greater than the required conductor size.

7-2.4 Joints. Joints shall be mechanically strong and shall be made so that they do not have an electrical resistance in excess of 2 ft (0.610 m) of conductor.

7-3 Antennas and Masts.

7-3.1 General. The zone of protection for watercraft is based on a striking distance of 100 ft (30 m). The zone of protection afforded by any configuration of masts or other elevated conductive objects can be readily determined graphically or mathematically as shown in Figure 7-3.1(a). Figure 7-3.1(b) provides an example of how the zone of protection is to be determined for a watercraft with multiple masts.

7-3.2 Strike Termination Devices. Strike termination devices (including conductive masts, etc.) meeting the requirements of Section 3-6 shall be so located and of sufficient height to provide a zone of protection that covers the entire watercraft. They shall be mechanically strong to withstand the roll and pitching action of the hull as well as heavy weather. The strike termination device shall be permitted to be raked at an angle, but shall be substantially vertical.

7-3.3 Metallic Masts. A metallic mast used as a strike termination device shall have a conductivity equivalent to a No. 4 AWG copper conductor. It shall be grounded in accordance with the requirements provided in Sections 7-4 and 7-5.

7-3.4 Nonmetallic Masts. A nonmetallic mast not within the zone of protection of a strike termination device shall be provided with an air terminal as described in Section 3-6. The air terminal shall extend a minimum of 6 in. (152 mm) above the mast. The air terminal shall be provided with a copper conductor or strip securely fastened to the mast. The down conductor shall have a conductivity equivalent to a No. 4 AWG copper conductor. A grounding system meeting the requirements of Section 7-5 also shall be provided.

7-3.5 Radio Antennas. A solid metal vertical radio antenna shall be permitted to serve as a strike termination device for small nonmetallic watercraft, provided a provision is made to ground the metal antenna with a conductor equivalent to a No. 4 AWG copper conductor. The conductor shall be routed vertically to the maximum extent practical (minimizing bends, etc.) to the lightning grounding plate, the lightning grounding strip under the watercraft, or to an equalization bus. The height of the antenna shall be sufficient to provide the required zone of protection for the watercraft and its occupants.

Because a loading coil presents a high impedance to the flow of lightning currents, the coil shall be shorted, equipped with a surge suppression device (lightning arrester) for bypassing the lightning current, or grounded above the coil.

Nonmetallic radio antennas with spirally wrapped conductors shall not be used for lightning protection.

7-3.6 Temporary Strike Termination Device. On small watercraft that cannot be equipped with a permanent strike termination device, a temporary strike termination device shall be permitted. The temporary strike termination device shall be located so as to provide a zone of protection covering the entire watercraft and its occupants when installed. Temporary strike termination devices shall have a conductivity equivalent to a No. 4 AWG copper conductor.

Exception: A solid stainless steel whip antenna or equivalent shall be permitted to be used as a temporary strike termination device.*

The location of the strike termination device base shall be such that persons on the watercraft can avoid physical contact with the strike termination device or its base.

7-4 Conductors.

7-4.1 Lightning Grounding Conductors. Lightning grounding conductors shall be routed directly to a ground, as discussed in Section 7-5, to the maximum extent practicable (minimizing bends, etc.). Lightning grounding conductors also shall be routed as remotely as possible from the watercraft's wiring to minimize sideflashes and to avoid introducing high voltages into the watercraft's wiring system. The watercraft wiring system shall be routed perpendicular to the lightning grounding conductors where practicable.

7-4.2* Interconnecting Conductors. An interconnecting conductor, equivalent to No. 8 AWG copper conductor, shall be provided at all locations where sideflashes are likely to occur. Large metallic masses that are subject to sideflashes shall be connected to the lightning grounding plate(s), the lightning grounding strip, or to the equalization bus, if provided, in accordance with Section 7-6.

7-4.3 Metallic Tanks. Metallic tanks shall be connected directly to the lightning ground plate(s), the lightning grounding strip, or to the equalization bus.

7-4.4 Shrouds and Stays. Shrouds and stays shall be permitted as part of the path to ground from the mast (strike termination device) to the lightning grounding plate or strip. The aggregate conductivity and inductance, including the mast, shall be not less than that of a No. 4 AWG copper conductor. Where stainless steel shrouds and stays are used in the lightning protection system, every shroud or stay shall be connected at its lower end or at the chainplates directly to the lightning grounding plate or lightning grounding strip with conductors having the minimum size of a No. 8 AWG copper conductor.

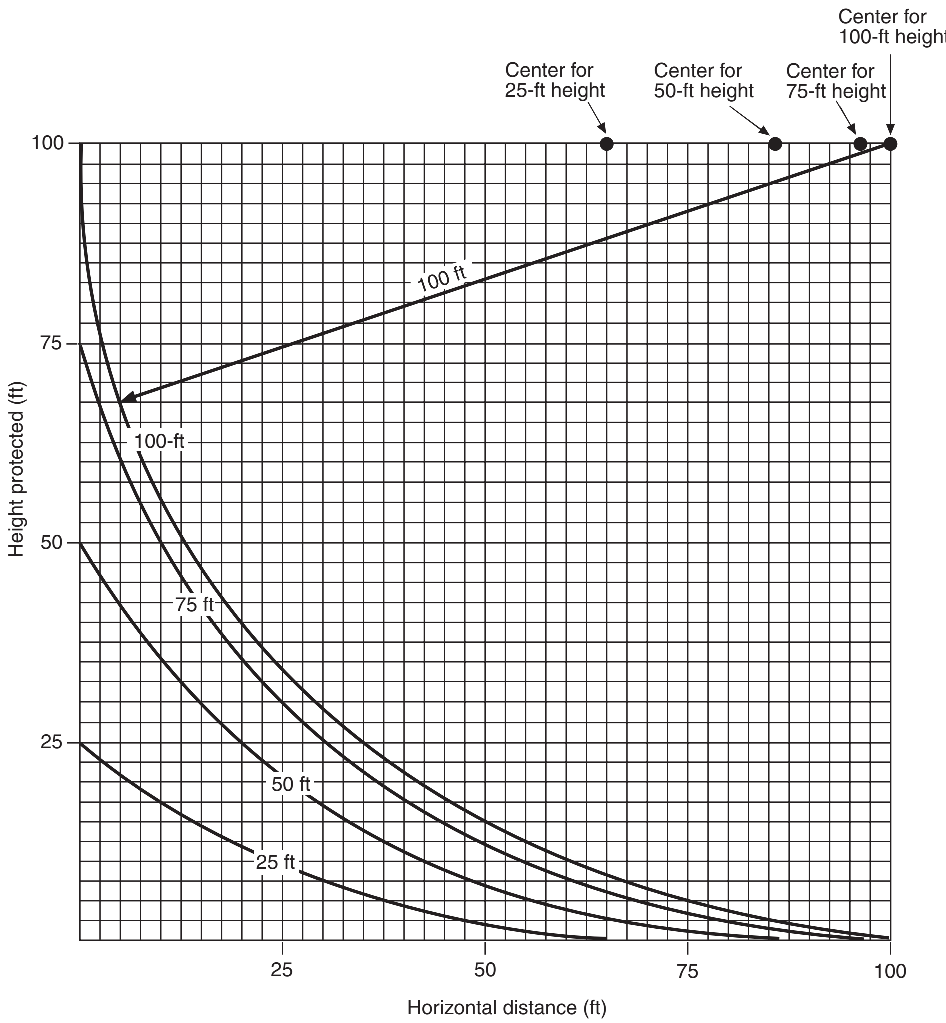
Stainless steel shrouds of small diameter and stays on small sailboats that are trailered without the required conductivity (less than that of a No. 8 AWG copper conductor) shall be grounded at their lower ends in addition to the grounding of the mast.

7-5 Grounding.

7-5.1 Watercraft with Metal Hulls. If an electrical connection exists between a metallic hull and a lightning air terminal or other metallic superstructure of sufficient height to provide the zone of protection specified in Section 7-3, no further protection shall be necessary; however, surge suppression in accordance with Section 3-18 shall be provided. Conducting objects projecting above metal masts or superstructures shall be grounded with a grounding conductor connected to the metal hull or superstructure.

7-5.2 Watercraft with Nonmetallic Hulls. Grounding plates or strips shall be installed on the underside of the hull of nonmetallic watercraft to provide a path for the lightning current into the water.

7-5.2.1 Grounding Plate. A grounding plate of copper, copper alloys, or stainless steel shall be provided. The plate shall have a minimum size of 1 $ft^2 \times {}^3/_{16}$-in. (0.09 $m^2 \times$ 4.8-mm) thick. It shall be located as closely as possible below the strike termination device. Through-hull connectors shall be metallic and have a cross-sectional area equivalent to a No. 4 AWG copper conductor.



Note: The distance can be determined analytically for a 100-ft (30-m) striking distance with the following equation:

$$d = \sqrt{h_1 (200 - h_1)} - \sqrt{h_2 (200 - h_2)}$$

where: d = horizontal distance (ft)
h_1 = height of strike termination device (ft)
h_2 = height of object to be protected (ft)

SI units: 1 ft = 0.305 m

Figure 7-3.1(a) Zone of protection—100-ft (30-m) striking distance.

7-5.2.2 Grounding Strip. An external grounding strip of copper, copper alloys, or stainless steel installed under the watercraft running fore and aft shall have a minimum thickness of $^3/_{16}$ in. (4.8 mm) and a minimum width of $^3/_4$ in. (19 mm). The length of the strip shall be permitted to extend from a point located directly below the strike termination device to the aft end of the watercraft where a direct connection shall be made to the engine. The total length of the strip shall be not less than 4 ft (1.2 m).

In a sailboat, the backstray and engine shall be electrically connected to the aft end of the strip. The strip shall be secured to the hull with one, or preferably two, galvanically compatible throughbolts at each end. The bolts shall have a minimum cross-sectional area equivalent to a No. 4 AWG copper conductor. The strip shall be located so that it is submerged under all operating conditions. If the single strip is not located so as to be continuously submerged when the vessel is heeled either to port or starboard, then a strip shall be required on both port and starboard sides. Where more than one grounding strip is provided, all of the grounding strips shall be bonded together.

All terminations to the strip shall be made as short and direct as possible.

Additional through-hull connections shall be permitted to be located along the length of the strip for additional connections, such as those on a two-masted sailboat. Because of the possibility of stray current corrosion of the securing bolts, the number of through-hull bolts shall be kept to a minimum. To minimize the number of through-hull bolt connections, an equalization bus shall be permitted to be installed in accordance with Section 7-6.

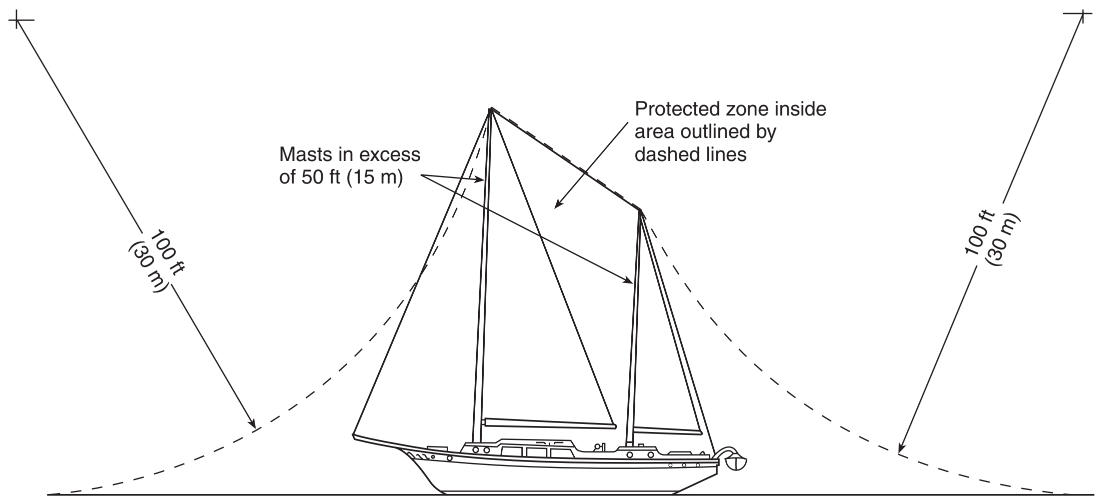


Figure 7-3.1(b) Diagram of boat with masts in excess of 50 ft (15 m) above the water. Protection based on lightning strike distance of 100 ft (30 m).

The aft end of the grounding strip shall be connected directly to the engine negative ground terminal to provide a path inside the hull for any stray dc currents that are imposed on the through-hull bolts from the lightning grounding strip where those bolts contact bilge water.

7-6 Interconnection of Metallic Masses.

7-6.1 Equalization Bus. On watercraft where several connections are made to the lightning grounding strip, an equalization bus shall be permitted to be installed inside the boat to minimize the number of through-hull bolts needed. The equalization bus, if used, shall be installed inside the watercraft parallel to the underwater location of the lightning grounding strip. Permanently installed large metallic masses inside the watercraft shall be connected directly to the equalization bus. The equalization bus shall be connected to the underwater lightning grounding strip at both ends.

7-6.2* Seacocks and Through-Hull Fittings. Seacocks and through-hull fittings shall not be connected to the main down conductor but shall be permitted to be connected to the underwater grounding strip, the lightning grounding plate, or the equalization bus.

7-6.3 Metal Masses. Metal masses such as engines, generators, metallic tanks, steering systems located inside the vessel, and metal life rails shall be connected to the lightning grounding plate, grounding strip, or equalization bus as directly as possible.

7-6.4 Engine Grounding. To minimize the flow of the lightning discharge currents through the engine bearings, the engine block shall be permitted to be grounded directly to the lightning grounding plate or lightning grounding strip rather than to an intermediate point in the system.

7-6.5 Protection of Equipment. Wherever possible, electronic equipment shall be enclosed in metal cabinets that are connected to the lightning grounding system with a minimum of a No. 8 AWG copper conductor. Surge suppression devices shall be installed on all wiring entering or leaving electronic equipment.

7-7 Nonmetallic Watercraft.

7-7.1 Sailboats. Sailboats without inboard engines that are equipped with metallic masts and metallic rigging shall be considered to be adequately protected if the mast and the rigging chain plates are all connected to a lightning grounding plate or lightning grounding strip located directly below the mast.

7-7.1.1 Open Day-Sailors. Adequate lightning protection on open day-sailors shall depend on the grounding of the rigging as well as the metal masts or the continuous metallic tracks on nonmetallic masts because stainless steel rigging and preventors usually are not equivalent to No. 8 AWG copper conductor. The rigging, metal masts, or metallic tracks on nonmetallic masts shall be connected at the lower ends to a lightning grounding plate or a lightning strip located directly below the mast. Metallic rudders at the aft end of the boat shall not be used as the lightning ground for the mast because of the need for a long, horizontal conductor to be run to the aft end of the boat. The tiller or other connections to metallic rudders which the operator could come into contact with shall be of nonconductive materials. Metallic keels or centerboards shall be directly connected to the lightning grounding plate or strip, or shall be permitted to serve as the lightning grounding means if they provide the 1 ft^2 (0.09 m^2) area required to be in contact with the water. If a centerboard is used as the lightning grounding means, a warning sign shall be provided that clearly states that the centerboard shall be in the down position in order to function as a lightning ground.

7-7.1.2 Cruising Sailboats. All shrouds, stays, sail tracks, and metallic masts shall be connected to the lightning grounding system since it is assumed that occupants of the boat will be in proximity of forestays, backstays, and shrouds during the normal operation of the boat. Grounding of all metallic masses on the boat shall be in accordance with all applicable sections of this standard.

7-7.2* Power Boats. Where practicable, lightning protection shall be provided through the use of a metallic radio antenna, as described in 7-3.5, or a temporary strike termination device, as described in 7-3.6.

Appendix A Explanatory Material

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

A-1-1.2 Electric generating facilities whose primary purpose is to generate electric power are excluded from this standard with regard to generation, transmission, and distribution of power. Most electrical utilities have standards covering the protection of their facilities and equipment. Installations not directly related to those areas and structures housing such installations can be protected against lightning by the provisions of this standard.

Lightning protection systems for structures used for production or storage of explosive materials require special consideration because of the sensitivity to arc or spark ignition of the structures' contents. Appendix K provides guidance for protection of structures housing explosive materials. Other standards and handbooks that provide guidance for military applications are found in Appendix M.

A-2-2

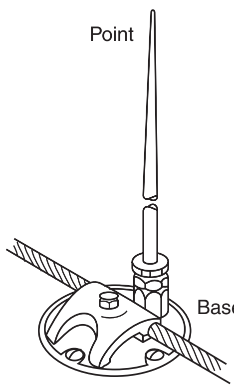


Figure A-2-2(a) Air terminal.

A-2-2 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A-2-2 Authority Having Jurisdiction. The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A-2-2 *[See Figure A-2-2(b).]*

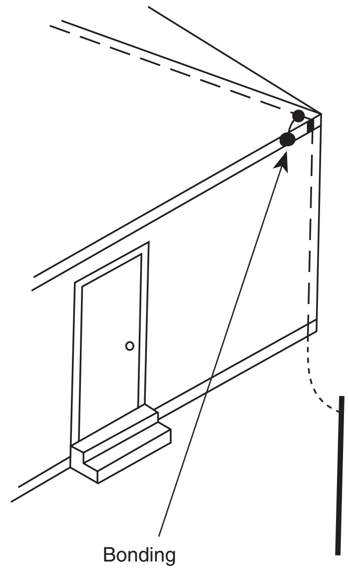


Figure A-2-2(b) Bonding.

A-2-2 *[See Figure A-2-2(c).]*

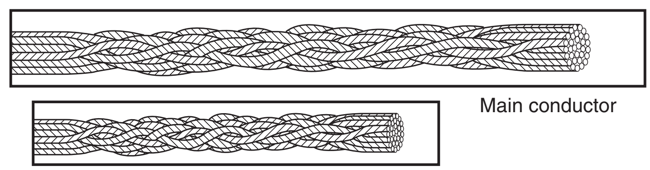


Figure A-2-2(c) Cable.

A-2-2 *[See Figure A-2-2(d).]*

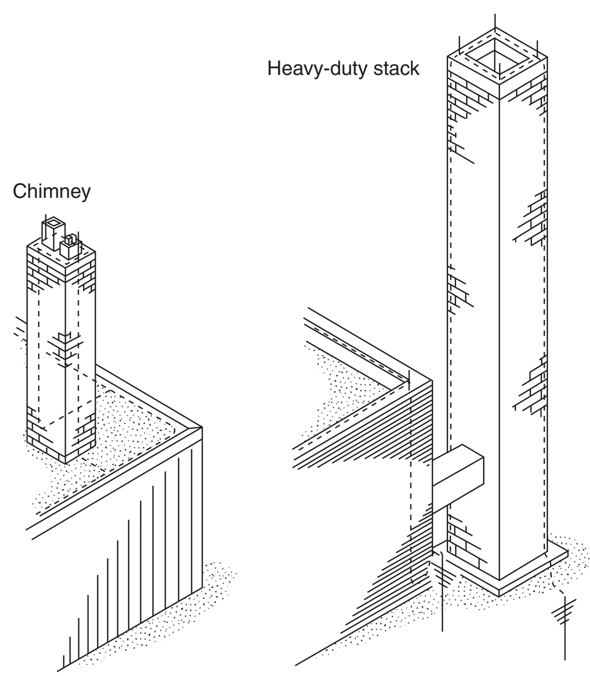


Figure A-2-2(d) Chimney.

A-2-2 *[See Figure A-2-2(e).]*

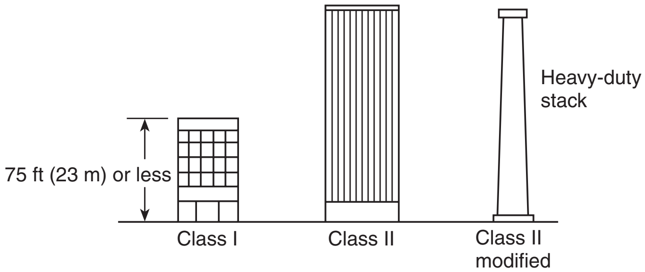


Figure A-2-2(e) Material classifications.

A-2-2 *[See Figure A-2-2(f).]*

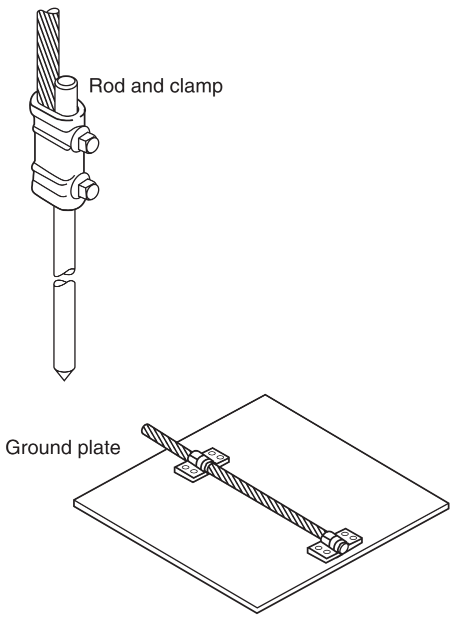


Figure A-2-2(f) Grounding devices.

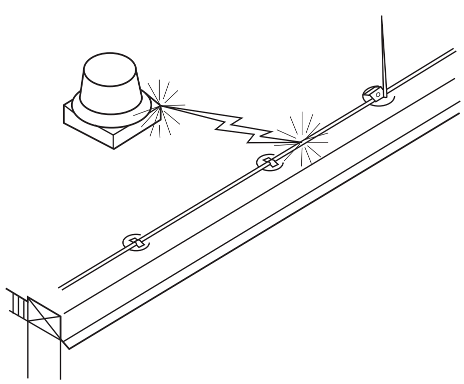


Figure A-2-2(g) Sideflash.

A-2-2 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A-2-2 *[See Figure A-2-2(g).]*

A-3-8.2 *[See Figure A-3-8.2.]*

A-3-13.1 Research has been presented that warns that stainless steel is very susceptible to corrosion in many soil conditions. Extreme caution should be used with proper soil analysis when this type of rod is used. For further information, see NFPA 70, *National Electrical Code®*, which contains detailed information on the grounding of electrical systems.

A-3-18 Electrical systems and utilization equipment within the structure can require further surge suppression. Such protection is not part of this standard. Documents such as ANSI/IEEE C-62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Systems*, NFPA 70, *National Electrical Code,* and UL 1449, *UL Standard for Safety Transient Voltage Surge Suppressors,* provide additional information.

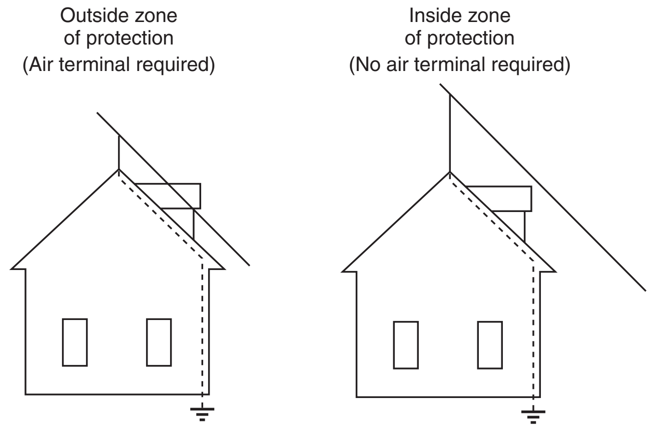


Figure A-3-8.2 Dormers.

A-3-20.1 For structures 60 ft (18 m) or less in height, a loop conductor should be provided for the interconnection of all ground terminals and other grounded media. Regardless of the building height, ground loop conductors should be installed underground in contact with earth. Ground-level potential equalization allows use of a ground ring electrode as a ground loop conductor. A ground ring electrode conforming to 3-13.3 shall be permitted to be utilized for the ground loop conductor.

A-3-20.2 In the case of flat or gently sloping roofs, the roof conductors required by 3-9.7 shall be permitted to be used for achieving roof-level potential equalization. In the case of pitched roofs, the interconnection should be a loop placed at the eave level.

A-3-21.3 In addition to the bonding of metal bodies, surge suppression should be provided to protect power, communication, and data lines from dangerous overvoltages and sparks caused by the lightning strikes. (*See Appendix J for a discussion of bonding and an understanding of problems often encountered.*)

A-5-9 A ground grid located within 50 ft (15 m) of the foundation of a stack and constructed of wires meeting the requirements of this standard for main conductors is an acceptable ground terminal and, if the stack is located within 50 ft (15 m) of the grid in all directions, can also serve as the bottom loop conductor required by 5-4.2.

A-6-1.1 Flammable vapors can emanate from a flammable liquid [flash point below 100°F (37.8°C)] or a combustible liquid [flash point at or above 100°F (37.8°C)] when the temperature of the liquid is at or above its flash point. This chapter applies to these liquids when stored at atmospheric pressure and ambient temperature. Provided that the temperature of the liquid remains below the flash point, combustible liquids stored under these conditions will not normally release significant vapors since their flash point is defined to be at or above100°F (37.8°C).

Metallic tanks, vessels, and process equipment that contain flammable or combustible liquids or flammable gases under pressure normally do not require lightning protection since this equipment is well shielded from lightning strikes. Equipment of this type is normally well grounded and is thick enough not to be punctured by a direct strike.

This chapter applies to flammable or combustible liquids such as gasoline, diesel, jet fuel, fuel oil, or crude oil stored at atmospheric pressure. It does not apply to liquids or gases stored under pressure, such as liquefied natural gases or liquefied petroleum gases.

A-6-3.3.3 The sideflash formulas are based on the impedance of main sized copper conductors. Other ground wire materials may require additional separation distance.

A-7-2.3 See NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft,* Table 7-12.5 for minimum strand sizes for watercraft conductors.

A-7-3.6 Exception. A solid stainless steel whip antenna or equivalent is permitted to be used because of its higher melting temperature, however it does not provide as low a resistance as a No. 4 AWG copper conductor.

A-7-4.2 Sideflash distances can be calculated using the formulas provided in Section 3-21. Sideflashes are more likely to occur if the routing of the lightning conductor is horizontal for some distance and if the metallic object provides a more direct path to ground.

A-7-6.2 Seacocks are particularly susceptible to damage and leaking after a strike and should be inspected after all suspected strikes.

A-7-7.2 At the approach of a thunderstorm, personnel should head for shore and quickly seek a land-based protected structure. There are many methods available by which lightning can be detected. These methods range from listening for static on AM radios, to single station detection devices, to sophisticated lightning location systems.

Appendix B Inspection and Maintenance of Lightning Protection Systems

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

B-1 Inspection of Lightning Protection Systems.

B-1.1 Frequency of Inspections. It is understood that all new lightning protection systems must be inspected following completion of their installation. However, it is also very important to make periodic inspections of existing systems. The interval between inspection should be determined by such factors as the following:

(a) Classification of structure or area protected

(b) Level of protection afforded by the system

(c) Immediate environment (corrosive atmospheres)

(d) Materials from which components are made

(e) Type of surface to which the lightning protection components are attached

(f) Trouble reports or complaints

B-1.1.1 In addition to the above, a lightning protection system should be inspected whenever any alterations or repairs are made to a protected structure, as well as following any known lightning discharge to the system.

B-1.1.2 It is recommended that lightning protection systems be visually inspected at least annually. In some areas where severe climatic changes occur it may be advisable to visually inspect systems semiannually or following extreme changes in ambient temperatures. Complete, in-depth inspections of all systems should be completed every three to five years. It is recommended that critical systems be inspected every one to three years depending on occupancy or the environment where the protected structure is located.

B-1.1.3 In most geographical areas, and especially in areas that experience extreme seasonal changes in temperature and rainfall, it is advisable to stagger inspections so that earth resistance measurements, for example, are made in the hot, dry months as well as the cool, wet months. Such staggering of inspections and testing is important in assessing the effectiveness of the lightning protection system during the various seasons throughout the year.

B-1.2 Visual Inspection. Visual inspections are made to ascertain the following:

(a) The system is in good repair.

(b) There are no loose connections that might result in high-resistance joints.

(c) No part of the system has been weakened by corrosion or vibration.

(d) All down conductors and ground terminals are intact (nonsevered).

(e) All conductors and system components are securely fastened to their mounting surfaces and are protected against accidental mechanical displacement as required.

(f) There have not been additions or alterations to the protected structure that would require additional protection.

(g) There has been no visual indication of damage to surge suppression (overvoltage) devices.

(h) The system complies in all respects with the current edition of this standard.

B-1.3 Complete Testing and Inspection. Complete testing and inspection includes the visual inspections described in B-1.2 and the following:

(a) Tests to verify continuity of those parts of the system that were concealed (built-in) during the initial installation and that are not now available for visual inspection.

(b) Ground resistance tests of the ground termination system and its individual ground electrodes if adequate disconnecting means have been provided. These test results should be compared with previous or original results or current accepted values, or both, for the soil conditions involved. If it is found that the test values differ substantially from previous values obtained under the same test procedures, additional investigations should be made to determine the reason for the difference.

(c) Continuity tests to determine if suitable equipotential bonding has been established for any new services or constructions that have been added to the interior of the structure since the last inspection.

B-1.4 Inspection Guides and Records. Inspection guides or forms should be prepared and made available to the authority responsible for conducting inspections of lightning protection systems. These guides should contain sufficient information to guide the inspector through the inspection process so that he or she may document all areas of importance relating to the methods of installation, the type and condition of system components, test methods, and the proper recording of the test data obtained.

B-1.5 Records and Test Data. The inspector or inspection authority should compile and maintain records pertaining to the following:

(a) General condition of air terminals, conductors, and other components

(b) General condition of corrosion-protection measures

(c) Security of attachment of conductors and components

(d) Resistance measurements of various parts of the ground terminal system

(e) Any variations from the requirements contained in this standard

B-2 Maintenance of Lightning Protection Systems.

B-2.1 General. Maintenance of a lightning protection system is extremely important even though the lightning-protection design engineer has taken special precautions to provide corrosion protection, and has sized the components according to their particular exposure to lightning damage. Many system components tend to lose their effectiveness over the years because of corrosion factors, weather-related damage, and stroke damage. The physical, as well as the electrical, characteristics of the lightning protection system must be maintained in order to maintain compliance with design requirements.

B-2.2 Maintenance Procedures.

B-2.2.1 Periodic maintenance programs should be established for all lightning protection systems. The frequency of maintenance procedures is dependent on the following:

(a) Weather-related degradation

(b) Frequency of stroke damage

(c) Protection level required

(d) Exposure to stroke damage

B-2.2.2 Lightning protection system maintenance procedures should be established for each system and should become a part of the overall maintenance program for the structure that it protects.

A maintenance program should contain a list of more or less routine items that can serve as a checklist and establish a definite maintenance procedure that can be followed regularly. It is the repeatability of the procedures that enhance the effectiveness of a good maintenance program.

A good maintenance program should contain provisions for the following:

(a) Inspection of all conductors and system components

(b) Tightening of all clamps and splicers

(c) Measurement of lightning protection system resistance

(d) Measurement of resistance of ground terminals

(e) Inspection or testing, or both, of surge suppression devices to determine their effectiveness compared with similar new devices

(f) Refastening and tightening of components and conductors as required

(g) Inspection and testing as required to determine if the effectiveness of the lightning protection system has been altered due to additions to, or changes in, the structure

B-2.3 Maintenance Records. Complete records should be kept of all maintenance procedures and routines and should include corrective actions that have been or will be taken. Such records provide a means of evaluating system components and their installation. They also serve as a basis for reviewing maintenance procedures as well as updating preventive maintenance programs.

Appendix C Guide for Personal Safety from Lightning

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

C-1 Scope. The purpose of this appendix is to furnish a guide for personal safety from lightning. Personnel can be at risk prior to any visual or audible indication of a thunderstorm. Any time that conditions that could lead to lightning activity exist, personnel safety should be considered. Lightning warning systems are available to provide early warning of lightning activity.

C-2 Personal Conduct during Lightning Activity.

C-2.1 Do not go out-of-doors or remain out, unless it is necessary. Seek shelter in structures such as the following:

(a) Dwellings or other buildings that are protected against lightning

(b) Underground shelters such as subways, tunnels, and caves

(c) Large metal-frame buildings

(d) Large unprotected buildings

(e) Enclosed automobiles, buses, and other vehicles with metal tops and bodies

(f) Enclosed metal trains and street cars

(g) Enclosed metal boats or ships

(h) Boats that are protected against lightning

(i) City streets shielded by nearby buildings

C-2.2 If possible, avoid places with little or no protection from lightning such as the following:

(a) Small, unprotected buildings, barns, sheds, and so forth

(b) Tents and temporary shelters

(c) Automobiles (nonmetal top or open)

(d) Trailers (nonmetal or open)

C-2.3 Certain locations are extremely hazardous during thunderstorms and should be avoided if at all possible. Approaching thunderstorms should be anticipated and the following locations avoided when thunderstorms are in the immediate vicinity:

(a) Hilltops and ridges

(b) Areas on top of buildings

(c) Open fields, athletic fields, golf courses

(d) Parking lots and tennis courts

(e) Swimming pools, lakes, and seashores

(f) Near wire fences, clotheslines, overhead wires, and railroad tracks

(g) Under isolated trees

(h) Near electrical appliances, telephones, plumbing fixtures, and metal or electrically conductive objects

C-2.4 It is especially hazardous to be riding in or on any of the following during thunderstorms while in the locations described in C-2.3:

(a) Open tractors or other farm machinery operated in open fields

(b) Golf carts, scooters, bicycles, or motorcycles

(c) Open boats (without masts) and Hovercraft

(d) Automobiles (nonmetal top or open)

C-2.5 It may not always be possible to choose a location that offers good protection from lightning, but the following rules should be observed when a location can be selected:

(a) Seek depressed areas—avoid mountaintops, hilltops, and other high places.

(b) Seek dense woods—avoid isolated trees.

(c) Seek buildings, tents, and shelters in low areas—avoid unprotected buildings.

(d) If hopelessly isolated in an exposed area, drop to knees and bend forward, putting hands on knees.

C-3 Protection for Personnel in Watercraft. Inasmuch as the basic purpose of protection against lightning is to ensure the safety of personnel, it is appropriate that the following precautions and suggestions be listed in addition to all applicable recommendations in the preceding sections.

C-3.1 One should remain inside a closed boat, as far as practical, during a lightning storm and should not dangle arms or legs in the water.

C-3.2 To the extent consistent with safe handling and navigation of the boat during a lightning storm, one should avoid making contact with any items connected to a lightning protection system and especially in such a way as to bridge between these items. For example, it is undesirable that an operator be in contact with reversing gear levers and spotlight control handle at the same time.

C-3.3 No one should be in the water during a lightning storm.

Appendix D Protection for Livestock in Fields

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

D-1 General.

D-1.1 The nature of the exposure of livestock in fields is such that it is not possible to eliminate the hazard entirely. However, application of the recommendations contained in this appendix can minimize the hazard.

D-1.2 The loss of livestock due to lightning during thunderstorms is caused in large measure by herds congregating under isolated trees in open pastures or drifting against ungrounded wire fences and receiving a sufficient discharge to kill them.

D-1.3 In pastures where shelter is available from wooded areas of considerable size, isolated trees should be removed unless protection is provided.

D-1.4 Fences built with metal posts set in the earth are as safe from lightning as it is practical to make them, especially if the electrical continuity is broken. Breaking the electrical continuity is very useful in that it reduces the possibility of a lightning stroke affecting the entire length of a fence, as is possible if the stroke is direct and the fence continuous, even though it may be grounded. The fences that give rise to the most trouble are those constructed with posts of poorly conducting material, such as wood.

D-2 Grounding of Wire Fences.

D-2.1 Where it is desirable or necessary to mitigate the danger from wire fences constructed with posts of nonconducting material, D-2.2 and D-2.3 should be applied.

D-2.2 Iron Posts. Ground connections may be made by inserting galvanized-iron posts, such as are ordinarily used for farm fencing, at intervals and attaching in electrical contact all of the wires of the fence. Grounding can also be achieved by driving a length of not less than $^1/_2$ in. (12.7 mm) in diameter galvanized-iron pipe beside the fence and attaching the wires by ties of galvanized-iron wire. If the ground is normally dry, the intervals between metal posts should not exceed about 150 ft (46 m). If the ground is normally damp, the metal posts may be placed up to about 300 ft (92 m) apart.

D-2.3 Depth of Grounds. Pipes should be extended into the ground at least 2 ft (0.6 m).

D-3 Breaking Continuity of Fence.

D-3.1 In addition to grounding the fence, its electrical continuity should be broken by inserting insulating material in breaks in the wires at intervals of about 500 ft (150 m). These insertions may be in the form of fence panels of wood or lengths of insulating material to the ends of which the wires can be attached. Such lengths of insulating material may consist of strips of wood about 2 in. × 2 in. × 24 in. (50 mm × 50 mm × 600 mm), or their equivalent as far as insulating properties and mechanical strength are concerned.

D-3.2 In areas where herds may congregate along fences, the continuity should be broken at more frequent intervals than described in D-3.1.

Appendix E Protection for Picnic Grounds, Playgrounds, Ball Parks, and Other Open Places

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

E-1 Picnic Grounds and Playgrounds. Protection from lightning may be provided by the methods indicated in E-1.1 or E-1.2.

E-1.1 Shelters with Lightning Protection Systems. Shelters with closed or open sides that are equipped with lightning protection systems should be provided. Down conductors should be shielded with nonconductive material resistant to impact and climate conditions to at least an 8-ft (2.4-m) height. Shelters with earthen floors should have the following:

(a) Ground terminals interconnected by an encircling, buried, bare copper conductor, or

(b) Ground terminals provided with buried radial conductors run out at least 10 ft (3 m) from the ground terminal away from the shelter.

E-1.2 Masts and Overhead Ground Wires. Masts (poles) on opposite sides of the grounds and near the edges should be erected. Overhead wires should be strung between the masts at least 20 ft (6.1 m) above the ground level. Down conductors should be connected to the overhead wires with ground terminals. Down conductors should be shielded with material resistant to impact and climate conditions to at least an 8-ft (2.4-m) height. The wires should be not less than No. 4 AWG copper or equivalent. If steel masts are used, down leads are not necessary but the foot of the mast should be grounded. If the area to be protected is extensive, it may be necessary to erect several masts around the perimeter so that the area is covered by a network of wires to form a zone of protection. [*See Figure 6-3.3.1(a) for an example.*]

E-2 Ball Parks and Racetracks.

E-2.1 Roofed Grandstands. Roofed grandstands are included within the scope of this standard.

E-2.2 Open Grandstands and Open Spectator Areas. Open grandstands and open spectator areas should be provided with masts and overhead ground wires as described in E-1.2.

E-3 Beaches. Beaches should be provided with shelters as described in E-1.1.

E-4 Piers.

E-4.1 Covered Piers. Covered piers are included within the scope of this standard.

E-4.2 Open Piers. Open piers should be provided with masts and overhead ground wires as described in E-1.2.

Appendix F Protection for Trees

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

F-1 General. Trees with trunks within 10 ft (3 m) of a structure, or with branches that extend to a height above the structure should be equipped with a lightning protection system because of the danger of sideflash, fire, or superheating of the moisture in the tree, which could result in the splintering of the tree. It might be desirable to equip other trees with a lightning protection system because of the tree's particular value to the owner. (*See Figure F-1.*)

F-2 Methods and Materials.

F-2.1 Conductors. Conductors should conform to the requirements of Chapter 3.

F-2.2 Coursing of Conductors. A single conductor should be run from the highest part of the tree along the trunk to a ground connection. If the tree is forked, branch conductors should be extended to the highest parts of the principal limbs. If the tree trunk is 3 ft (0.9 m) in diameter or larger, two down conductors should be run on opposite sides of the trunk and interconnected.

F-2.3 Air Terminals. The conductors should be extended to the highest part of the tree terminating with an air terminal.

F-2.4 Attachment of Conductors. Conductors should be securely attached to the tree in such a way as to allow for swaying in the wind and growth without danger of breakage.

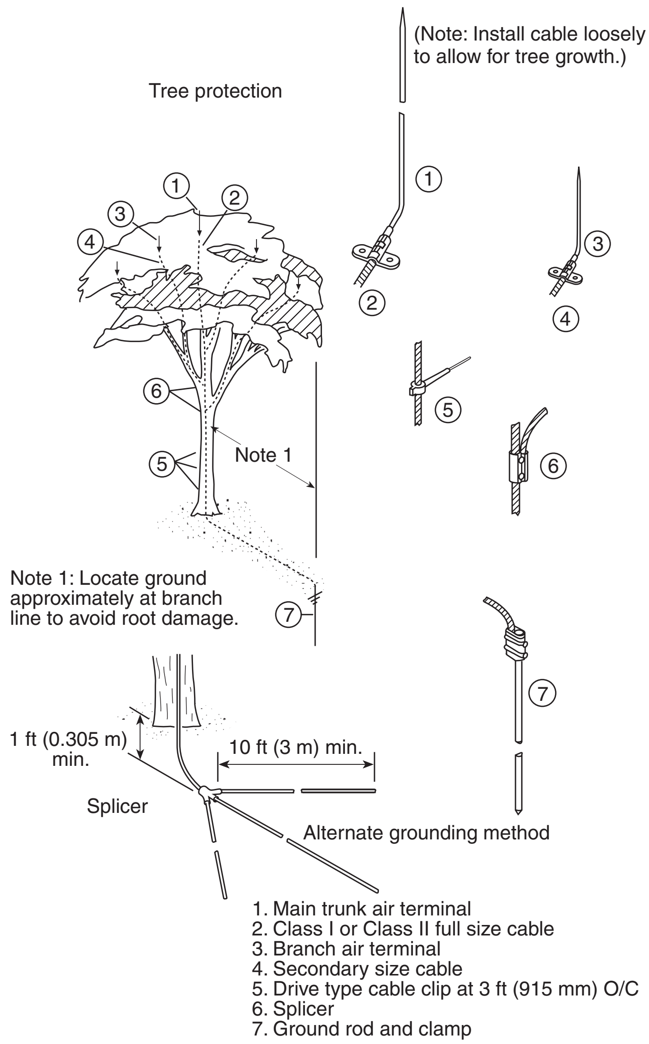


Figure F-1 Protection for trees.

F-2.5 Ground Terminals. Ground terminals for conductors should be in accordance with the following:

(a) Be made from each conductor, descend the trunk of the tree, extend three or more radial conductors in trenches 1 ft (0.3 m) deep, and be spaced at equal intervals about the base to a distance of not less than 10 ft (3 m)

(b) Have the radial conductors extended to the branch line not less than 25 ft (7.6 m)

(c) Have the out ends connected to the radial conductors with a conductor that encircles the tree at a depth of not less than 1 ft (0.3 m)

(d) Be bonded to an underground metallic water pipe where available within 25 ft (7.6 m) of the branch line

Appendix G Protection for Parked Aircraft

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

G-1 General Principles.

G-1.1 For the purposes of this appendix, aircraft includes airplanes, helicopters, and lighter-than-air craft. Aircraft can best be protected by being placed inside a properly lightning-protected hangar. Hangar facilities should be provided with grounding receptacles to permit interconnection of metal aircraft with the hangar lightning protection system. It is important that hangar floors, aprons, and aircraft parking areas be kept free of gasoline or other flammable liquids.

G-1.2 All metal airplanes parked outside hangars should be grounded. This grounding may be achieved by the use of adequately grounded metal tie-down cables or the equivalent. Aircraft having fabric or plastic covering materials can be protected by connecting its metal frame to ground. For additional protection of aircraft parked outside hangars, an overhead ground wire or mast-type lightning protection system may be provided. The height should be in accordance with the zones of protection described in Chapter 3.

G-1.3 The effects of lightning strikes to metal and composite aircraft are a matter of continuous study. The use of surge suppression circuitry on critical navigational, radio-communication, and radar equipment can help to minimize these effects. Suitable equipment and electrical wiring layout can also aid in reducing lightning-induced problems.

G-1.4 Commercial aircraft have grown considerably larger in recent years and in many cases are taller than surrounding airport terminal buildings. A review of available lightning-strike injury data indicates that nearly all of the reported personnel injuries were the result of lightning-induced static discharge.

G-1.5 The grounding methods used for aircraft undergoing fuel servicing and certain maintenance operations are not necessarily adequate to provide effective lightning protection for aircraft or personnel. The installation of additional grounding straps, preferably at the aircraft's extremities, during thunderstorm activity will provide alternative paths to ground for any current flow resulting from the rapid adjustment in the aircraft surface charge. Experience has shown that additional grounding straps offer little protection in the event of a direct strike to the aircraft. Fuel-servicing operations and other maintenance operations involving the use of flammable liquids or the release of flammable vapors should be suspended during lightning storms. Refer to NFPA 407, *Standard for Aircraft Fuel Servicing*, and NFPA 410, *Standard on Aircraft Maintenance,* for more information.

G-1.6 Baggage handling, exterior maintenance, and servicing of parked aircraft should be suspended when a thunderstorm is in the vicinity of an airport. Lightning-warning equipment can be utilized to aid in determining when to suspend these operations. There are many detection methods capable of detecting and tracking approaching storms. One such method, atmospherics, is being used to establish lightning-detection networks that now cover approximately half of the United States. While atmospherics equipment can give positional information of distant lightning, it gives no warning of a cloud directly overhead becoming electrified. Devices that measure some property of the electric field can detect the development of a hazardous condition and provide a warning prior to the first discharge.

G-1.7 Cables connected to parked aircraft should not be handled when a thunderstorm is in the vicinity. The use of hand signals, without the use of headsets, is recommended for ground-to-cockpit communications during this period.

Appendix H Risk Assessment Guide

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

H-1 General.

H-1.1 This lightning risk assessment guide is prepared to assist in the analysis of various criteria to determine the risk of loss due to lightning. As a guide, it is not possible to cover each special design element that may render a structure more or less susceptible to lightning damage. In special cases, personal and economic factors may be very important and should be considered in addition to the assessment obtained by use of this guide.

H-1.2 If the structure is in a high risk situation, a risk index, *R*, should be computed for a wide range of structures in the environment concerned. The structure's index is then compared to the index of these other structures so that a judgment of local risk weighting can be made.

H-2 Determining the Risk. The assessment of risk index, *R*, is given in Table H-2. The risk index, *R*, is obtained by dividing the sum of the values given in Tables H-2(a) through H-2(e) by the lightning frequency index value obtained from Table H-2(f).

The risk index, *R*, is calculated using the following formula:

$$R = \frac{A + B + C + D + E}{F}$$

Table H-2 Assessment of Risk, *R*

R Value	Risk Value
0–2	Light
2–3	Light to Moderate
3–4	Moderate
4–7	Moderate to Severe
Over 7	Severe

The computed *R* values for the eastern United States should be multiplied by a factor varying from 1.5 in the northeast to 0.5 in the southeast. This factor is due to the differences in storm characteristics in these regions.

Table H-2(a) Index *A* — Type of Structure

Structure	Index Value
Single family residence less than 5,000 ft^2 (465 m^2)	1
Single family residence over 5,000 ft^2 (465 m^2)	2
Residential, office, or factory building less than 50 ft (15 m) in height:	
Covering less than 25,000 ft^2 (2,323 m^2) of ground area	3
Covering over 25,000 ft^2 (2,323 m^2) of ground area	5
Residential, office, or factory building from 50 ft to 75 ft (15 m to 23 m) high	4
Residential, office, or factory building from 75 ft to 150 ft (23 m to 46 m) high	5
Residential, office, or factory building from 150 ft (46 m) or higher	8
Municipal services buildings, fire, police, water, sewer, etc.	7
Hangars	7
Power-generating stations, central telephone exchanges	8
Water towers and cooling towers	8
Libraries, museums, historical structures	8
Farm buildings	9
Golf shelters and other recreational shelters	9
Places of public assembly such as schools, churches, theaters, stadiums	9
Slender structures such as smokestacks, church steeples and spires, control towers, lighthouses, etc.	10
Hospitals, nursing homes, housing for the elderly or handicapped	10
Buildings housing the manufacture, handling, or storage of hazardous materials	10

Table H-2(b) Index *B* — Type of Construction

Structural Framework	Roof Type	Index Value
Nonmetallic	Wood	5
(Other than wood)	Composition	3
	Metal — not continuous	4
	Metal — electrically continuous	1
Wood	Wood	5
	Composition	3
	Metal — not continuous	4
	Metal — electrically continuous	2
Reinforced Concrete	Wood	5
	Composition	3
	Metal — not continuous	4
	Metal — electrically continuous	1
Structural Steel	Wood	4
	Composition	3
	Metal — not continuous	3
	Metal — electrically continuous	1

NOTE: Composition roofs include asphalt, tar, tile, slate, etc.

Table H-2(c) Index *C* — Relative Location

Location	Index Value
Structures in areas of higher structures:	
Small structures — covering ground area of less than 10,000 ft^2 (929 m^2)	1
Large structures — covering ground area of more than 10,000 ft^2 (929 m^2)	2
Structures in areas of lower structures:	
Small structures — covering ground area of less than 10,000 ft^2 (929 m^2)	4
Large structures — covering ground area of more than 10,000 ft^2 (929 m^2)	5
Structures extending up to 50 ft (15.2 m) above adjacentstructures or terrain	7
Structures extending more than 50 ft (15.2 m) above adjacent structures or terrain	10

Table H-2(d) Index *D* — Topography

Location	Index Value
On flat land	1
On hillside	2
On hilltop	4
On mountaintop	5

Table H-2(e) Index *E* — Occupancy and Contents

Occupancy and Contents	Index Value
Noncombustible materials — unoccupied	1
Residential furnishings	2
Ordinary furnishings or equipment	2
Cattle and livestock	3
Small assembly of people — less than 50	4
Combustible materials	5
Large assembly of people — 50 or more	6
High value materials or equipment	7
Essential services — police, fire, etc.	8
Immobile or bedfast persons	8
Flammable liquids or gases — gasoline, hydrogen, etc.	8
Critical operating equipment	9
Historic contents	10
Explosives and explosive ingredients	10

Table H-2(f) Index *F* — Lightning Frequency Isoceraunic Level [See Figures H-2(a) or H-2(b).]

Isoceraunic Level	Index Value
0–5	9
6–10	8
11–20	7
21–30	6
31–40	5
41–50	4
51–60	3
61–70	2
Over 70	1

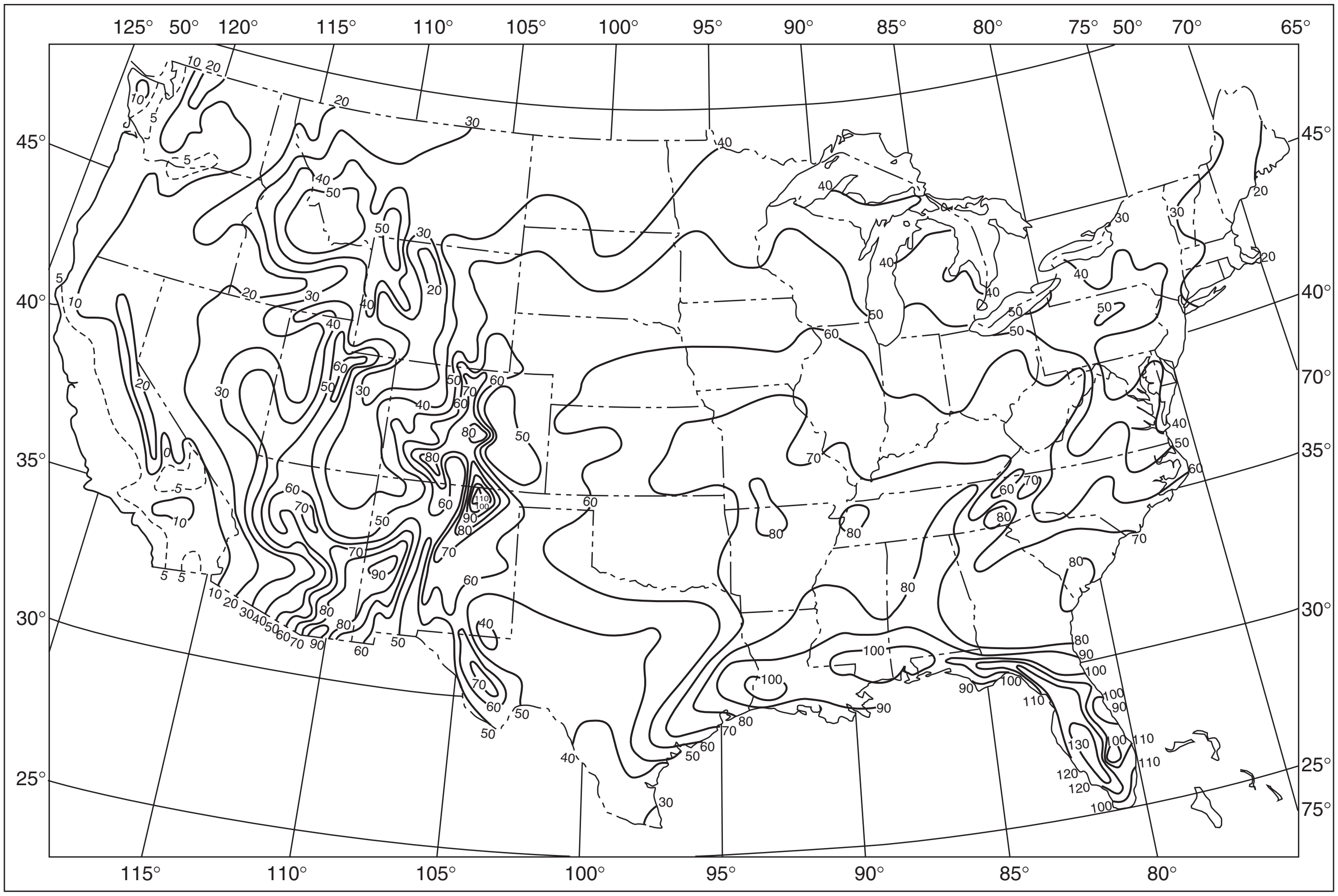


Figure H-2(a) Statistics for continental United States showing mean annual number of days with thunderstorms. Data for the contiguous United States based on the period 1948–1972. The highest frequency is encountered in south-central Florida. Since 1894, the recording of thunderstorms has been defined as the local calendar day during which thunder was heard. A day with thunderstorms is so recorded regardless of the number occurring on that day. The occurrence of lightning without thunder is not recorded as a thunderstorm. Statistics vary widely with local and climatic conditions. ***(Data supplied by Environmental Science Service Administration, U.S. Department of Commerce.)***

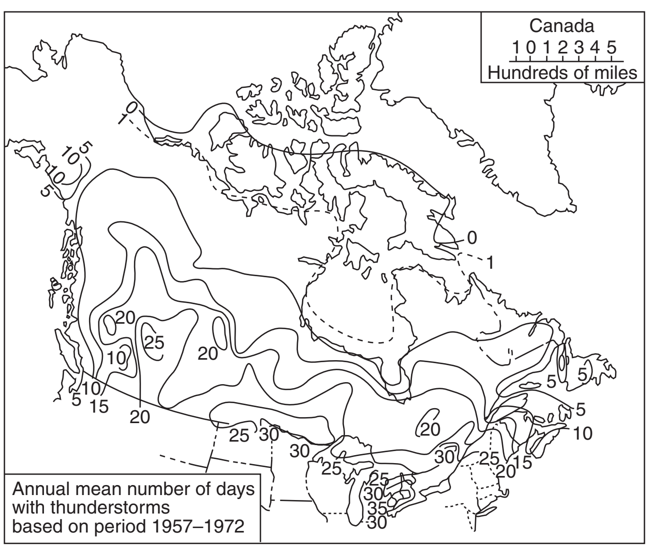


Figure H-2(b) Canadian statistics showing annual average number of days with thunderstorms. Data based on the period 1957–1972. ***(Meteorological Division, Department of Transportation, Canada.)***

Appendix I Ground Measurement Techniques

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

I-1 General.

I-1.1 In order to determine the ground resistance of a lightning protection system, it is necessary to remove it from any other ground connection. This may prove a virtually impossible task necessitating certain assumptions. In reality, ground-resistance measuring equipment works at low frequencies relative to the lightning discharge. The resistance it computes is therefore often affected by the resistance of power-system ground electrodes or a similar ground medium that may be several thousand feet from the structure being protected. The ground resistance to be used to calculate lightning conductor potentials when a high-frequency lightning discharge strikes a building must be the grounds in the immediate area of the building, not the remote ones that ground measuring equipment probably monitor.

I-1.2 If the building is small, and the lightning protection system can be disconnected totally from any other grounding network, its resistance can be measured by the three-point technique described in I-1.3. If the building is large or cannot be disconnected totally from any other grounding network, then the ground resistance of individual isolated lightning-protection ground rods should be measured by the three-point technique described in I-1.3 and this resistance multiplied by a factor depending on the number of ground rods.

I-1.3 The principle of ground resistance measurement is shown in Figure I-1.3. *L* is the lightning ground rod or ground rod system, *P* is a test probe, and *A* is an auxiliary current probe. *M* is the standard ac measuring equipment for three-point technique ground resistance measurements. Convenient distances for *LP* and *LA* are 75 ft (22 m) and 120 ft (36 m), respectively. In general, *P* should be at 62 percent of the distance from *L* to *A*. If 120 ft (36 m) is not convenient, it could be increased significantly [or reduced to no less than 50 ft (15.2 m)], provided *LP* is increased proportionately.

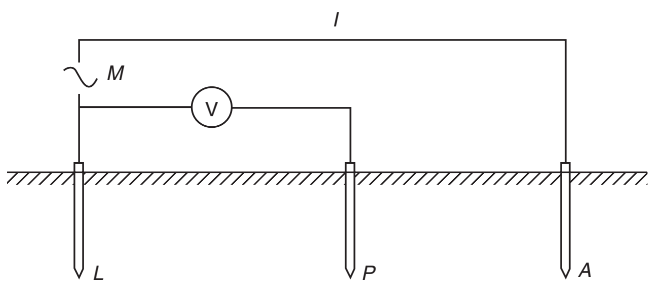


Figure I-1.3 Measurement of ground resistance.

A current, *I*, is passed through the electrode or electrodes to be tested, *L*, and through an auxiliary probe, *A*. The distance, *LA*, is long compared to the electrode length. The voltage, *V*, between *L* and *P* is measured by the test equipment, which also monitors *I* and calculates the ground resistance, *R*, as *V/I*. Alternating current is used to avoid errors due to electrolytic factors in the soil and to remove effects due to stray currents.

Three-point ground resistance measuring equipment using these principles is relatively inexpensive and allows direct reading of *R*.

I-1.4 Variations in soil resistivity due to temperature and moisture fluctuations can affect the measured ground resistance. A good designer will measure ground resistance under average or high resistivity conditions in order to design a lightning protection system to function adequately.

If the building ground is complex in nature, the resistance of single ground rods may be measured and certain assumptions made. The average single ground rod resistance, R_m, must be multiplied by a factor depending on the number of lightning-protection ground rods, *n*, spaced at least 35 ft (10.7 m) apart.

The total system ground resistance, *R*, can be calculated from the following formula:

$$R = 1.1\left(\frac{R_m}{n}\right)$$

Appendix J Explanation of Bonding Principles

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

J-1 General. Lightning strikes may give rise to harmful potential differences in and on a building. The major concern in the protection of a building is the occurrence of potential differences between the conductors of the lightning protection system and other grounded metal bodies and wires belonging to the building. These potential differences are caused by resistive and inductive effects and can be of such a magnitude that dangerous sparking can occur. In order to reduce the possibility of sparking, it is necessary to equalize potentials by bonding grounded metal bodies to the lightning protection system.

J-1.1 Where installing (or modifying) lightning protection systems on existing structures, bonding of certain grounded metal bodies may present difficult installation problems due to the inaccessibility of building systems. Placement of conductors to avoid grounded metal bodies or increasing the number of down conductors to shorten the required bonding distances are options to overcome these problems.

J-2 Potential Differences. Figure J-2 illustrates the generation of potential differences between conductors of the lightning protection system and other grounded metal bodies and wires.

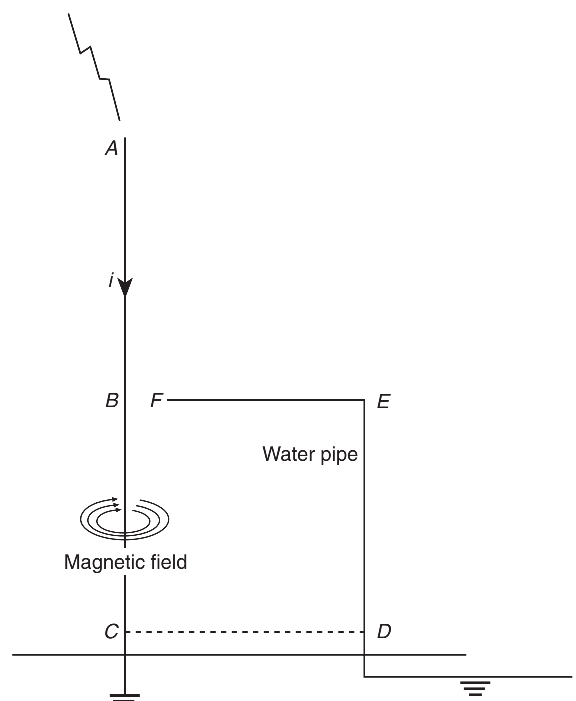


Figure J-2 The magnetic field around a conductor.

J-2.1 Resistive Effect. In the situation where conductor *C* is connected only to a ground terminal and the water pipe is independently grounded, a large potential may exist between *B* and *F*. Assuming a resistance of 20 ohms between C and ground and a lightning current of 100,000 amps, then Ohm's law (voltage = current × resistance) indicates that a potential of 2 million volts exists on conductor *ABC*. Because no current is initially passing through the water pipe, its potential is zero volts. The difference of potential of 2 million volts between *B* and *F* is sufficient for a sideflash of over 6 ft (2 m). In order to reduce this potential difference to zero, this standard requires equalization of potentials at ground level in accordance with 3-20.1. Such a bond is shown as *CD* in Figure J-2.

With bond *CD* in position, the resistance between *B* and *F* is essentially zero, hence during a lightning strike the potential at *B* due to the resistive effect is similar to that at *F*. Therefore the resistive effect can be neglected for bonding purposes.

J-2.2 Inductive Effect. When a large current passes down the lightning conductor *ABC*, a magnetic field is generated in circular motion around the conductor as shown in Figure J-2. The higher the lightning current, the higher the magnetic field. These magnetic field lines can be referred to as magnetic flux.

The loop *BCDEF* is intercepted by these lines of magnetic flux. The rate of change of the flux passing through this loop induces a voltage in the loop, creating a potential difference between *B* and *F*. This potential difference can be in the order of a few million volts, again causing a sideflash.

The bonding techniques described in this standard call for bonding the gaps, such as *BF*, over which high potentials exist in order to remove the spark and provide a safe path to ground for the current. The bonding-distance formulas are calculated from the laws of physics, making assumptions on the relevant lightning characteristics that influence the induced voltage. The assumptions for this standard are based on an extremely severe lightning current, thereby providing a bonding distance that is almost totally protective.

The voltage across the gap *BF* is related to the size of the loop *BCDEF* but dominantly to the height *BC* rather than *CD*; hence the height *h* term in the formulas of 3-21.2. Equalizing the potentials at frequent heights in accordance with Section 3-20 also reduces the size of the loop *BCDEF*, thereby keeping the gap voltage to a controllable value that can be removed by simple bonding.

J-2.3 One factor that is difficult to control is the problem related to power and communication lines entering the building. For all intents, such lines are at ground potential relative to the extremely high induced voltages. If the line *DEF* was such an electrical, telephone, power, or data line not bonded at ground, the voltage across the loop would be enhanced by the resistive effect described by Ohm's law as well as by the inductive effect. Hence, *BF* could soon approach breakdown. This would lead to sparks causing fire as well as the obvious electrical, electronic, and human life problems. All such lines entering the building should have electrical bonding through surge protection as specified in Section 3-18, thereby reducing the resistive component and controlling dangerous sparking and damage. If just one wire, however, does not have such suppression devices, the dangers described above still exist, even to the protected building and the electrical equipment. Table J-2.3 shows sample calculations.

J-2.4 In order to reduce the voltage across the gap, *BF*, so as to make bonding less necessary, it is possible to provide more down conductors. This standard requires down conductors every 100 ft (30 m) (*see 3-9.10*), but the number of down conductors, *n*, required in the bonding formula of 3-21.2 is restricted. It can be shown theoretically for structures less than 60 ft (18 m) in height that for a series of planar down conductors spaced 50 ft (15 m) apart *n* can be no bigger than 1.5, and for a similar three-dimensional situation *n* can be no bigger than 2.25. These values of *n* also apply to the upper 60 ft (18 m) of a tall structure. As the lightning current passes into the lower portion of a tall structure, however, the value of *n* must be calculated on the assumption that the current flow down the structure is much more symmetrical through the down conductors. This implies that for all but the upper 60 ft (18 m) of a structure the bonding distance can be calculated from a formula involving a larger value of *n*, as shown in 3-21.2.

J-2.5 Sideflashing can easily occur to grounded objects within the building. The intensity of the electric field in air is greater than that in concrete by approximately a factor of two, allowing for a reduction of the sideflash distance through a wall cavity.

If an individual touches a correctly bonded connection within the building, he or she should suffer no harm. This scenario is similar to that of a bird sitting on a high-voltage wire unaware that the bird's potential is changing from over a thousand volts positive to over a thousand volts negative several times a second.

Appendix K Protection of Structures Housing Explosive Materials

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

K-1 General. This appendix provides the minimum technical recommendations for lightning protection of structures housing explosive materials.

K-1.1 Due to the possibility of danger to the surrounding area, an increased level of protection efficiency as defined herein is necessary for such structures. The decision of when to protect these structures should be left to the authority having jurisdiction.

K-1.2 The protection of the contents contained in structures housing explosives should take into account the packages used to contain these materials as well as bonding or grounding requirements specified by the authority having jurisdiction.

Table J-2.3 Sample Calculations of Bonding Distances

		D		
***h* (ft)**	K_m	***n* = 1.0**	***n* = 1.5**	***n* = 2.25**
10	1.0	1 ft 8 in.	1 ft $1^3/_8$ in.	9 in.
	0.5	10 in.	$6^3/_4$ in.	$4^1/_2$ in.
20	1.0	3 ft 4 in.	2 ft $2^3/_4$in.	1 ft 6 in.
	0.5	1 ft 8 in.	1 ft $1^3/_8$in.	9 in.
30	1.0	5 ft 0 in.	3 ft 4 in.	2 ft $2^3/_4$ in.
	0.5	2 ft 6 in.	1 ft 8 in.	1 ft $1^3/_8$ in.
40	1.0	6 ft 8 in.	4 ft 6 in.	3 ft
	0.5	3 ft 4 in.	2 ft 3 in.	1 ft 6 in.

K-2 Design Considerations. Lightning protection systems designed to protect structures housing explosives and energetic materials should be based on a striking distance of 100 ft (33 m) as discussed in 6-3.3.

NOTE: When the effects of electromagnetic coupling are of concern, a mast of overhead wire (catenary) systems might be preferred over integral systems unless a Faraday cage or shield is required. The removal (isolation) of the down conductors will reduce the magnetic field strength in the structure and reduce the probability of a sideflash from a down conductor.

K-3 Types of Systems.

K-3.1 Mast-type Systems. Mast-type systems should be designed as specified in 6-3.3.2.

K-3.2 Overhead Wire (Catenary) Systems. Catenary systems should be designed as specified in 6-3.3.2.

K-3.3 Integral Systems. An integral lightning protection system is a system that utilizes air terminals mounted directly on the structure to be protected. These types of air termination systems are as described in Chapter 3. Air terminal spacing should be modified as necessary to provide a zone of protection defined by a 100-ft (33-m) striking distance.

When an integral lightning protection system is used to protect the structures covered by this appendix, it is critical that the bonding requirements of Chapter 3 be met. It is also critical that a rigorous maintenance schedule be maintained for this type of system.

K-3.4 Faraday Cage. The optimum scheme for protecting extremely sensitive operations from all forms of electromagnetic radiation is to enclose the operation(s) or facility inside a Faraday cage. A true Faraday cage is difficult to construct and is economically justified only for critical facilities or where extremely sensitive operations warrant this level of protection.

Effective lightning protection is similarly provided by metallic structures such as those formed by the steel arch or the reinforcing steel in the walls and floors of earth-covered magazines if the steel reinforcement is bonded together and it meets the minimum ground system resistance recommendations of Section K-4.

K-4 Grounding.

K-4.1 General. A ground loop conductor should be required for all lightning protection systems used to protect the subject structures. All down conductors, structural steel, ground rods, and other grounding systems should be connected to the ground loop conductor.

Exception: For structures with areas of 500 ft² (46.5 m²) or less or those that can be protected by a single mast or air terminal, the ground loop conductors should not be required.

K-4.2 Metal Portable Magazines. Portable magazines that meet the recommendations of a Faraday cage as described in K-3.4 should be grounded. Main size conductors should be used to interconnect the portable magazine to the ground system. The following lightning protection recommendations for portable magazines are for single and group configurations.

(a) *Single Portable Magazines.* Single portable magazines less than 25 ft^2 (2.323 m^2) (using outside dimensions) need only a single ground rod. Single portable magazines greater than or equal to 25 ft^2 (2.323 m^2) should be grounded by using a minimum of two separate ground rods each placed in a different corner. Connections to existing ground loop conductors may be substituted for ground rods. All earth connections should provide as low as practical resistance-to-earth.

(b) *Portable Magazine Groups.* A portable magazine group is formed when two or more portable magazines are bonded together aboveground. Portable magazine groups should meet the following bonding and grounding recommendations:

1. Each group should have a minimum of two connections to earth. Groups exceeding 250 ft (76.2 m) in perimeter should have a connection to earth for every 100 ft (30.5 m) of perimeter or fraction thereof such that the average distance between all connections to earth does not exceed 100 ft (30.5 m).

2. For small groups requiring only two connections to earth, the connections should be placed at opposite ends of the group, as far apart as is practical.

3. Connections to existing ground loop conductors may be substituted for ground rods. All earth connections should provide as low as practical resistance-to-earth.

K-5 Bonding.

K-5.1 General. It is critical that the bonding requirements of Chapter 3 be enforced for the protection of structures housing explosives or other energetic materials. The material used to bond items to the grounding loop conductor should meet the requirements of Section 3-2. Section 3-2 provides the requirements for the use of dissimilar metals.

K-5.2 Bonding Resistance. The resistance of any object bonded to the lightning protection system should not exceed 1 ohm. For static dissipative systems such as conductive floors, workbenches, etc., bond resistance of 1 megohm is acceptable.

K-5.3 Painting. Wires and conductors bonded to the lightning protection system should not be painted.

K-5.4 Magazines.

K-5.4.1 Earth-Covered Magazines. Metal ventilators, steel doors, door frames, and steel reinforcement should be bonded to the structure's grounding system. Incoming power, data, and communication cables should be bonded to the ground loop conductor or steel reinforcement as it enters the structure.

K-5.4.2 Metal Portable Magazines. Portable box-type magazines made of $^3/_{16}$-in. (4.8-mm) steel or equivalent where the walls, floor, and roof are welded together should require bonding of the doors across the hinges. Bonding of services, data lines, and communication lines also should be provided.

K-5.5 Fences. Fences should have bonding across gates as well as other discontinuities and should be bonded to the lightning protection system ground loop conductor if they cross or come within the sideflash distance of the structure of a lightning protection system. Bonding across discontinuities in metallic fences should be provided as necessary for electrical continuity.

K-5.6 Railroad Tracks. All railroad tracks that cross or come within the sideflash distance of a structure's lightning protection system should be bonded to the lightning protection system ground loop conductors. If the tracks are used to carry electrical signals, they should have insulated joints immediately external to bond the lightning protection system's ground loop conductor. If these tracks enter a facility, they also should be bonded to the frame of the structure (or equivalent).

K-6 Surge Suppression. Surge suppression should be required for all power, communication, or data conductors entering or exiting a structure housing explosives.

K-7 Maintenance and Inspection. The effectiveness of a lightning protection system is best ensured by a quality control program designed to ensure that the system is not degraded by age, mechanical damage, or modifications to the structure. A maintenance and inspection plan should be developed for all protection systems used to protect structures housing explosives.

The initial installation should be inspected by the authority having jurisdiction (or their designated representative). It should be recertified after any work is done on the structure.

K-7.1 General. To ensure that the protection system used to protect structures housing explosives is properly maintained, it should be inspected visually twice a year and inspected electrically approximately once a year. To ensure that the systems are tested during all four seasons over a six-year period, seven-month and 14-month test cycles are suggested.

K-7.2 Visual (Seven-Month) Test. The lightning protection system should be visually inspected every seven months for evidence of corrosion or broken wires/connections. All necessary repairs should be made immediately. Any detected damage to the system should be entered in the test records as recommended in B-1.5.

K-7.3 Electrical (14-Month) Test. The lightning protection system should be tested electrically every 14 months. The test should be conducted in accordance with the appropriate test equipment manufacturer's instructions by personnel familiar with lightning protection system testing.

K-7.4 Test Equipment. Only those instruments designed specifically for earth resistance testing are acceptable for use in this application. The instrument used in earth-resistance testing should be capable of measuring 0 to 10 ohms ± 10 percent. The instrument used to measure bonding resistance should be capable of measuring 0 to 1 ohm ± 10 percent.

Appendix L Principles of Lightning Protection

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

L-1 Fundamental Principles of Lightning Protection.

L-1.1 The fundamental principle in the protection of life and property against lightning is to provide a means by which a lightning discharge can enter or leave the earth without resulting damage or loss. A low impedance path that the discharge current will follow in preference to all alternative high impedance paths offered by building materials such as wood, brick, tile, stone, or concrete should be offered. When lightning follows the higher impedance paths, damage may be caused by the heat and mechanical forces generated during the passage of the discharge. Most metals, being good electrical conductors, are virtually unaffected by either the heat or the mechanical forces if they are of sufficient size to carry the current that can be expected. The metallic path must be continuous from the ground terminal to the strike termination device. Care should be exercised in the selection of metal conductors to ensure the integrity of the lightning conductor for an extended period. A nonferrous metal such as copper or aluminum will provide, in most atmospheres, a lasting conductor free of the effects of rust or corrosion.

L-1.2 Parts of structures most likely to be struck by lightning are those that project above surrounding parts such as chimneys, ventilators, flagpoles, towers, water tanks, spires, steeples, deck railings, shafthouses, gables, skylights, dormers, ridges, and parapets. The edges and corners of the roof are the parts most likely to be struck on flat or gently sloping roofed buildings.

L-2 Lightning Protection Systems.

L-2.1 Lightning protection systems consist of the following three basic parts that provide the low impedance metal path required:

(a) A system of strike termination devices on the roof and other elevated locations

(b) A system of ground terminals

(c) A conductor system connecting the strike termination devices to the ground terminals

Properly located and installed, these basic components improve the likelihood that the lightning discharge will be conducted harmlessly between the strike termination devices and the ground terminals.

L-2.2 While intercepting, conducting, and dissipating the main discharge, the three basic protection system components do not ensure safety from possible secondary effects of a lightning strike. Therefore, secondary conductors are provided to interconnect metal bodies to ensure that such metal bodies are maintained at the same electrical potential so as to prevent sideflashes or spark-over. Surge suppression devices are also provided to protect power lines and associated equipment from both direct discharges and induced currents.

L-2.3 Metal parts of a structure may be used as part of the lightning protection system in some cases. For example, the structural metal framing, which has sufficient cross-sectional area to equal the conductivity of main lightning conductors, and which is electrically continuous, may be used in lieu of separate down conductors. In such cases, air terminals may be bonded to the framework at the top, and ground terminals may be provided at the bottom, as described elsewhere in this standard. Structures with $^{3}/_{16}$-in. (4.8-mm) thick, or thicker, metal shells or skins that are electrically continuous might not require a system of air terminals and down conductors.

L-3 Items to Consider when Planning Protection.

L-3.1 The best time to design a lightning protection system for a structure is during the planning phase, and the best time to install the system can be during construction. System components may be built-in so as to be protected from mechanical displacement and environmental effects. In addition, aesthetic advantages may be gained by such concealment. Generally, it is less expensive to meet lightning protection requirements during construction.

L-3.2 The structure should be examined and installation of air terminals should be planned for all areas or parts likely to receive a lightning discharge. The object is to intercept the discharge immediately above the parts liable to be struck and to provide a direct path to earth, rather than to attempt to divert the discharge in a direction it would not be likely to take. The air terminals should be placed high enough above the structure to obviate danger of fire from the arc.

L-3.3 Conductors should be installed to offer the least impedance to the passage of stroke current between the strike termination devices and earth. The most direct path, without sharp bends or narrow loops, is best. The impedance of the conductor system is practically inversely proportional to the number of widely separated paths. Accordingly, there should be at least two paths to ground and more, if practicable, from each strike termination device. The number of paths is increased and the impedance decreased by connecting the conductors to form a cage enclosing the building.

L-3.4 Properly made ground connections are essential to the effective functioning of a lightning protection system, and every effort should be made to provide ample contact with the earth. This does not necessarily mean that the resistance of the ground connection should be low, but rather that the distribution of metal in the earth or upon its surface in extreme cases should be such as to permit the dissipation of a stroke of lightning without damage.

L-3.5 Low resistance is desirable, but not essential, as may be shown by the extreme case on the one hand of a building resting on moist clay soil, and on the other by a building resting on bare solid rock. In the first case, if the soil is of normal resistivity or from 4,000 ohm-centimeters to 50,000 ohm-centimeters, the resistance of a ground connection made by extending the conductor 10 ft (3 m) into the ground will be from about 15 ohms to 200 ohms, and two such ground connections on a small rectangular building have been found by experience to be sufficient. Under these favorable conditions, providing adequate means for collecting and dissipating the energy of a flash without serious chance of damage is a simple and comparatively inexpensive matter.

L-3.6 In the second case, it would be impossible to make a ground connection in the ordinary sense of the term because most kinds of rocks are insulating, or at leas,t of high resistivity, and in order to obtain effective grounding other more elaborate means are necessary. The most effective means would be an extensive wire network laid on the surface of the rock surrounding the building to which the down conductors could be connected. The resistance to earth at some distant point of such an arrangement would be high but at the same time the potential distribution about the building would be substantially the same, as though it were resting on conducting soil, and the resulting protective effect also would be substantially the same.

L-3.7 In general, the extent of the grounding arrangements will depend on the character of the soil, ranging from simple extension of the conductor into the ground where the soil is deep and of high conductivity to an elaborate buried network where the soil is very dry or of very poor conductivity. Where a network is required, it should be buried if there is soil enough to permit it, as this adds to its effectiveness. Its extent will be determined largely by the judgment of the person planning the installation with due regard to the following rule: The more extensive the underground metal available, the more effective the protection.

L-3.8 Where practicable, each ground terminal connection should extend or have a branch that extends below and at least 2 ft (0.6 m) away from the foundation walls of the building in order to minimize the change of damage to foundation walls, footings, and stemwalls.

L-3.9 When a lightning conductor system is placed on a building, within or about which there are metal objects of considerable size within a few feet of a conductor, there will be a tendency for sparks or sideflashes to jump between the metal object and the conductor. To prevent damage, interconnecting conductors should be provided at all places where sideflashes are likely to occur.

L-3.10 Lightning currents entering protected buildings on overhead or underground power lines, or telephone conductors, or television or radio antennas are not necessarily restricted to associated wiring systems and appliances. Therefore, such systems should be equipped with appropriate protective devices and bonded to ensure a common potential.

L-3.11 Because a lightning protection system is expected to remain in working condition for long periods with minimum attention, the mechanical construction should be strong and the materials used should offer resistance to corrosion and mechanical injury.

L-4 Inspection and Maintenance of Lightning Protection Systems. It has been shown that in cases where damage has occurred to a protected structure, the damage was due to additions or repairs to the building or to deterioration or mechanical damage that was allowed to go undetected and unrepaired, or both. Therefore, it is recommended that an annual visual inspection be made and that the system be thoroughly inspected every five years.

L-5 Indirect Losses. In addition to direct losses such as destruction of buildings by lightning, fire resulting from lightning, and the killing of livestock, indirect losses sometimes accompany the destruction or damage of buildings and their contents. An interruption to business or farming operations, especially at certain times of the year, may involve losses quite distinct from, and in addition to, the losses arising from the direct destruction of material property. There are cases where whole communities depend on the integrity of a single structure for their safety and comfort. For example, a community may depend on a water-pumping plant, a telephone relay station, a police station, or a fire station. A stroke of lightning to the unprotected chimney of a pumping plant might have serious consequences such as a lack of sanitary drinking water, irrigating water, or water for fire protection.

Appendix M Referenced Publications

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

M-1 The following documents or portions thereof are referenced within this standard for informational purposes only and are thus not considered part of the requirements of this standard. The edition indicated here for each reference is the current edition as of the date of the NFPA issuance of this standard.

M-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 70, *National Electrical Code®*, 1996 edition.

NFPA 302, *Fire Protection, Standard for Pleasure and Commer Motor Craft*, 1994 edition.

NFPA 407 , *Standard for Aircraft Fuel Servicing*, 1996 edition.

NFPA 410, *Standard on Aircraft Maintenance*, 1994 edition.

M-1.2 IEC Publications. International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, 1211 Geneva 20, Switzerland.

IEC 1024-1, *Protection of Structures Against Lightning*, Part 1, 1992.

IEC 1312-1, *Protection Against Lightning Electromagnetic Impulse*, Part 1: General Principles, 1995.

IEC 1662, *Assessment of the Risk of Damage Due to Lightning*, First Edition, 1995.

IEC DIS81 (BC/CO)14, *Protection of Structures Against Lightning*, Part 1: General Principles, Section 1: Guide A — Selection of Protection Levels for Lightning Protection Systems, 1991.

M-1.3 IEEE Publications. Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

IEEE C62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Systems*, 1993.

IEEE 0093-9994/1100-0465 IEEE 1978, "Protection Zone for Buildings Against Lightning Strokes Using Transmission Protection Practices," Ralph H. Lee, Fellow.

M-1.4 Military Publications. This publication makes reference to the following military standards and handbooks. They are available from Naval Publications and Forms Center, Philadelphia, PA, Headquarters, Army Material Command Code DRXAM-ABS, Alexandria, VA, or Air Force Publications Center, Baltimore, MD.

AFR 127-100, *Explosives Safety Standards*, Dept. of Air Force, Washington, DC, May 1983.

AMCR 385-100, *Safety Manual*, Chapter 8, Army Material Command, Washington, DC, 1985.

DoD 6055.9-STD, *Ammunition and Explosives Safety Standards*, Chapter 7, Dept. of Defense, Washington, DC, October 1992.

MIL-HDBK-419A, *Grounding, Bonding and Surge Suppression*, Volumes I and II, Dept. of Defense, Washington, DC, December 1987.

NAVSEA OP-5, *Ammunition and Explosives Ashore*, Volume 1, Sixth Revision, Chapter 6, Naval Sea Systems Command, Washington, DC, March 1995.

M-1.5 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062.

UL 1449, *UL Standard for Safety Transient Voltage Surge Suppressors*, 1996.

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