Specification. Installation. Inspection.

LPI

LIGHTNING PROTECTION INSTITUTE

LPI-175 / 2023 Edition

Standard of Practice For The
DESIGN - INSTALLATION - INSPECTION
Of Lightning Protection Systems

www.lightning.org 800.488.6864

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System Overview

General Industry Information

The **Lightning Protection Institute** is a nationwide not-for-profit organization founded in 1955 to promote lightning protection education, awareness, and safety. The lightning protection industry began in the United States when Benjamin Franklin postulated that lightning was electricity, and a metal rod could be used to carry the lightning away from a building. Lightning is the direct cause of over 50 deaths and 400 injuries each year, and it is difficult to protect individuals in exposed outdoor areas. Direct lightning strikes cause fire damage in excess of $200 million per year, and insurance companies pay claims in the billions of dollars associated with lightning either directly or indirectly. Most of these property losses could be minimized, if not eliminated, through the implementation of proper lightning protection for structures. LPI is dedicated to ensuring that today's lightning protection systems provide the best possible quality in both materials and installation practices for maximum safety.

The **National Fire Protection Assoc. (NFPA)** publishes document **# 780** titled Standard for the Installation of Lightning Protection Systems, an ANSI Standard, considered the national design guide for complete lightning protection systems in the United States. NFPA published its first document on lightning protection in 1904. Similar NFPA documents like the National Electrical Code (NEC – NFPA 70), National Fuel Gas Code (NFPA 54), and Uniform Fire Code (NFPA 1) are developed by the committee process to review acceptance of new safety information on specific fire related subjects, and the standards are available for adoption by local authorities having jurisdiction over construction projects.

The lightning protection Standard # 780 is reviewed on a three-year cycle for updating. NFPA 780 includes lightning protection for typical building construction in Chapter 4 as general requirements for structures. The 780 document covers many specialty constructions from hazardous materials storage to boats and ships to open picnic structures, and gives recommendations for personal safety outdoors. NFPA 780 provides the best we know today in theory and technology on protection systems tested by experienced industry professionals in a legally recognized format.

Product testing for lightning protection material components in the factory prior to shipment for listing and labeling is handled by **Underwriters Laboratories, Inc. (UL)**. The UL Standard **96** addresses the minimum requirements for construction of air terminals, cable conductors, fittings, connectors, and fasteners used in quality lightning protection systems. UL has inspection personnel who visit production facilities on a regular basis to verify compliance for continued use of their approved merchandise labels.

Field inspection of completed lightning protection installations may also be arranged with UL through installing contractors listed in their program. UL has issued a "Master Label" product for complete systems fully compliant with their Standard UL 96A. Standard 96A is based on the general requirements of NFPA 780, but UL has a Standards Technical Panel (STP) to review the requirements for a more inspectable format which leads to some differences. UL will also inspect to some other nationally recognized Standards (like NFPA 780) for fully compliant systems. Some partial constructions may be available for field inspection under their “Letter of Findings” program.

The **Lightning Protection Institute (LPI)** adopts the latest edition of the NFPA 780 Standard as its reference document for system design. LPI advocates use of UL as the third-party inspection authority for components according to their document UL 96. LPI publishes this document **# 175** and Inspection Guide LPI #177, based on NFPA 780, with additional explanatory material helpful to installer and inspector member personnel.

LPI provides the industry self-policing testing program for Journeyman, Master Installer, and Designer Inspector Certification of members. Individuals sit for exams which include the requirements of the above listed lightning protection Standards and application of those principles to design examples. Membership renewal is required each year with additional examinations taken approximately every three years when the national Standards are updated. Contracting with professionals qualified through the LPI process ensures an added level of quality assurance for initial system installation and a resource for future inspection and maintenance of existing systems.

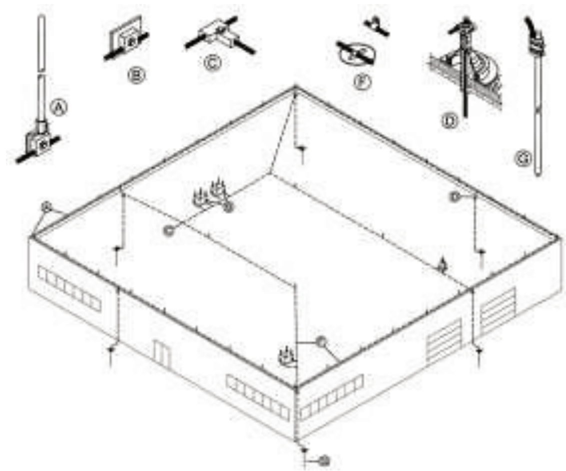
LPI has implemented an **inspection program** for completed installations under the name **LPI-IP**. LPI-IP provides a certification service more thorough and complete than any previous inspection program from LPI or others currently available in the marketplace. Through the use of check points, reviews, and on-site inspections, LPI-IP system certification ensures safety using qualified installer personnel and independent Nationally Recognized Testing Laboratory (NRTL) inspectors. LPI-IP offers a “Master Installation Certificate” for complete structures, a “Reconditioned Master Installation Certificate” for previously certified constructions, and a “Limited Scope Inspection” for partial systems in designated contracts. This is a critical element to the specifier, owner, and property insurer providing verification by a third-party independent source of quality lightning protection installations.

Lightning protection systems for structures are typically not a requirement of national building codes, although the Standards may be adopted by the authority having jurisdiction for general construction or specific occupancies. Since lightning protection may be considered an option, it is crucial that the specifier, construction contractor, and property insurer be familiar with the national Standards to provide the highest level of safety available. **Lightning protection systems** have a remarkable record of protecting against physical danger to people, structural damage to buildings, and failure of internal systems and equipment. The value received begins with proper design, continues through quality installation practices, and must include inspection and certification. The ultimate goal is safe haven, security of investment, and elimination of potential system downtime in opposition to one of nature's most destructive events.

General System Information

The Standards in the United States for complete lightning protection systems include **NFPA 780, UL 96 & 96A, and LPI 175 & 177**. These Standards are based on the fundamental principle of providing a reasonably direct, low-resistance, low impedance metallic path for lightning current to follow, and making provisions to prevent destruction, fire, damage, death, or injury as the current flows from the roof levels to below grade. The Standards represent a consensus of authorities regarding basic requirements for construction and performance of qualified designs and products. Based on sound engineering principles, research, records of tests and field experience, a complete protection system is expected to create personal and structural safety from lightning and its secondary effects. The Standards are under continuous review for new products, construction techniques, and validated scientific developments to address the lightning hazard. Although material components may appear very similar, the configuration of a total system design has changed dramatically over the last 25 years to reflect today's lifestyles.

There are **five elements** that need to be in place to provide an effective lightning protection system. **Strike termination devices** must be suitable to accept direct lightning attachment and patterned to accept strikes before they reach insulated building materials. **Cable conductors** route lightning current over and through the construction, without damage, between strike terminations at the top and the grounding electrode system at the bottom.



The below grade **grounding electrode system** must efficiently move the lightning to its final destination away from the structure and its contents. **Bonding** or the interconnection of the lightning protection system to other internal grounded metallic systems must be accommodated to eliminate the opportunity for lightning to sideflash internally. Finally **surge protective devices** must be installed at every service entrance to stop the intrusion of lightning from utility lines, and further equalize potential between grounded systems during lightning events. When these elements are identified properly in the design stage, incorporated into a neat workmanlike installation, and no changes to the building occur, the system will protect against lightning damage. Elements of this passive grounding system always serve a similar function, but the total design is specific for each particular structure.

Lightning protection components are made from **materials** that are resistant to corrosion and they must be protected from accelerated deterioration. Many system components will be exposed to the atmosphere and climate. Combinations of materials that form electrolytic couples in the presence of moisture shall not be used. Current carrying system components must be highly conductive. Prevailing site soil conditions will impact in-ground system components. The system life and maintenance/replacement cycle is dependent on material choice and the local environment. System materials must be coordinated with the structural materials in use – including flashings, copings, ventilator housings, various roofing systems – to maintain the moisture envelope for the intended life of the building.

Copper, copper alloys (including brass and bronze), and aluminum are the basic system component materials. They serve the best combination of function for current carrying and weathering. Since aluminum materials have slightly lower current carrying capability and mechanical strength than similar sized copper products, listed and labeled materials for lightning protection include larger physical size parts. For example to be considered equivalent, a minimum size air terminal would be ½” diameter in aluminum, versus 3/8” diameter in copper.

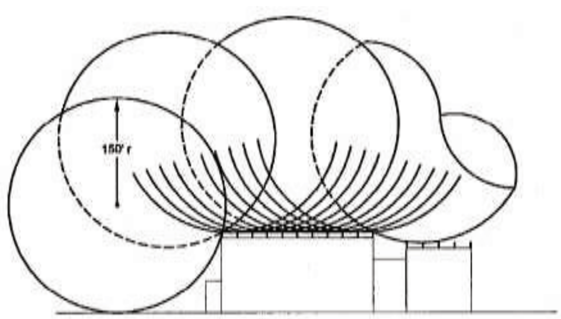
Water running off copper will oxidize aluminum and galvanized surfaces, so coordination of system design must include galvanic considerations for potential mounting problems. Qualified bimetallic fittings are used to coordinate system components for required transitions from aluminum to copper. These may include listed products for the purpose, or in some cases stainless steel components. Aluminum can never come in contact with the earth or soil. Aluminum should never contact alkaline based paint surfaces or be embedded directly in concrete.

If any product is subject to unusual mechanical damage or displacement, it may be protected with a molding or covering, but care must be exercised to allow strike terminations and other roof mounted components to serve their function in accepting attachments. Lightning protection components below the strike terminals may be **concealed** within the building below the roof level during construction or when accessible. The speed of lightning current and splitting the flow among multiple paths will not permit components to heat to any instantaneous ignition temperature hazardous to typical building materials. Incorporating the system into the construction allows interconnection of structural metal framing and internal grounded systems, and provides protection against displacement and maintenance issues which are beneficial in extending the life of a system.

Materials suitable for use in lightning protection systems are **listed, labeled, and tested** according to UL Standard 96. Consideration for conductor design includes maximizing surface area to carry lightning and flexibility of the configuration to make bends and turns required in installation practices. Air terminal bases efficiently accomplish the transfer of a strike from termination device to cable conductor and securely mount to various building surfaces under severe weather conditions. Splicing fittings must maintain contact with conductor lengths adequate to accomplish current transfer and weather the exposed environment. Grounding electrodes must provide the proper earth contact to disperse the charge and satisfy requirements for life cycle suitability in various soil compositions. Bonding devices are sized to provide adequate interconnection of systems to create potential equalization throughout the structure. Surge Protective Devices are qualified at higher current levels to meet the needs associated with lightning attachments.

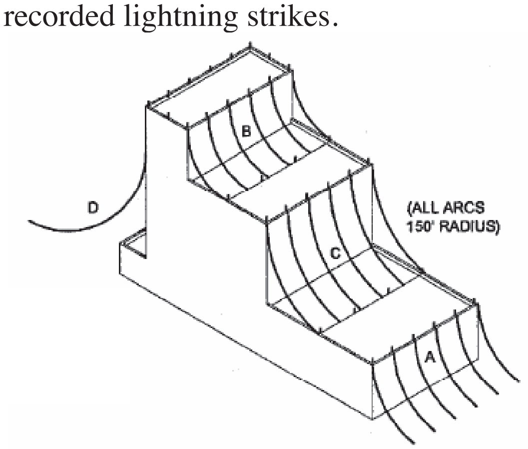
Strike Termination

Strike termination devices serve the system function of accepting the direct lightning attachments. They represent the umbrella against penetration of lightning to non-conductive building materials to guard against fire or explosion. Any metallic body 3/16” thick or more projecting above a structure will accept a lightning strike without burning through. Therefore, in some cases construction elements may be incorporated as strike terminations. Tall masts or overhead ground wires similar to power transmission line protection may serve as strike terminations. In most cases, however, small specific purpose **air terminals** constitute the majority of strike termination systems. These unobtrusive components are preferred for ease of mounting and aesthetic reasons, and can be coordinated into a most effective configuration for all typical building constructions.



The atmosphere surrounding us is electrically charged, but free air maintains a relatively balanced ion distribution. When we raise a building into the air, a tree or even a person to a lesser extent, we change that electrical balance. The **electrical field** accumulates to change points in the geometry of ground mounted objects. Items like ridges and particularly ridge ends, edges of flat roofed buildings and even more the corners become points of accumulation for ions that increase susceptibility to lightning attachments. A proper system of strike termination devices accounts for these realities by using air terminals in a configured pattern designed to use the building’s points of natural ionic accumulation to pull lightning into the protection system. The taller the structure and the more severe the planar changes (like a vertical wall to a horizontal flat roof) the greater the opportunity for attachment at these critical junctions. Designing a **system of air terminals** projecting only 10 inches above these structural points of emphasis and along ridges and edges has been proven, in more than a century of practice, to provide interception of some 95% of recorded lightning flashes, including the most violent. Some lower potential lightning strokes could theoretically attach on flat planes away from strike terminations designed to the Standards, but the consequences are within acceptable limits for ordinary construction. Considering the lower energy level required for a bypass, the other structural grounding components included in a complete lightning protection system, and the random probability for connection with a system component anyway, this method of building protection is considered most efficient.

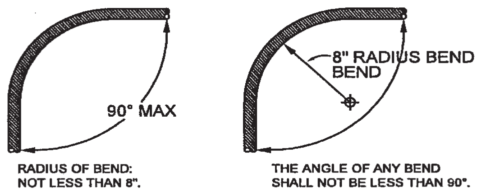
Protecting the highest most prominent building elements with strike termination devices, based on a building’s geometry, also provides some level of protection for lower extensions of the structure, or items in the "shadow" of the higher fully protected areas. A **zone of protection** exists from any vertical strike termination device and more than that from a vertical fully protected building level. Zone of protection is described in the lightning Standards using a 150 feet (45 meters) radius sphere model to identify items under the protection of higher system elements or building extensions to distances that require further protection by additional strike terminals. This is like rolling a 300 feet (92 meters) diameter ball from grade up against and then over a building to the opposite grade level in every conceivable direction. If the ball touches insulated building material, then an additional strike terminal is added. Areas supported by strike terminals, a strike terminal and grade, and vertical walls are then under the protection of properly designed system elements. This **geometric model** for protecting total structures is based on the last step in the lightning attachment process, and again covers well over 90% of conceivable strikes. On more critical structures, like those containing explosives or flammable liquids and vapors, the model is reduced to a 100 feet (30 meters) radius sphere that covers in excess of 98% of recorded lightning strikes.



The **strike termination system** defends the structure against lightning attachment by providing preferred attachment points. Copper or aluminum air terminals are preferred in most cases based on their conductivity and suitability to exposure to weather. Qualified prominent metallic building elements may also serve the function. In special circumstances where lightning cannot be allowed to penetrate, the use of tall masts and overhead ground wires used in a reduced zone model can provide additional protection. Protecting things like lighting standards or trees can provide some area protection based on the zone model. Strike termination design configuration is the first key element to providing a complete lightning protection system.

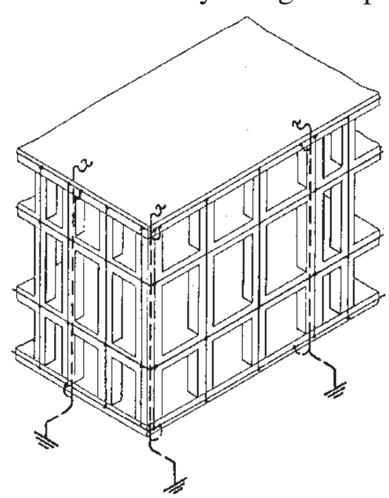
Conductors

The **conductor system** component of complete lightning protection includes main sized cables, the structural steel of a building, and bonding or interconnection wires to internal grounded building systems. The **main conductors** perform the current carrying function from the strike termination devices to the grounding system. Main cables are highly conductive copper or aluminum that perform well in an external environment. Lightning seeks a path toward ground, so even with very conductive materials, the routing of cables needs to be maintained in a horizontal or downward coursing. This is similar in concept to the gravity flow of water on sloped flat areas to roof drains or in gutter to downspout systems. Cables need to be routed using long smooth bends of no less than 90 degrees. Lightning will place significant mechanical force on cables, and sharp bends or corners can be damaged or lightning can arc over in the worst cases. This mechanical force can be compared to sending pressurized water through a fire hose – the conductor will try to straighten itself creating a damage concern for splice fittings, fasteners, or the conductor itself.



Copper and aluminum main cable conductors for lightning protection are designed to a smooth weave or rope-lay standard using smaller gauge individual wires. This construction allows a maximum surface area per unit weight of conductor to accommodate lightning which travels quickly on the surface. This construction also allows for easier bending and forming of the conductor system along, around and over building construction elements. Exposed conductors are fastened at maximum three feet intervals to maintain the system in place against wind and weather. All strike termination devices must be connected to the conductors with a **minimum of two paths** to the grounding system. Strike termination devices covering various areas of a structure must be interconnected to form a single system either by roof conductors, at down conductors, or by interconnection of grounding system elements for different roof levels or projections. Lightning cable conductors may be concealed below or within construction – in attics and wall spaces, or in concrete pours – because the speed of lightning lowers the potential for heating of the conductors to the spark ignition temperature of building materials to well below damaging levels.

Downleads or down conductors are the elements of the main conductor system that generally bring the lightning from the roof level system to the grounding system. This may include cable conductor, or **qualified continuous steel framework** of 3/16" thickness or greater, or a combination. Reinforcing steel or rebar is not acceptable as a substitute for cable conductor, but each cable downlead must be bonded to the structural framing at the top and bottom of each vertical run. All strike termination devices must have a minimum of two paths to ground to split the lightning along multiple paths, so the smallest building must have two downleads minimum. Downleads for large buildings may be calculated at 100 feet average intervals for the perimeter footprint of the building, although system components for special building design elements may necessitate additional down conductors to meet multiple path requirements. It is important to calculate the footprint of the protected perimeter to get the proper distribution for downleads for ridged roofs which include strike terminations only along the apex.



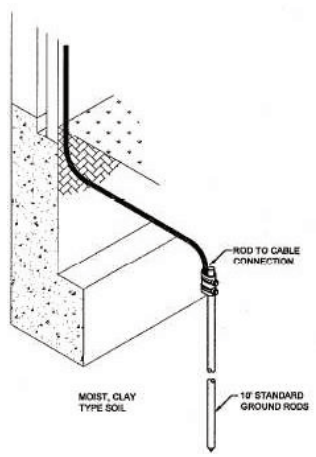
Providing **multiple paths** for lightning current has the great advantage of lowering the total energy on any given conductor. This impacts not only conductor sizing, but also keeps the lightning to our specified paths to minimize side-flashing to internal systems and lessen potential internal induction problems. The lightning protection Standards call for a minimum number on the perimeter, but more paths can be very beneficial in providing a cage of protection for equipment and people inside. The fact that **steel frame construction** creates the largest number of qualified vertical paths interconnected horizontally on multilevel structures makes its use as downleads preferred to give an improved shield against lightning side-effect intrusion. Although cable conductors are required for downleads in poured concrete construction, the required bonding of the rebar helps create a similar network of protection in high rise construction projects.

Grounding

Properly made **ground connections** are essential to the effective functioning of a lightning protection system, as they serve to distribute lightning into earth ground. This does not mean that the resistance of the ground connection must be low, but rather that the distribution of metal in the earth, or upon its surface in extreme cases, shall be such as to permit the dissipation of a lightning discharge without causing damage.

Low resistance is desirable but not essential, as may be shown by the extreme cases on the one hand of a building resting in moist clay soil and on the other hand by a building sitting on bare rock. In the first case, if soil is of normal resistivity, the resistance of a proper grounding electrode would be expected to be less than 50 ohms, and two such connections to ground on a small rectangular building have been found by experience to be sufficient. Under these favorable conditions, providing adequate means to dissipate the energy of a flash without chance of serious damage is a simple matter. In the second case, it would be impossible to make a good ground connection in the ordinary sense of the term, because most kinds of rock are insulating or at least of high resistivity; hence, in order to obtain an effective ground, more elaborate means are necessary. The most effective systems consist of an **extensive wire network** laid on the surface of the rock surrounding the building to which the down conductors are connected. The resistance between such an arrangement and earth may be high, but at the same time, the potential distribution about the building is substantially the same as though it were resting on conducting soil and the resulting protective effect is also substantially the same. The lightning protection grounding electrode system serves to take the lightning into whatever soil strata exists, and route it away from the structure.

A **grounding electrode network** will be determined largely by the experience and judgment of the person planning the installation with due regard to the minimum requirements of the Standards, which are intended to cover the ordinary cases that are likely to be encountered, keeping in mind that, in general, the more extensive the underground metal available, the more effective the grounding system



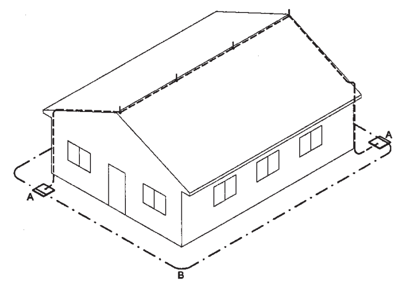
The grounding arrangement depends on the character of the soil, ranging from single ground rods where soil is deep, to the use of multiple electrodes, ground plates, radials, or buried wire networks where soil is shallow, dry, or of poor conductivity.

Each **downlead cable** shall terminate to a grounding electrode connection dedicated to the lightning protection system. Electrical or communication system electrodes must not be used in lieu of lightning ground electrodes. The final product must include the bonding together of separate grounding electrodes of different systems.

Wherever practical, connections to grounding electrodes should be made exterior to the foundation wall or far enough away to avoid buried footings, pipe caps, etc. Grounding electrodes should be installed below the frost line where possible. The materials used for grounding electrodes must be suitable to any alkaline or acid composition of soils for long life.

During a discharge of lightning current on a system of conductors, the grounding electrodes are to be thought of as the points through which the heavy current flows between the strike termination system and the earth about the structure. Therefore, placement with the view of carrying the **flow of current away from the structure** in the most advantageous manner is important. This will be realized by placing grounding devices at the outer extremities, such as corners and outside walls of the structure, and avoiding as far as possible the flow of current under a building. In some cases, particularly when additions to an existing building or zero property line construction are involved, it may be necessary to place downleads and grounding inside and under a structure.

A **ground loop** encircling a structure interconnecting all downlead cables at their base and/or grounding electrode devices is the best way to equalize potential for an entire lightning protection system. It is always possible to have varying resistance values for individual grounding electrodes even on the same structure.



A: OPTIONAL GROUND PLATES
B: ENCIRCLING COUNTERPOISE
(GROUNDING IN SOIL LESS THAN 1'-0" DEEP)

FIGURE 32

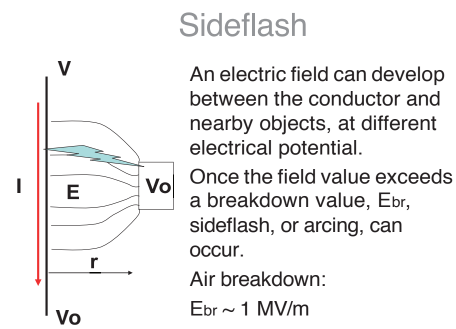
Since splitting the lightning along multiple paths begins at the strike termination point and follows through the conductor system to ground, different resistance values of electrodes can upset this function. An in-ground loop solves this potential problem and provides an extensive wire network to enhance the grounding system. A ground loop is required for every structure **exceeding 60 feet** in height. If an interconnecting loop cannot be installed in the earth, then it may be placed within the construction to fulfill this requirement. This ground level loop also accommodates connection with other building grounded systems.

All grounding media in or on a structure shall be interconnected to provide a **common ground potential** using main size lightning conductor. This includes the lightning protection grounding electrode system, electric, communication, and antenna **system grounds along with metallic piping** systems entering the structure like water, gas and LPG lines, metal conduits, etc. Interconnection to gas lines shall be made on the customer side of the meter to avoid defeating any cathodic protection of service lines. Where all these systems are bonded to a continuous metallic water line system, only one connection is required between the lightning protection grounding and the water line. System interconnection may be made at multiple points near structure entrances for systems, or one hard connection at a ground bar may be used. Bringing all building grounded systems to the same potential at grade is the first step toward protecting internal components and people from lightning. It begins the bonding process against side flashes from system components to internal building systems.

Potential Equalization (Bonding)

The major current carrying components of the lightning protection system were described in their earliest form by Benjamin Franklin. Modern techniques for component manufacture and designs incorporating the system on and in a structure have changed the system look, but the philosophy behind strike termination, conduction, and grounding remains similar – accept the lightning and send it to ground. The most dramatic changes involved in lightning protection system design come from adaptations in how we build and outfit the modern building, or what we might call the "indoor plumbing factor". The **modern building** counts metallic piping like plumbing, sewer, and gas systems, along with circuitry for electrical and communication systems, which all provide internal paths for lightning to damage components and bring people closer to danger.

At the inception of a lightning strike to a system, there may be an immediate rise to 1,000,000 volts at prominent components traveling to 0 volts at earth ground. Any other independently grounded building system in close proximity to lightning protection components would be at 0 volts, so the natural tendency is for some or all the lightning to leave our current carrying system and flash over to the alternate ground path. If the distance between potential paths is short enough the **arc over or sideflash** may occur through air or building materials, either of which creates the potential for fire or explosion.



Since internal grounded building systems permeate a structure, this potential exists at roof level, on or in building walls, and even potentially below grade. Lightning spreads out from system grounding electrodes near the earth's surface and can return on metallic pipes or other grounds back into the building. Alternate paths from interior grounded circuitry are not designed to carry lightning current (a fire hazard), and junctions in metallic pipes are not designed as current carrying devices leading to heat deformation or shock problems. Equipment within structures, from a sink connected to both the water and sewer lines to a personal computer connected to both the electric power and phone or antenna circuits, become additional points for lightning current to arc between **independently grounded systems** creating significant havoc.

A complete lightning protection system addresses this issue through bonding or the interconnection of metallic building systems with the lightning system to create a **common ground potential**. When grounded systems are bonded together there is no reason for the lightning to leave our designed current carrying path because the arbitrary arc-over points don't exist. It is required to interconnect every grounded

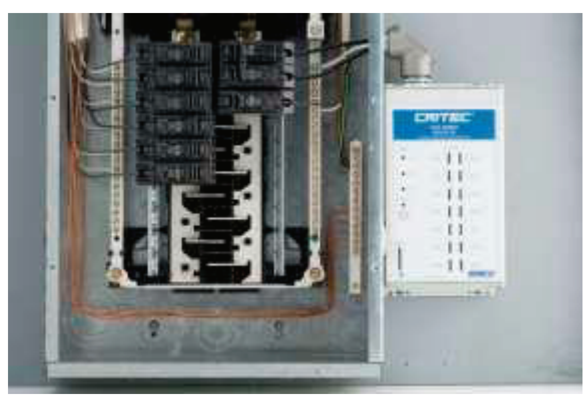
building system and continuous metallic piping system with the lightning protection grounding electrode system near grade level. Low profile structures may only need interconnection of systems near the roof level when they are in close proximity to lightning protection system components. As structures get taller, it becomes a requirement to interconnect the top of the vertical extension of each internal grounded system with the lightning protection roof system. Finally, in high rise construction, building grounded systems are interconnected at grade level, roof level, and at intermediate levels to provide sufficient potential equalization between long conductor runs to avoid arc over.
Internal arcing between grounded systems is also a function of how many paths we have from the roof lightning protection system to the grounding system. The more paths the more we split the lightning into lower voltage segments, the less potential for arc over through any medium to alternate systems. Incorporating a steel superstructure into the lightning protection system provides columns and beams and intermediate connections to **maximize splitting** the lightning and thus **minimize difference of potential** problems internally. Standards require the interconnection of cable downleads to reinforcing steel (rebar) in poured columns at the top and bottom of each run creating a similar effect, although this mechanical structural system is not deemed suitable for carrying lightning current by itself. The reinforcing steel, grounded internal systems and lightning protection must also be interconnected at 200 feet vertical intervals to maintain potential equalization.

Bonding together of grounded systems is typically accomplished with smaller **fittings and cables or wire** runs on roof areas of structures. Interconnection for potential equalization is simply not the same as providing current carrying capability. However in many cases it is easier to use full size system components because designs place them close to desired bonding points. When we bond within construction or below grade it is more typical to use full size components mainly for a more robust mechanical strength against construction realities.

Extension of the lightning protection system to include **grounded system** bonding for any structure is a critical element based on the individual design of the building for the occupancy and processes specific to its intended use.

<u>Surge Protection</u>

Lightning protection systems are designed first and foremost as fire protection systems – to stop the building from burning down and losing the people and equipment inside. Bringing metallic services into a structure provides paths for lightning to follow from the outside environment to create hazards within. We bond or interconnect grounds and pipes to the lightning protection system to avoid a portion of this problem. The next step is to provide protection on circuits associated with electrical, communication, and/or data lines that can transmit lightning into a structure.

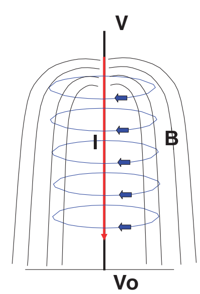


The severest problems are associated with **utility service lines** that are extensive systems, either pole mounted or buried, that can transmit additional indirect strikes to the building. A complete lightning protection system according to the Standards includes surge protective devices at every entrance of building service conductors, whether they are utility or possibly structure-mounted like an antenna system.

Surge protective devices for building entrances are designed to "ride" the line, sense overvoltage problems, and send excessive energy directly to ground. SPDs designed for lightning surges must react quickly to the onset of the sharply rising waveform and be able to sustain the ground connection through the severe overvoltage incident, then reset to their monitoring role. Most devices have two or more internal elements to accomplish the task, and react at something around 150% of the standard operating voltage of the system. SPD elements can be thought of as self-sacrificial and may burn out over time protecting against a multitude of small surges (like standard switching surges from power transmission) or a few massive surges like direct lightning attachments. Therefore it is important to have SPDs accessible for view or to have indicator lights or other identifiers to know your protection continues as designed. Since service entrances for various systems operate at different voltages, SPD components must be individually sized for each system and are generally packaged individually to address specific functions, but if services enter a utility room for distribution throughout the building in a common area a single SPD may be designed to serve several functions in one housing. Since adding ground path length only serves to slow the reaction time of SPD components, the SPD should be connected as directly to the grounding system as possible always with minimum lead length.

Properly installed Type 1 or Type 2 listed **surge protective devices at all entrances** on circuit conductor feeders protect a massive entrance of lightning to the structure saving wiring from burning and generally protecting items such as large motors, light fixtures, and other robust utilization equipment. This is the specific Standards requirement – protect against destruction of the building. Internal to every modern structure, we have a variety of devices that operate at low voltages including circuit boards truly not designed to operate at the 150% let-through level of entrance only SPDs.

How Surge Occurs



Current flow through an impedance leads to a voltage.
An electric field (E) will develop.
A magnetic field (B) will develop.
Coupling (capacitive & inductive) can occur through these fields.

There are also inductive effects possible to internal wiring and equipment with even a well-designed lightning protection system. The current of a massive direct lightning strike to a structure creates a magnetic field extending from the conductors, so any alternate circuit proximate may experience some added voltage through induction. Protection of audio/video components, communications systems, computer equipment and/or process machinery may be of great importance to the quality of the establishment, continuity of business without interruption, and the physical protection of equipment users.

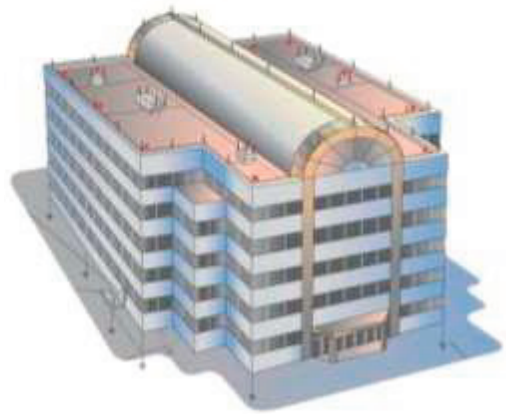
SPDs installed at utilization equipment should provide protection for all circuits feeding the device to provide a common ground point. Since systems of utilization equipment are generally specific for the facility, an individualized assessment will normally be needed to determine cost effective solutions.

When surge protective devices send energy to the ground system this instantaneous connection of all wiring systems functions to provide **potential equalization** for those metallic systems, just as bonding between the lightning protection system components and alternate building system grounds provides common interconnection. Advances in technology continue to change the environment of structures where we live, work, and enjoy entertainment. The application of SPDs along with the current carrying components and interconnection of grounded building systems provides the complete package for a full lightning protection system to protect structure, people, and equipment within.

<u>Inspection & Maintenance</u>

The exposed components for a lightning protection system are copper, aluminum, or other metal designed to carry current, provide bonding connections, and remain functional in an open weather environment. As with any other building element made of similar materials, oxidation or corrosion of components would not be expected under normal conditions for an extended period, or the normal **"lifetime" of the structure**. System components concealed within construction between the roof and grade are protected against weathering and abuse. The grounding electrode system may be protected from atmospheric conditions of weathering, but is subject to potential degradation from soil compositions and moisture. A proper initial installation might be expected to provide protection forever or at least for the reasonable useful life of a particular building.

There are additional realities of construction, our use of buildings, and even unknowns in local conditions that require consideration of **maintenance** for the lightning protection system. A passive grounding system like lightning protection is not easily assessed by laymen – you can't flip a switch or turn on a faucet to see if it is in working condition.



There are obvious times when changes to the structure create a need for maintenance or extension of the original system. Reroofing the building, making additions to the building's structural frame, or adding vent stacks or antennas for new internal processes are obvious areas needing review and treatment. Not so obvious, but reported as the greatest cause for required review of systems is the habit of workers from other trades removing and failing to reinstall system components because they do not understand the importance of the total lightning protection **system design.** It is also possible that a neighboring process stack will emit a substance carried by the wind toward your system components that works to degrade materials at a much faster than expected rate. Any and all of these items call for periodic inspection and maintenance to assure the system is functional when placed under lightning strike conditions, but it certainly could be ignored with serious unintended consequences.

A **program of inspection** and possible maintenance should be implemented to assure continued effectiveness of the system on the structure. A visual inspection can be accomplished yearly using a checklist and modest training from your lightning protection provider to account for any minor repairs like loose fittings, improper anchoring, damage to exposed cables, replacement of removed hardware, or damage to surge protective devices. This could be done by a regular building maintenance technician or even the building owner with some guidance. If a lightning protection professional is not used for every yearly inspection, then at three year intervals it would be important to have a "testing" inspection by bringing in a knowledgeable individual – inspector or installer – for a more thorough examination.

A complete **testing inspection** would include the visual checks along with continuity testing to verify system effectiveness from roof to grade, and ground testing to validate the concealed underground electrodes function. A quality assurance program designed for maintenance of your lightning protection system will eliminate surprises that could lead to disastrous consequences.

The implementation of a **lightning protection system** includes some art, science, craftsmanship, and technological intuition. This is a specialized industry with its own Standards designed purpose specific to deal with nature's great random destroyer. As in any endeavor the background, training, and certification of the individuals involved in the design, installation, and inspection of a complete lightning protection system determines the ultimate quality. The **Lightning Protection Institute** focuses our efforts to educate professionals, owners, users, and the general public on safe and effective lightning protection and provides quality resources through our membership to accomplish this important service for the entire construction industry.

GENERAL REQUIREMENTS

1) Research indicates that lightning protection for buildings, trees, and open structures can reduce damage and personal injury from lightning. The critical design purpose of this document is to stop the initiation and spread of fire in insulated building materials caused by lightning. Resolving the structural issue with direct strike and protection against utility transmitted lightning according to this standard will assist in protecting personnel and equipment inside the structure. The prime purpose of this Standard is to describe and encourage use of quality lightning protection systems for fire safety.

2) This document covers the protection from lightning of buildings and structures, elevated storage silos, heavy duty stacks, trees, and open shelters. The protection of structures containing flammable vapors, gases, or liquids; structures housing explosive materials; wind turbines; watercraft; solar arrays; along with electric transmission and distribution systems is not included. Conventional structures used for these purposes may be protected in accordance with this Standard; however items not included are covered by alternate standards – See NFPA 780 for more information.

3) The LPI Board of Directors has considered proposed methods of lightning protection other than interception, conducting, and grounding. Proposals must be legally adopted in the United States, such as accreditation by the National Fire Protection Assoc., must be recognized by independent scientific research, and must have long historical documentation of use in the U.S. lightning protection industry. Proposed system designs or material components that do not meet these criteria are not included.

4) This Standard is based on the fundamental principle of providing a reasonably direct, low-resistance, low impedance metallic path for lightning current to follow, and making provisions to prevent destruction, fire, damage, death, or injury as the current flows from the roof levels to below grade. This Standard represents a consensus of authorities regarding basic requirements for construction and performance of products classified under this category. Requirements are based on sound engineering principles, research, records of tests and field experience. They reflect an appreciation of the problems of manufacture, installation and use derived from consultation with manufacturers, users, design engineers, inspection authorities, and others having specialized experience. Requirements are subject to revisions that further experience and investigation may show are necessary or desirable.

5) Observance of this Standard is one of the conditions of system certification by LPI. The Institute, however, assumes no responsibility for the effect of such observance or nonobservance upon the relations between the manufacturer, installer and any other party or parties arising out of the sale or use of lightning protection system products or designs. It is generally acknowledged that lightning is a stochastic, if not capricious, natural process. Its behavior is not completely understood. This Standard provides requirements within the limits of the current state of knowledge for the installation of a quality lightning protection system.

6) A product that complies with these requirements will not necessarily be eligible for certification if, when examined and tested, it is found to have other features that impair the result contemplated by these requirements. A product employing materials or having forms of construction differing from those detailed in these requirements may be examined and independently tested according to the intent of the requirements and, if found to be substantially equivalent, may be accepted for certified systems.

7) Lightning protection systems shall be installed in a neat and workmanlike manner. The individual responsible for the installation shall be certified for fitness on the requirements of this standard as a Master Installer or Designer Inspector.

8) Material components used for lightning protection systems shall be compatible with the building surface where mounted. For example, copper lightning protection materials shall not be installed on aluminum roofing or siding materials or other aluminum surfaces; and aluminum lightning protection materials shall not be installed on copper surfaces, etc.

SYSTEM CERTIFICATION

9) This Standard and the companion document **LPI 177 – "Inspection Guide for Certified Systems"** are the compliance documents for installation of Certified Systems with the **Lightning Protection Institute – Inspection Program (LPI-IP)**. Contact LPI-IP for more information at www.LPI-IP.com.

10) LPI-IP also offers installation confirmation for systems in compliance with alternate nationally recognized Standards, including NFPA 780 & UL 96A.

11) The LPI-IP Certified System program is designed to add installer credentials in addition to trained and tested field inspection for quality assurance throughout the design and installation process for the entire lightning protection system. An LPI Certified Master Installer is responsible for each project application. Photo records are required to certify system components which are to be concealed in the ground, inside the structure or below the exposed roof areas. An owner's representative is required to sign the application to verify the concealed work is in place. The design drawing and photos are reviewed by engineering personnel in the LPI-IP office for completeness. LPI-IP field inspection then qualifies the exposed system components and final installed design. When a Certified Master Installer is not involved in the project, a Certified Designer Inspector can serve this function. If the Designer Inspector serves the function normally handled by a Master Installer, then final field inspection will include a third-party representative of the LPI-IP program not associated with the Designer Inspector.

12) The LPI Certified System is divided into subprograms based on scope of work. A system for a complete structure qualifies for a **Master Installation Certificate**. The **Reconditioned Master Installation Certificate** is used for structures that previously received certification and are brought up to date with current Standards. For contracts which include systems only on partial structures (e.g. additions, cooling towers), a **Limited Scope Inspection Report** application is filed with LPI-IP.

13) Surge protective devices, required by the Standards at the service entrance for each electrical, communication, and/or antenna system, may be handled by separate contracts through the electrical or specialty contractors installing those systems. In the case where inspection and certification of the lightning protection system does not include SPDs as part of the contract (structural protection only), all the above certification types are available with an exclusion for surge products.

14) Where an unprotected structure of different ownership is attached to a fully protected LPI Certified System, the owner of the protected building or his representative shall be advised by letter from the Master Installer of the potential danger to the property due to its attachment to the unprotected section.

15) This LPI175 document, NFPA 780, and UL 96A have differing revision cycles accomplished by different committees. The application process for LPI-IP inspections includes designating the control Standard for inspection. In the event multiple Standards are specified, there may be variations in some requirements. In cases where differing requirements may be considered for design criteria, LPI-IP will make the final determination of the most beneficial design and installation technique to provide the best level of safety for the property under consideration.

16) Underwriters Laboratories, Inc. Standard UL 96 is the compliance document for quality, sizes, and dimensions of air terminals, conductors, connectors, fasteners, and all other materials and products used in LPI-IP Certified Systems. All materials and components used for a Certified System must be listed and/or certified to indicate that they have been manufactured, tested, and factory inspected for compliance with UL 96. Products listed and labeled for use in lightning protection systems by alternate independent testing laboratories shall be verified as compliant to the UL 96 document. Listed or labeled equipment shall be installed and used in accordance with any limitations and instructions included in the listing or labeling.

17) A Certificate signed by the Director of LPI-IP shall be provided to the Master Installer who shall then forward it to the Owner of the protected property or to a third party representative designated by the Owner.

18) The application and Inspection Report is retained in LPI-IP files along with copies of as-built drawings and/or any accompanying photographs or statements related to the project.

19) All LPI-IP system certifications have an expiration date 3 years from their date of issue. This conforms to the typical cycle to new editions of the Standards documents. LPI-IP will contact the Master Installer at the end of the 3-year period to arrange for inspection and possible maintenance of the certified system.

20) LPI-IP Certified System Benefits:

- Compliance with national Standards at all stages of system installation.
- Installations supervised by field technicians tested for competence by LPI
- Coverage of partial systems or additions to existing buildings and system updates.
- Field inspection by LPI-IP trained and tested inspectors
- Factory inspected and certified components.
- Inspection and/or photo record of components and connections prior to concealment.
- Timely final inspection.
- Future contact for inspection and maintenance.

INSPECTION AND MAINTENANCE

21) A lightning protection system in accordance with this Standard is a passive grounding system that is effective in protecting against lightning damage as originally installed and inspected. However, any system of this nature must be reinspected at regular intervals to verify its continued effectiveness, similar to inspections of roofing materials, flashings, or exterior wall coverings. Unusual weathering, the addition of protruding bodies, or lack of care by other maintenance trades may render portions of the system ineffective over time. An inspection and maintenance procedure is recommended, and may be conducted by the system installer, an owner's representative, or a qualified inspection authority.
Keeping the lightning protection system up to date with current standards ensures the greatest level of safety. When a lightning protection system is upgraded, as-built drawings should be revised to document modifications. These drawings should include test point locations, where applicable. Where required by the AHJ, test records of the new configured system should be provided to establish a new baseline for future test measurements.

22) Annual visual inspection of the completed system is recommended. A sample visual inspection format is included in the back of the LPI 177 Inspection Guide document.

23) It is recommended that at three-year intervals a qualified engineer (Certified Designer Inspector) or lightning protection installer (Certified Master Installer) conduct a more thorough inspection. This three-year inspection should include continuity testing and a ground resistance check, using a properly calibrated approved ohms resistance-measuring device. If long term ground testing is anticipated for concealed systems, provisions must be made by the owner/engineer prior to the original installation. These could include adding junction boxes or access wells at downlead and/or ground locations. At this time application may be made to LPI-IP for a recertification of the system to current Standards requirements using the **Reconditioned Master Installation Certificate** application for previously certified systems.

24) Any structural additions to a building that do not fall within a zone of protection, described in paragraphs **89 to 99,** of the existing system shall be equipped with a full lightning protection system properly interconnected with the existing building system. The completed system for the addition would then be certified using the **Limited Scope Inspection** application.

25) New protruding metal bodies, such as mechanical equipment, antennas, or equipment vents, added to the building shall be bonded to the lightning protection system as required by the provisions of this Standard, if they are not within a zone of protection of the existing lightning protection system. The **Limited Scope Inspection** from LPI-IP may apply for the units individually, or the contract may constitute bringing the entire system up to current Standards for the **Reconditioned Master Installation Certificate.**

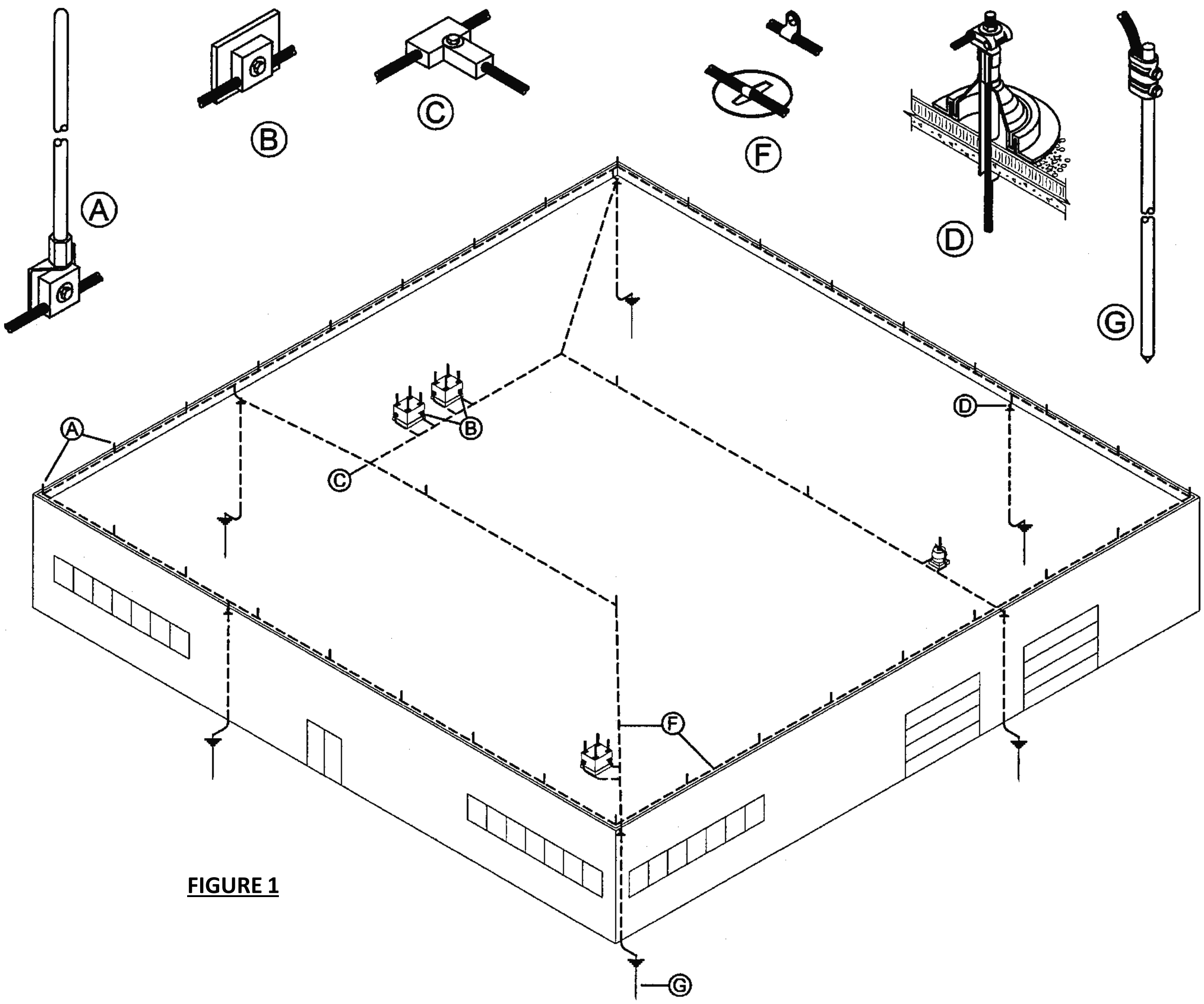


FIGURE 1

DEFINITIONS

Air Terminal – A manufactured strike termination device intended to provide an intentional attachment point for flashes to the lightning protection system.

Approved – Acceptable to the authority having jurisdiction.

Authority Having Jurisdiction – The organization, office, or individual responsible for approval and enforcement of equipment, materials, 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.

Bonding Conductor – A conductor used for potential equalization between grounded metal bodies or electrically conductive objects and a lightning protection system. The bonding conductors are normally smaller in size than current carrying conductors.

Cable – A factory assembly combining multiple wire strands together to form a single conductor.

Catenary Lightning Protection System – A lightning protection system consisting of one or more overhead ground wires (also known as "overhead shielding").

Chimney – A structure containing one or more vertical or nearly vertical passageways for conveying flue gases to the outside atmosphere. A chimney does not meet the criteria defined for a heavy duty stack (below).

Class I Materials – Air terminals, conductors, grounding electrodes, and associated fittings required for the protection of structures not exceeding 75 ft. (23m) in height.

Class II Materials – Air terminals, conductors, grounding electrodes, and associated fittings required for the protection of structures exceeding 75 ft. (23m) in height.

Combination Waveform Generator – A surge generator with a 2 ohm internal impedance producing a 1.2/50 μs open circuit voltage and an 8/20 μs short-circuit current wave shape.

Conductors – Devices defined by this Standard as suitable to carry lightning current or make bonding interconnections.

Copper-Clad Steel – Steel rod or wire with a coating of copper bonded to it.

Fastener – A component or set of components used to securely attach materials to the structure.

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

Grounding Electrode –A component of a lightning protection system installed for the purpose of transferring the current on the lightning conductors into the earth.

Ground Loop Conductor – A main-size loop conductor installed within 12 ft. (3.6 m) vertically of the base of the structure to provide a common ground potential. A ground ring electrode that provides the common grounding requirements meets the requirements of a ground loop conductor.

Inherently Bonded – Bonding between metal bodies, building framework, and lightning protection system components that are joined through construction. The bonding resistance value should typically be in the tens of milliohms but should not exceed 200 milliohms.

Integral Lightning Protection System – A lightning protection system directly attached to the structure.

Heavy Duty Stack – A smoke or vent stack with a flue that has a cross-sectional area greater than 500 square inches (0.3 square meters) and a height greater than 75 ft. (23m) above grade level.

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 the equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Lightning Protection System – A complete system of strike termination devices, main conductors (including conductive structural members), grounding electrodes, bonding or interconnecting conductors, surge protective devices, and other connectors or fittings required to complete the system.

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, materials, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

Loop Conductor – A conductor encircling a structure that is used to interconnect grounding electrodes, main conductors, and/or other electrically conductive bodies.

Main Conductor – A conductor intended to be used to carry lightning currents between strike termination devices and grounding electrodes. This may include strike termination devices, cables, lightning protection fittings, grounding electrodes, or metallic structural members.

Maximum Continuous Operating Voltage (MCOV) – The maximum designated rms value of the power frequency voltage that can be continuously applied to the mode of protection of a surge protective device (SPD).

Maximum Discharge Current (I_{max}) – The maximum instantaneous value of the current through the SPD having an 8/20 μs waveform.

Measured Limiting Voltage (MLV) – Maximum magnitude of voltage that is measured across the terminals of the surge protective device (SPD) during the application of impulses of specified wave shape and amplitude.

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 (according to this Standard) to provide an electrical path equivalent to that of lightning conductors.

Nominal Discharge Current (I_n) – Peak value of 8/20 μs current waveform selected by the manufacturer for which an SPD remains functional after 15 surges.

Nominal System Voltage – The nominal voltage (rms) of the power frequency supply.

Normal Operating Voltage – The normal ac power frequency voltage rating, as specified by the manufacturer, to which the surge protective device (SPD) may be connected.

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 conductive metal bodies and a component of a lightning protection system or ground.

Spark Gap – Any short air space between two conductors that are electrically insulated from or remotely electrically connected to each other.

Standard – A document, the main text of which contains mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law.

Strike Termination Device – A component of a lightning protection system that intercepts lightning flashes and connects them to a path to ground. Strike termination devices include air terminals, metal masts, qualified permanent metal parts of structures as described in this Standard, and overhead ground wires installed in catenary lightning protection systems.

Surge – A transient wave of current, potential or power in an electric circuit.

Surge Arrestor – A protective device for limiting surge voltages by discharging or bypassing the surge current.

Surge Protector – A protective device for limiting excessive potential and current on signal, data, and communication circuits caused by lightning, contact with power conductors, power induction, and rises in ground potential, while also preventing the continued flow of the follow current while remaining capable of repeating these functions.

Surge Protective Device (SPD) – A protective device for limiting the transient voltages by diverting or limiting the surge current and preventing the continued flow of the follow current while remaining capable of repeating these functions.

Tank Battery – A group of tanks and the associated process equipment for crude oil production or saltwater disposal.

Transient – A subcycle disturbance in the ac waveform that is evidenced by a sharp, brief discontinuity of the waveform.

Voltage Protection Rating (VPR) – A rating (or ratings) selected by the manufacturer based on the measured limiting voltage determined when the SPD is subjected to a combination waveform with an open circuit

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

FIGURE 3 - LIGHTNING PROTECTION GLOSSARY

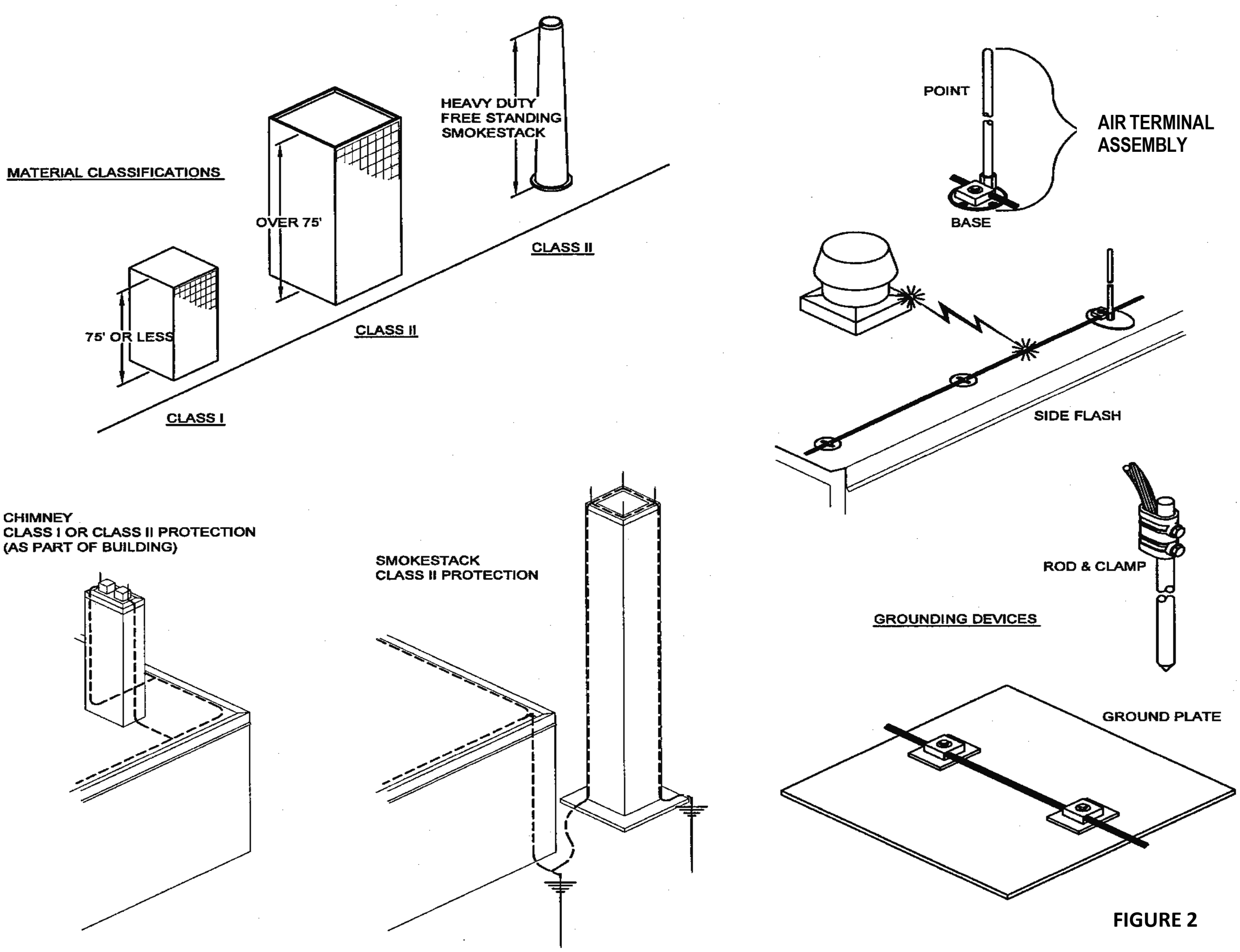


FIGURE 2

GENERAL REQUIREMENTS FOR STRUCTURES

Material Sizes

26) Any structure that is used for commercial, industrial, farm, institutional, recreational or residential purposes shall meet the following general requirements as a minimum for a complete lightning protection system.

27) Any structure not exceeding 75 ft. (23m) in height shall be protected with Class I materials as shown in **TABLE 1** (Air Terminals) and **TABLE 2** (Main Conductors).

28) Structures exceeding 75 ft. (23m) in height shall be protected with Class II materials as shown in **TABLE 1** (Air Terminals) and **TABLE 2** (Main Conductors).

29) If part of a structure exceeds 75 ft. (23m) in height and the remaining portion does not exceed 75 ft. (23m) in height, the requirements for Class II materials shall apply only to that portion exceeding 75 ft. (23m) in height. Class II conductors extending down from the higher portion shall be carried to the grade level ground system. An existing structure requiring Class I materials on which a new addition requires Class II materials shall be permitted to use the existing ground ring conductor installed and determined to be suitable for continued service.

30) Every lightning protection section on a structure shall be interconnected with the balance of the system on that structure to form a single grounded system. Interconnections between system sections may be made at main roof levels, intermediate building levels, or below grade. An interconnection between lightning protection sections may also be made by bonding separately to continuous building structural metallic members.

Material Considerations

31) Lightning protection systems shall be made of materials that are resistant to corrosion or protected against corrosion. Current carrying system components shall be highly conductive. Components in many cases are exposed to the atmosphere and climate, located on the top and sides of a structure. Combinations of materials that form electrolytic couples of such a nature that in the presence of moisture corrosion is accelerated shall not be used. The in-ground system components are subject to the prevailing site soil conditions. The system life and maintenance/replacement schedule for lightning protection products is determined by the local environment and the choice of materials used.

32) One or more of the following materials shall be used:

a) Copper. Copper shall be of the grade required for commercial electrical work and shall be of 95 percent conductivity when annealed.
b) Copper Alloys. Copper alloy shall be as resistant to corrosion as copper.
c) Aluminum. Conductors shall be of electrical grade aluminum with a minimum chemical composition of 99% aluminum.

33) Any part of a lightning protection system that is subject to mechanical damage or displacement shall be protected with a protective molding or covering. Where metal pipe or tubing is used around the conductor, the conductor shall be electrically connected to the pipe or tubing at both ends.

The requirement to protect conductors from mechanical damage does not preclude the running of exposed wiring at roofing perimeters, on roof surfaces, or other similar locations where incidental foot traffic or manual disturbance of the conductor is possible. This paragraph is not intended to require the concealment of all exposed lightning protection components in conduit or similar.

34) A non-metallic shield against corrosion or mechanical damage should not affect the function of a full-sized lightning protection component. Care should be exercised to leave all metallic strike termination devices exposed to serve their function in capturing attachments and providing a zone of protection.

Copper

35) Copper lightning protection materials shall not be installed on or in contact with aluminum roofing, siding, or other aluminum surfaces. Rain water running off copper components will deteriorate aluminum, so the full path of water needs to be considered to assure no damage to the structural components.

36) Protection shall be provided against deterioration of lightning protection components due to local conditions. Copper components installed within 24 in. (600mm) of the top of a chimney or vent emitting corrosive gases shall be protected by a hot-dipped lead or tin coating. For reference, examples of some metals typically acceptable for use with copper are: Brass, Lead, Monel, Nickel, Stainless Steel, and Tin.

Aluminum

37) Aluminum lightning protection equipment shall not be installed on or in contact with copper roofing materials and other copper surfaces, or where exposed to runoff from copper surfaces. As a reference, examples of some metals typically acceptable for use with aluminum are: Galvanized Steel, Lead, Magnesium, Stainless Steel, Wrought Iron, and Zinc.

38) Aluminum materials shall not be used for direct grounding of aluminum lightning protection systems. Aluminum materials shall not come into direct contact with earth.

39) Only approved bimetallic fittings shall be used to join aluminum and copper lightning protection system components. The connection of aluminum conductors to ground equipment shall be made at a point not less than 18 inches (457mm) above grade level. Where downleads are concealed the transition shall be at least 18 inches (457mm) above the lowest slab, floor or footing to be pierced.

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

Connectors and Fittings

41) Connector fittings shall be used at all “end-to-end”, “tee”, “Y”, or parallel splices of lightning conductors.

42) Fittings shall be attached so as to withstand a pull test of 200 lb. (890 N).

43) Conductor connections shall be bolted, welded, high compression, or crimp type. Crimp type connections shall not be used in Class II system installations.

44) Connectors and fittings shall be compatible for use with the conductor and the surfaces on which they are installed.

45) Approved bimetallic connectors and fittings shall be used for splicing conductors or bonding dissimilar metals. Artificial coatings, shims, or other specialty devices used for the protection of metallic surfaces cannot be used if they do not allow the required surface contact for joining components to surfaces.

46) Fittings used for required connections to metal bodies in or on a structure shall be secured to the metal body by bolting, brazing, welding, screwing, or high-compression connectors listed for the purpose.

Fasteners

47) Exposed cable conductors shall be fastened to the structure at intervals not exceeding 3 ft. (0.9 m).

48) 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.

49) Fasteners may include attachment to the structure by nails, screws, bolts, adhesives, masonry anchors as necessary with no combination of materials used that will form an electrolytic couple in the presence of moisture for the fastener, attachment device, or structure.

50) Masonry anchors used to attach lightning protection components shall have a minimum outside diameter of ¼" (6.4 mm). Holes made to receive the body of the anchor shall be of the correct size and made in the brick, stone or other masonry unit rather than in mortar joints. The fit shall be tight against moisture reducing the possibility of damage due to freezing.

STRIKE TERMINATION DEVICES

51) Strike termination devices include air terminals, metal masts, permanent metal parts of structures and overhead ground wires. Combinations of these devices shall be permitted for a total protection system. Strike termination devices shall protect all roofs and roof projections of a building subject to a direct lightning strike. Strike termination devices shall be provided where required by the following sections of this standard. Strike termination devices can be added, but are not required for those parts of a structure located within a zone of protection.

52) Metal parts of a structure that are exposed to direct lightning flashes and that have a metal thickness of 3/16 in. (4.8mm) or greater serve as strike termination devices and shall require only connection to the lightning protection system. Metal handrails outside a zone of protection having a wall thickness of 1 ⁄8 in. (3.2 mm) thick or greater shall only require connection to the lightning protection system. Connection shall provide a minimum of two paths to ground (subject to "dead-end" exceptions in paragraph **104**. The metal needs to be connected to the lightning protection system using main size conductor and a bonding device having a minimum 3 in.^{2} (1940 mm^2) of contact surface or a minimum of 1 ½ in. (38mm) of contact along the axis of a round surface.

Provisions shall be made to guard against the corrosive effect introduced by dissimilar metals at points of bonding. Connection points shall generally be bare metal to bare metal with required corrosion protection applied after bonding **(See Figure 3)**.

Metal bodies with less thickness than stated above require air terminals, either mounted to the metal body or nearby, placing it within a zone of protection similar to non-metallic structure surfaces.

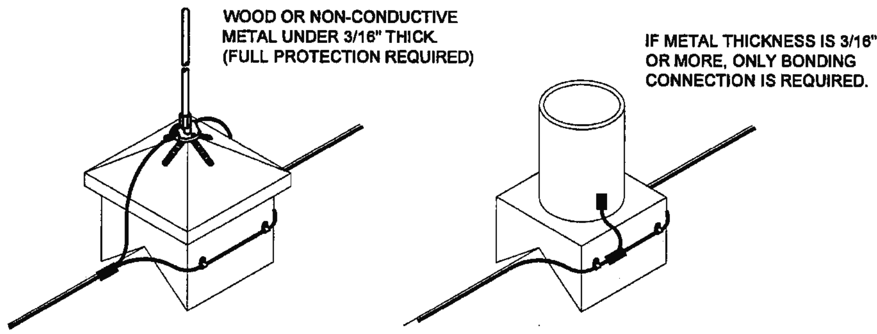


FIGURE 3

53) Air terminals are designed to serve as strike termination devices. All air terminals used for LPI Certified Systems shall be subjected to factory inspection or certification by an independent testing agency to Standard UL 96 requirements. Air terminals on Class I structures (75 feet (23m) high or less) and Class II structures (over 75 feet (23m)) shall be sized according to the materials table below **(See TABLE 1).**

TABLE 1
AIR TERMINALS - MINIMUM MATERIAL REQUIREMENTS

Classification	Product	Dimension	Copper	Aluminum
Class I	Solid Air Terminal	Diameter	3/8 in. (9.5 mm)	1/2 in. (12.7mm)
	Tubular Air Terminal	Diameter	5/8 in. (15.9 mm)	5/8 in. (15.9mm)
		Wall Thickness	0.032 in. (0.81 mm)	0.064 in. (1.63mm)
Class II	Solid Air Terminal	Diameter	1/2 in. (12.7 mm)	5/8 in. (15.9mm)

54) Air terminals shall extend above the object or area to be protected not less than 10 inches.

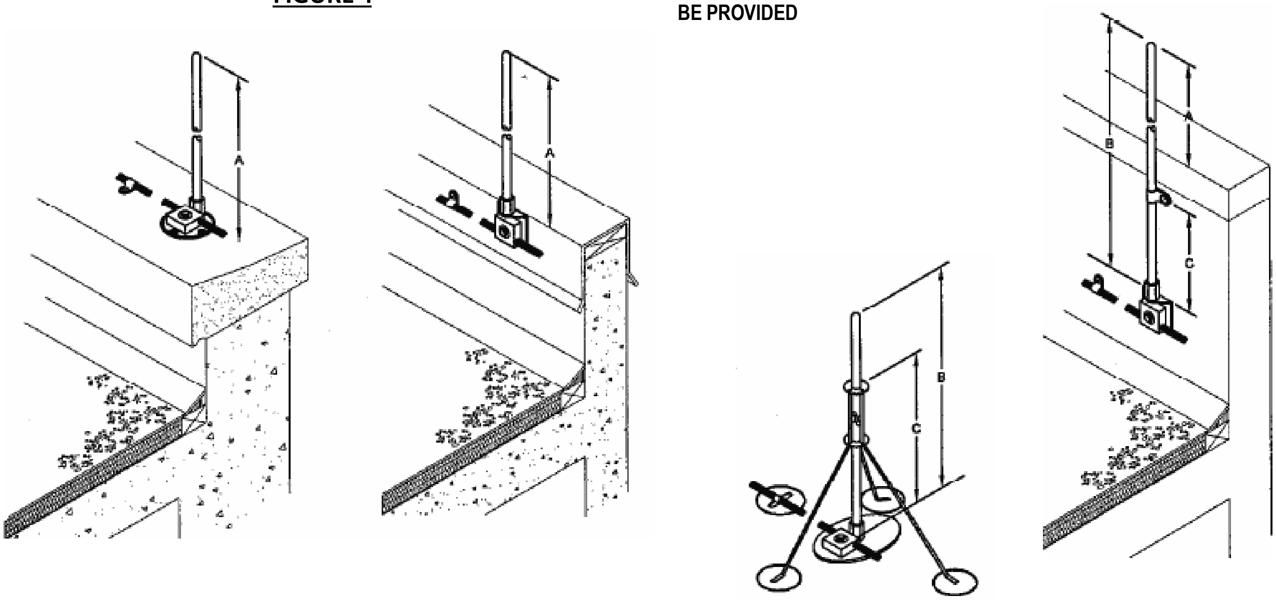
55) Air terminals shall be secured against overturning or displacement by attachment to the object to be protected or using braces permanently and rigidly attached to the structure. Air terminals exceeding 24 inches (600 mm) in height above the object they are to protect shall be supported at a point not less than one-half their height **(See Figure 4).**

A – AIR TERMINALS MINIMUM 10" ABOVE OBJECT PROTECTED

B – AIR TERMINALS OVER 24" TALL MUST BE BRACED

C – SUITABLE AIR TERMINAL BRACES SHALL BE PROVIDED

FIGURE 4



56) An ornament or decoration on a freestanding, unbraced air terminal shall not present in any plane, a wind resistance area in excess of 20 sq. in. (0.01 m²). This requirement permits the use of an ornamental ball 5 in. (127 mm) or less in diameter **(See Figure 5)**.

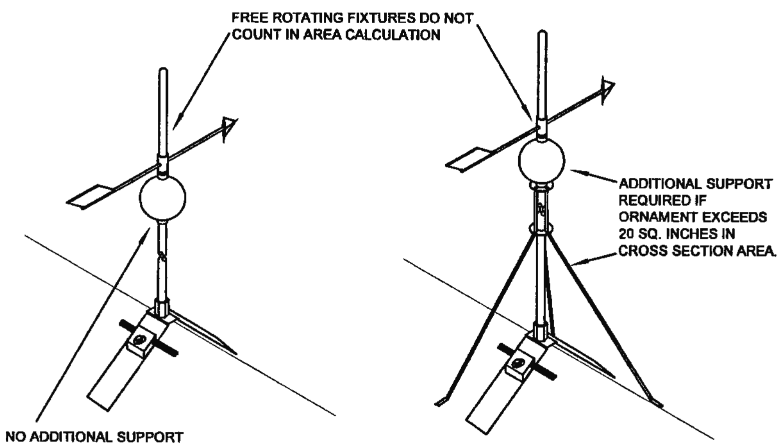
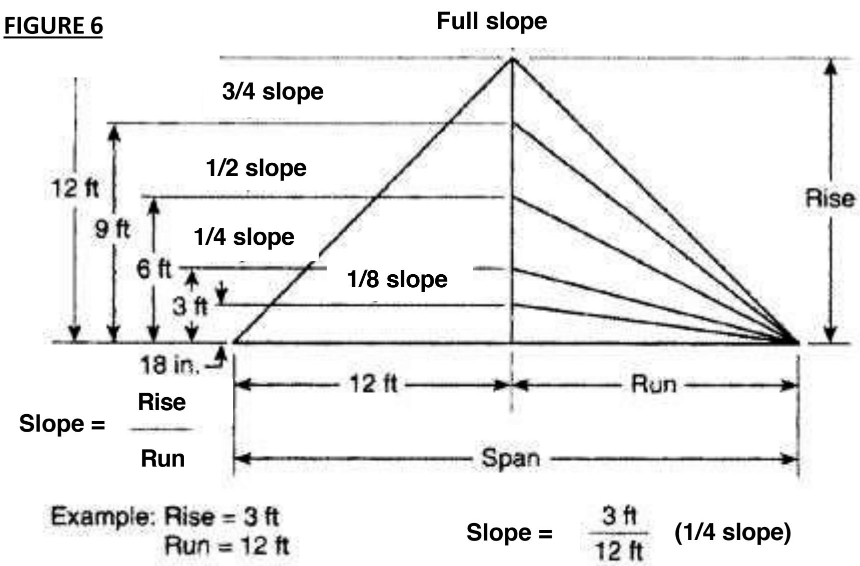


FIGURE 5

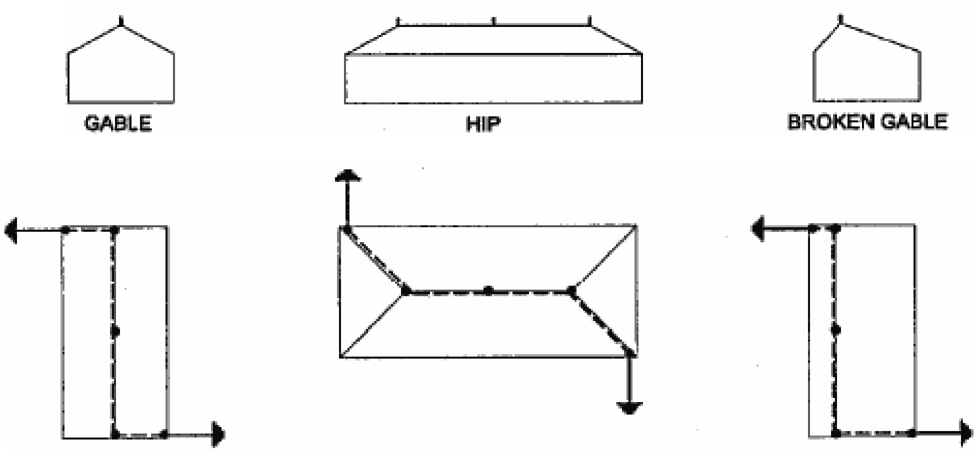
Strike Termination Devices for Standard Roof Types

57) Pitched roofs shall be defined as roofs having a span of 40 ft. (12 m) or less and a slope 1/8 or greater and roofs having a span of more than 40 ft. (12 m) and a slope ¼ or greater. All other roofs are gently sloping and are to be treated as flat **(See Figure 6).**

FIGURE 6



58) Strike termination devices shall be placed at or within 2 feet (0.6 m) of the ridge ends on pitched roofs or within 2 ft. (0.6m) of the outside edges and corners of flat and gently sloping roofs **(See Figures 7 & 9).**



Where one side of the roof is defined as "gently sloping", the ridge and the gently sloping side shall be fully protected.

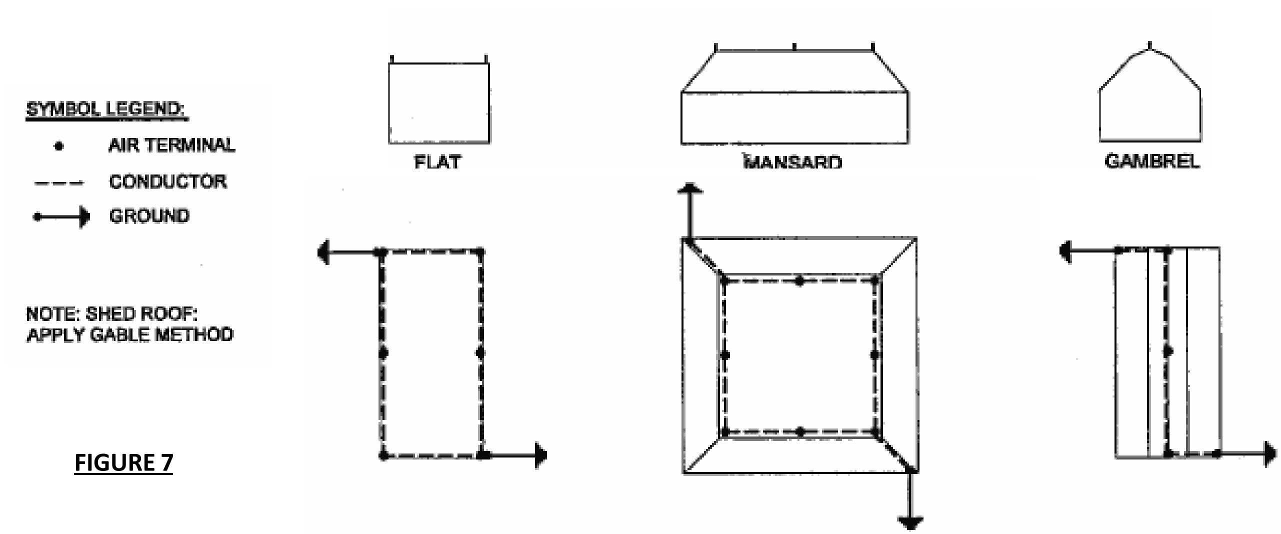


FIGURE 7

59) Strike termination devices shall be placed on ridges of pitched (gable, gambrel, shed, or hip) roofs and around the perimeter of a flat or gently sloping roof. Roof hips shall not be considered as ridges and do not require air terminals. Strike termination devices shall be placed at intervals not exceeding 20 feet (6 m) for air terminals less than 24 inches (600 mm) high. Strike termination devices 24 in. (600 mm) or more above the object or area to be protected shall be permitted to be located at intervals not exceeding 25 ft. (7.6 m).

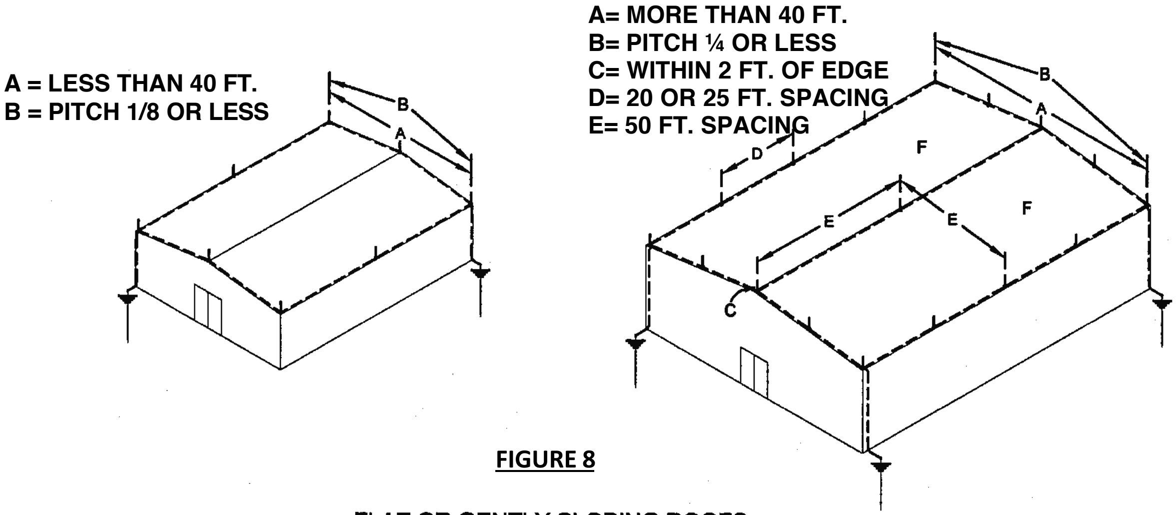


FIGURE 8

FLAT OR GENTLY SLOPING ROOFS

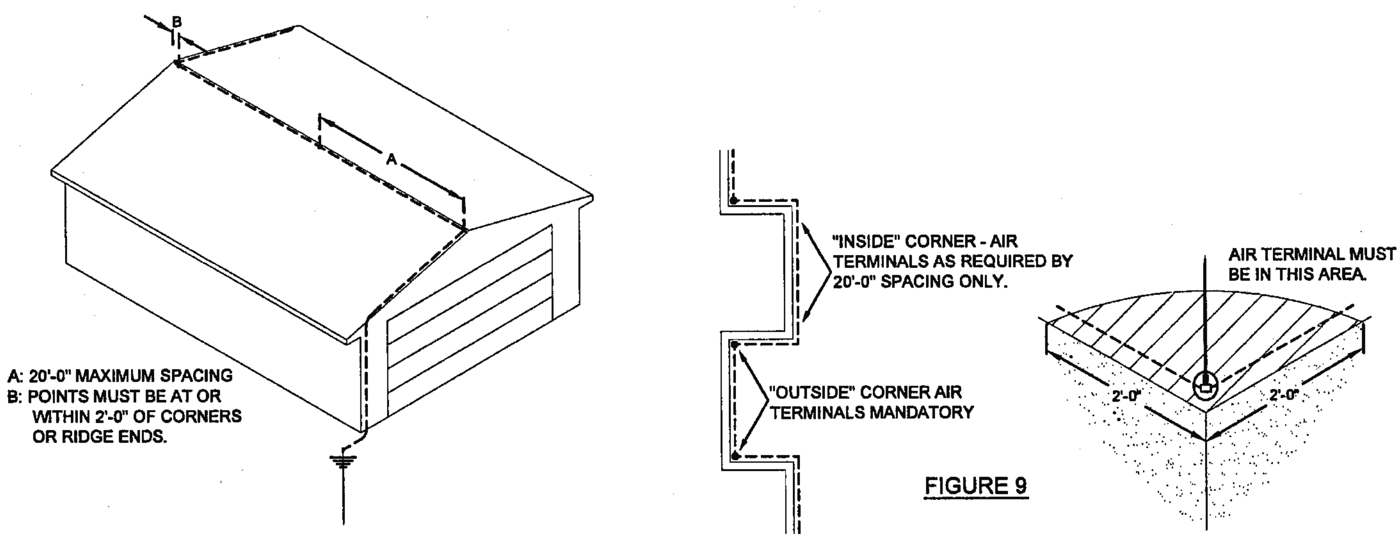


FIGURE 9

60) A pitched roof shall have the ridge or peak fully protected with strike termination devices and may need additional protection for the eave and intermediate roof areas based on the following:

A) When the eave height is 50 ft. (15 m) or less above grade, protection shall be required for the ridge only, where there is no horizontal portion of the building that extends beyond the eaves, other than a gutter with a maximum horizontal projection of 2 ft. (0.6 m).

B) Pitched roofs with eaves height over 150 ft. (45 m) shall have strike termination devices located according to the 150 ft. (45 m) radius sphere geometric method **(See Figure 17)**.

C) For pitched roofs with a span of 100 ft. (30m) or less and eave heights between 50 ft. (15 m) and 150 ft. (45 m) above grade, strike termination devices may be omitted at the eaves and mid-roof if the slope is equal to or steeper than the tangent of the 150 ft. (45 m) radius arc at eave elevation **(See Figure 10).**

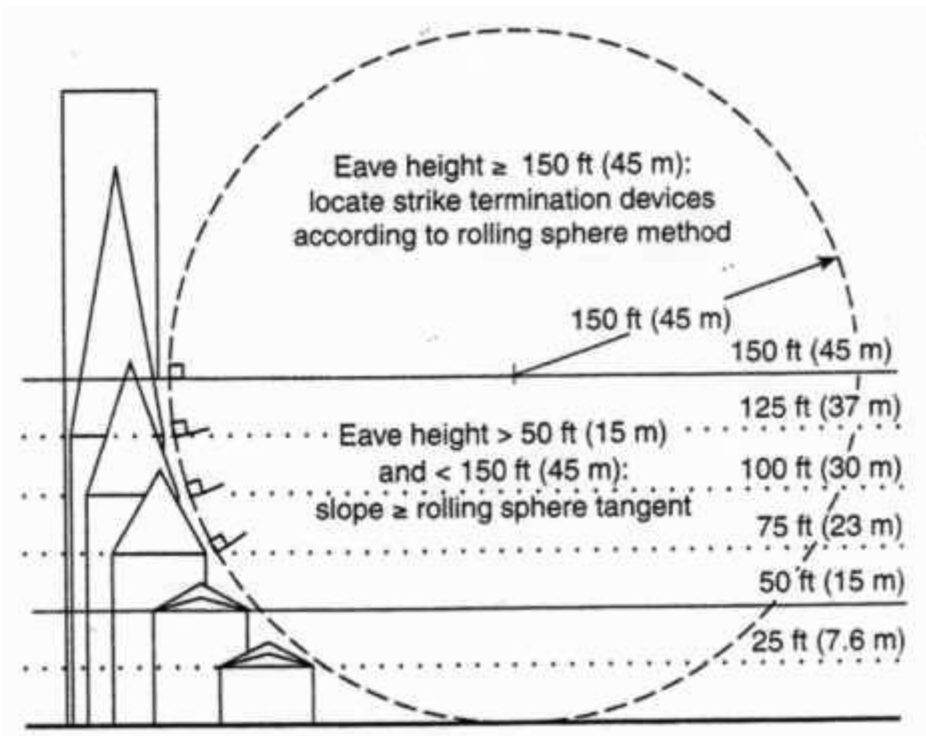


FIGURE 10

61) Flat or gently sloping roofs that exceed 50 ft. (15 m) in width and length shall have additional strike termination devices located at intervals not to exceed 50 ft. (15 m) minimum on the flat or gently sloping areas.

62) These mid-roof areas can also be protected using taller strike termination devices that create zones of protection using the rolling sphere method so the sphere does not contact the flat roof area or roof projections. The 150 ft. (45m) radius zone of protection arc may be applied to mid-roof air terminal placement with consideration of the radius sag between air terminals. **Figure 11** will assist in determining spacing for air terminals according to their respective heights above flat roof areas. (Allowance has been made for a 2-inch protective clearance.)

HEIGHT OF AIR TERMINAL	RADIUS OF PROTECTED ZONE
10"	15'-9½"
12"	17'-3 1/2"
15"	19'-3 7/8"
18"	21'-1 15/16"
24"	24'-4 15/16"
36"	29'-10 3/16"
48"	34'-4 15/16"
60"	38'-4 7/8"
66"	40'-2 15/16"
72"	42'-0"
84"	45'-3 7/8"
96"	48'-4"

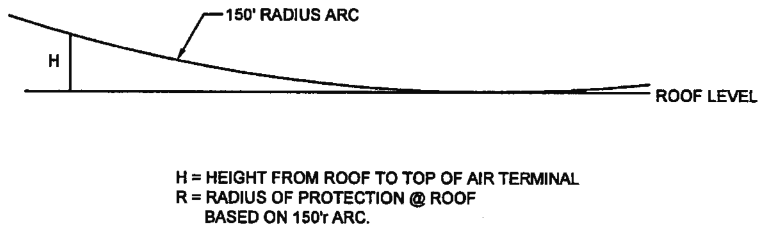


FIGURE 11

63) Roof top equipment, such as air handling units and vents, may be utilized to elevate the strike termination devices to achieve desired heights for mid-roof zones of protection afforded by the 150 ft. (45 m) radius arc. Masts and overhead ground wire systems used for the protection of roof areas of ordinary structures shall use the 150 ft. (45 m) radius rolling sphere method, and are subject to the additional requirements of paragraphs **80 – 88**.

(THIS ILLUSTRATION SHOWS TALL MIDROOF AIR TERMINALS WITH EXTENDED ZONES OF PROTECTION; PERIMETER AIR TERMINALS ARE SHOWN AS REQUIRED PER PARAGRAPHS 59 & 60.)

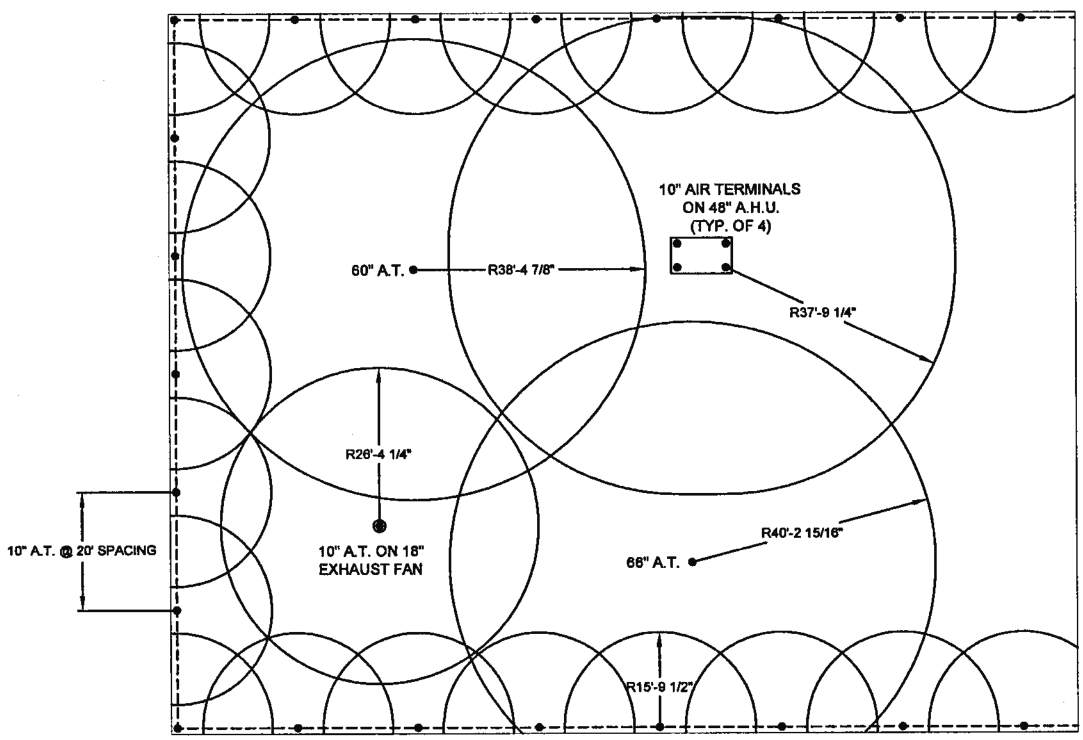


FIGURE 12

(PARTIAL ROOF PLAN)

Protecting Projections on Structures

64) Roof top or outside wall projections include, but are not limited to the following: masonry chimneys, metal chimney vents, cupolas, dormers, exhaust fans, gravity vents, equipment penthouses, air handling units, cooling towers, ladders, handrails.

65) 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 serve as strike termination devices and shall be connected per paragraph **26**.

66) Small objects on roofs that are less than 10 in. (254mm) above the roof shall not require strike termination devices unless they are located within 3 ft. (0.9m) of the ridge or roof edge. Strike termination devices shall be required on all additional projections that are not located within a zone of protection, including metal parts of a structure having a metal thickness of less than 3/16 in. (4.8 mm).

67) Strike termination devices shall be attached to a projection so that no outside corner or edge is more than 2 feet (0.6 m) from a strike termination device. Strike termination devices may be anchored directly to the projection or may be secured by an acceptable metal band around the chimney or other projection.

68) Where only one strike termination device is required on an object, at least one main-size conductor shall connect the strike termination device to a main conductor providing two or more paths to ground from that location in accordance with paragraphs **102 – 104**.

Note: There is no length restriction on a vertical conductor that connects the strike termination device to the main roof conductor. The horizontal lead length for a single conductor run may comply with the "dead end" criteria in paragraph **104 (See Figure 13).**

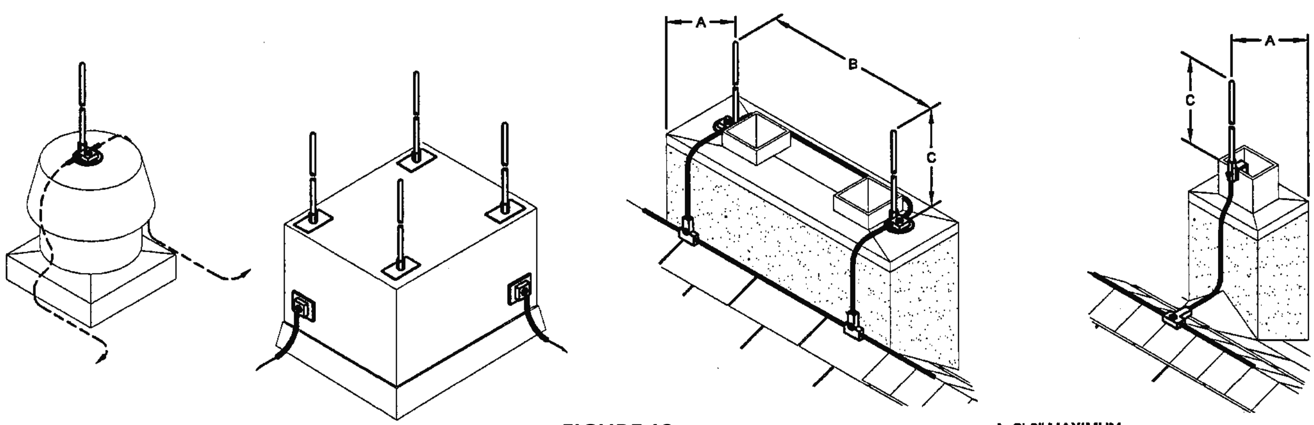


FIGURE 13

A: 2'-0" MAXIMUM
B: 20'-0" MAXIMUM
C: 10" MINIMUM - 36" MAXIMUM

69) Roof top mechanical units with continuous metal housings less than 3/16" (4.8 mm) thick shall be protected by air terminals per paragraph **67** on base fittings secured to the unit by one of the following methods.

a. Bases secured to the bare metal of the housing with a minimum contact area of 3 in.² (1940 mm²), or mounted by drilling and tapping to the unit's frame shall be permitted to use the unit's metal housing in lieu of main cable conductors where the minimum thickness of the housing is 0.064 in. (1.63mm) or greater and is electrically continuous. At least two main-size conductors shall be installed with connections made to bare metal at the base or lower edge of the unit with bonding devices having a surface contact area of 3 in.² (1940 mm²) providing two or more paths

to the system. The unit's bonding plates shall be located as far apart as practicable on the electrically continuous metal housing.
b. Bases secured to metallic housings using adhesives or thin metallic units not meeting the minimum thickness requirement (0.064") shall use main cable conductor connected to the roof system similar to non-metallic surface protection.

70) Movable or Rotating objects on roofs shall be placed in a zone of protection where practical. Examples may include windsocks, cranes, or window washing davits. Movable or rotating metal objects outside the zone of protection shall be interconnected with the building's system according to the following:
a. The fixed portion of the movable or rotating metal object shall be connected to the lightning protection system according to Paragraph **52**.
b. If possible, a bonding jumper connecting the metal movable or rotating portion to the fixed portion should be included.

71) On chimneys or vents where fuels are used whose fumes are corrosive, copper lightning protection system components shall be hot-dip lead coated or tinned to prevent corrosion within the top 24 inches (0.6 m) of the chimney exhaust.

72) Guy wires used to support a tall projection shall be securely bonded to the system at the top and bottom. Connections of metal guys to a metal stack may constitute the top or upper bonding connections, or guy anchors extending into the building's bonded structural metal frame may constitute the bottom bonding connection. Turnbuckles, eyebolts, etc. are not considered to provide continuity and shall be jumped using bonding conductor.

73) Prominent dormers, which are as high as or higher than the main ridge, shall be protected with strike termination devices and conductors as any other standard ridged or gently sloping roofed area. Dormers and roof projections below the main ridge shall require protection only on those areas extending outside the zone of protection provided by the strike termination devices according to the 150 ft. (45 m) radius protected zone **(See Figure 14).**

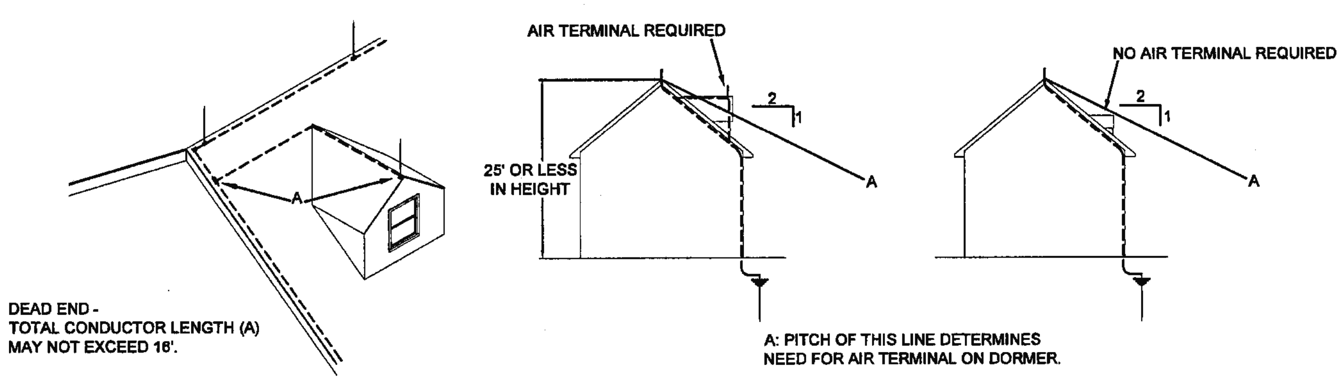


FIGURE 14

74) Each television or radio antenna mast serving a protected building shall be effectively bonded to the building lightning protection system to serve as a strike termination device when structural thickness allows, or placed under a zone of protection using strike termination devices mounted to the antenna mast, framework or remotely. Consideration must be given to the fact thin metallic supports could be damaged and damage to the antenna lead-in conductors will most likely occur if antennas are used as strike termination devices. Antennas should be placed in a zone of protection and isolated from the lightning protection system. Communications conductors should not be located near lightning conductors. Refer to paragraphs **208 - 214** for surge protective device requirements on antenna systems.

Strike Termination Devices for Specialty Roof Types

75) Roofs with multiple or intermediate ridges – Strike termination devices shall be located along the outermost ridges of buildings that have a series of parallel, similar height intermediate ridges at the same intervals as required by paragraph **59**. 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 (i.e. the intermediate ridge(s) constitute a "common plane", which is treated as a flat roofed area). If any intermediate ridge is higher than the outermost ridges, it shall be treated as a main ridge and protected accordingly **(See Figure 15).**

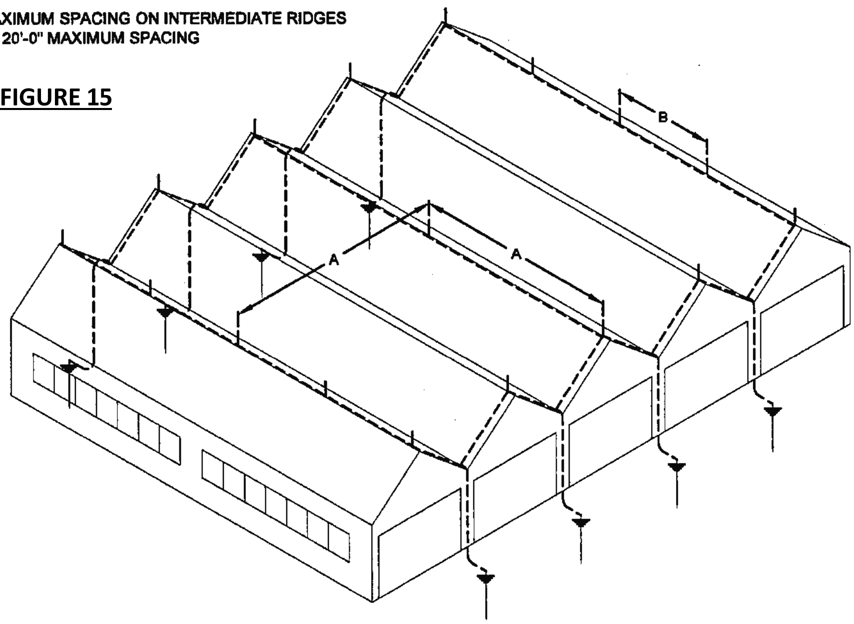


FIGURE 15

76) Irregular perimeters on flat or gently sloping roofs – Structures that have exterior wall designs resulting in irregular roof perimeters shall be treated on an individual basis. The outermost projections may be considered to form an imaginary roof edge, and strike termination devices may be located in accordance with paragraph **59** above rather than placing a device at each intermediate corner. 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 an approved splice fitting **(See Figure 16)**.

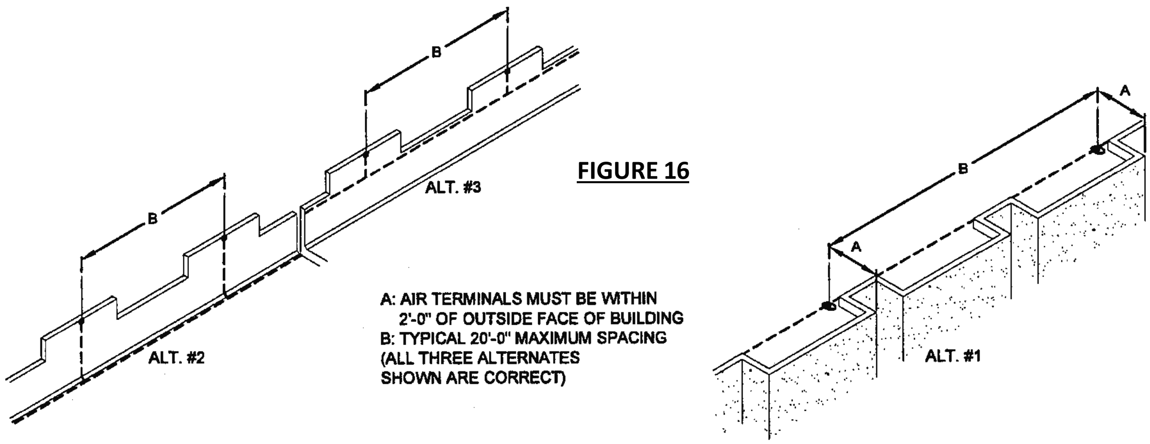


FIGURE 16

77) Open areas in flat roofs – The perimeter of open areas (mechanical wells or interior courtyards) shall be protected in accordance with paragraphs **58 - 59** if the open area perimeter exceeds 300 ft. (90 m), and provided both rectangular dimensions exceed 50 ft. (15 m).

78) Domed or rounded roofs –

A) Strike termination devices shall be located so that no portion of the structure is located outside a zone of protection, based on the 150 ft. (45 m) sphere method striking distance **(See Figure 17A).**

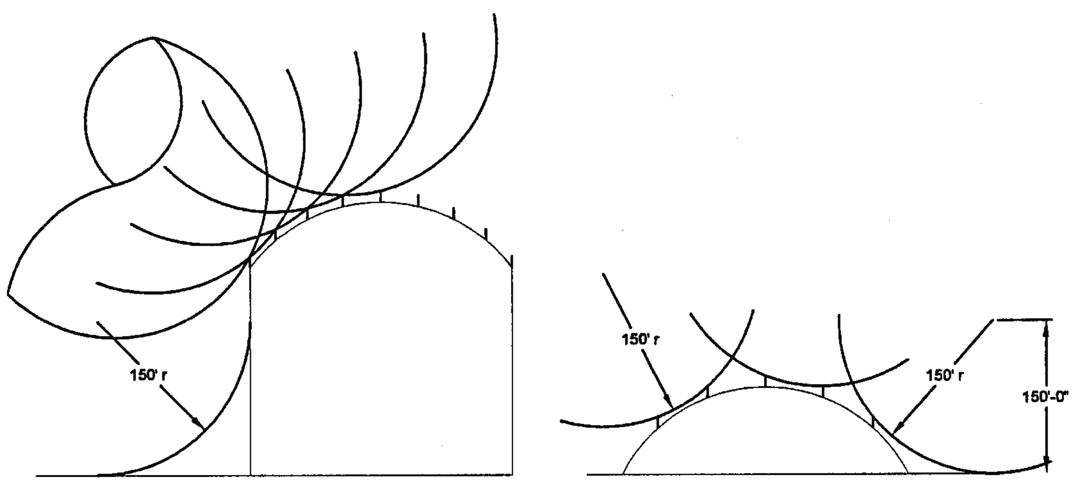


FIGURE 17A

B) A curved perimeter of a structure shall be protected so that the outer edge of the structure is less than 24 in. (600 mm) from a straight line or chord between two adjacent air terminals (See Figure 17B).

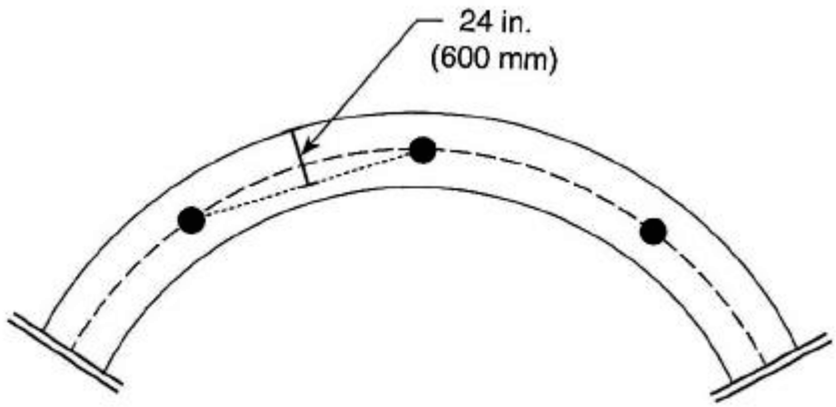


Figure 17B

79) Parking Ramps - Parking ramps shall be protected in accordance with all conditions set forth previously. If difficulty is encountered in complying with the requirement for placing air terminals in open center areas due to traffic flow, one acceptable alternative is to either bond to or mount air terminals on metal light standards which project above the roof (top level) in as close an approximation of the required spacing as possible. Where no such projections exist, a second alternative is to imbed a grounded ¼ inch x 1 inch copper bar in the concrete at the locations where center roof cable runs would normally be placed with the top face of the bar exposed flush with the top of the concrete. Alternately, copper cable conductor may be imbedded in the concrete at the required location of center roof cable runs and flush mounted ground plates placed at normal air terminal locations.

MASTS AND OVERHEAD GROUND WIRES

80) Masts or overhead ground wires may be used as part of any lightning protection system. In certain conditions an open area or unusual structure may need to be placed within a zone of protection. When that is the case, grounded masts or overhead cables supported by two or more masts should be considered.

81) A representation of the zone of protection of a single grounded or continuous metal mast is shown in **Figure 18**. The zone of protection is based on the 150-ft. (45 m) radius arc method. The arc passes through the tip of the metal mast or it may rest on the vertical surface of a mast taller than 150 ft. (45 m). The base of the arc is tangent to ground, either grade level or strike termination devices.

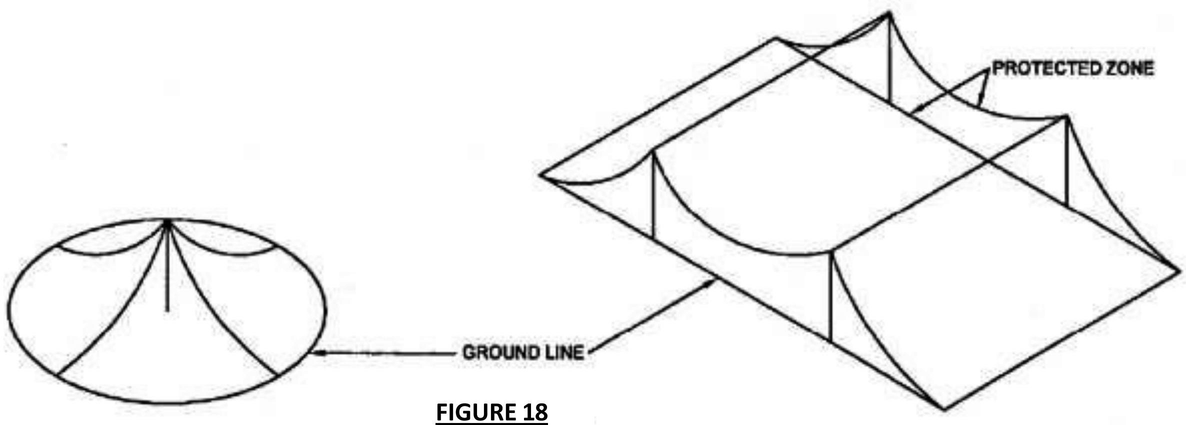


FIGURE 18

82) A representation of the zone of protection of a grounded cable or catenary supported by masts is based on the 150 ft. (45 m) radius arc method, where the arc is tangent to the cable and to ground at grade level. Where more than one grounded cable is used in parallel, the protected area is the 150 ft. (45 m) radius arc method tangent to both cables **(See Figure 18).**

83) Where single masts or overhead ground wires are used to protect structures housing explosive or flammable materials, the zone of protection shall be determined in the manner described above, except by use of a 100 ft. (30 m) radius arc method, in lieu of the 150 ft. radius arc for conventional areas. This creates a higher level of protection against lightning intrusion.

84) Where masts of wood or other non-conductive material are used, a strike termination device shall be securely fastened projecting a minimum of 10 in. (254 mm) above the top of each mast and connected to the grounding system. A non-conductive mast shall have a down conductor run to a grounding electrode or system as described in paragraphs **132 - 144 (See Figure 19).**

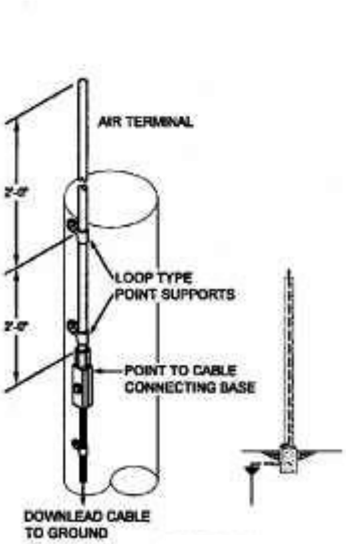


FIGURE 19

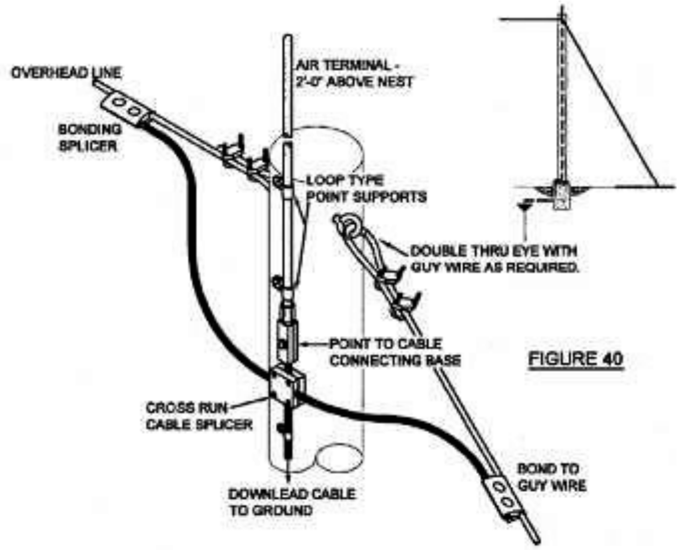


FIGURE 40

85) Overhead ground wire material shall be constructed of aluminum, copper, stainless steel, or protected steel such as copper-clad, aluminum clad, or aluminum conductor steel reinforced (ACSR) The overhead ground wire material shall be chosen to minimize corrosion from conditions at the site. The overhead ground wire shall be a minimum diameter of ½ in. (13mm) and shall be self-supporting with minimum sag under all conditions. Connections between galvanized steel overhead ground wires and copper conductors shall be made through a suitable component that does not permit direct contact between the two materials. Overhead ground wires shall have a minimum cross-sectional area equal to that of a main conductor. When steel or stainless-steel cable is used for the overhead ground wire, it shall have a minimum diameter of ½ in. (12.7 mm).

86) Guy cables may be used as down conductors if they meet the material and size requirements for a main size conductor. Guy cables not used as conductors shall be bonded top and bottom, if not inherently grounded by design.

87) Single masts or support masts with overhead cables shall be separated from a protected structure by a distance exceeding the bonding or sideflash distance (paragraphs **166 – 167)** to avoid arc over to the protected structure.

Sideflash distance from a mast shall be calculated using the following formula:

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

Where:
D = sideflash distance from a mast
h = height of structure (or object being calculated)

The sideflash distance from an overhead ground wire shall be calculated as follows:

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

Where:
D = sideflash distance from the overhead ground wire

l = length of lightning protection conductor between the nearest grounded point and the point being calculated ***(See note below)**
n = 1 where there is a single overhead ground wire that exceeds 100 ft. (60 m) in horizontal length
n = 1.5 where there are one or two down conductors connected to the overhead ground wire spaced greater than 25 ft. (7.6m) and less than 100 ft. apart along the length of the overhead ground wire
n = 2.25 where there are more than two down conductors connected to the overhead ground wires spaced more than 25 ft. apart and less than 100 ft. apart along the length of the overhead ground wire.

***Note**: In the calculation of spacing from an overhead wire supported by a metal mast, it shall be permitted to consider the grounded point to be the attachment point on the metal mast where the overhead wire is electrically connected. For calculation of sideflash from a mast and the calculations for overhead wires supported by nonmetallic masts, the grounded point shall be considered the grounding system connection.

88) A mast and overhead wire system shall have a common ground interconnection with the structure to be protected in accordance with the requirements of paragraphs **145 - 152**.

ZONE OF PROTECTION

89) Providing the required protection along building ridges, around the perimeter of flat or gently sloping roofs, protecting prominent vents and chimneys and/or large open mid-roof areas will place these main roof areas under a protective zone of the strike termination devices. The protected zone extends from these main protected roof levels and can cover horizontal projections from lower walls and lower roof areas. The geometry of a structure or the prominent strike termination devices determines the zone of protection for lower roof areas or projections. This standard uses the 150 ft. (45 m) radius sphere method to calculate areas that are considered within a zone of protection (requiring no additional strike termination devices), and those which need additional protection.

90) The 150 ft. (45 m) radius sphere method “rolls a ball” of this size up and over the structure in every possible direction from grade level to the opposite grade level. The 150 ft. (45 m) radius “ball” must be supported off insulated building materials by grounded bodies. Grounded bodies are considered to be the earth or soil, all strike termination devices and components connected to the lightning protection system, or a vertical building wall with strike termination devices mounted above. When the sphere model is rolled up and over the structure, supported by these grounded bodies or surfaces, the areas not touched by the “ball” are considered to be under the zone of protection of the lightning protection system **(See Figure 20).**

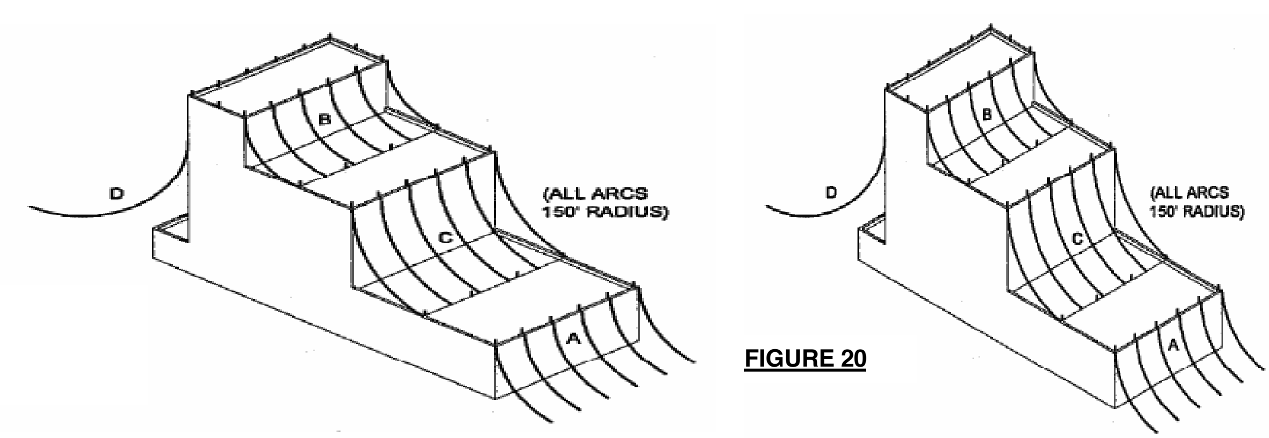


FIGURE 20

Protection Calculations for Structures

91) Figure 21 depicts the 150 ft. (45 m) geometric method for structures of selected heights up to 150 ft. (45 m). Based on the height of a strike termination device on a fully protected roof level of 25ft. (7.5 m), 50 ft. (15 m), 75 ft. (22.5 m), 100ft. (30 m), or 150 ft. (45 m) above the level under consideration, reference to the appropriate curve shows the anticipated zone of protection of a higher roof (horizontal distance) on the lower elevation.

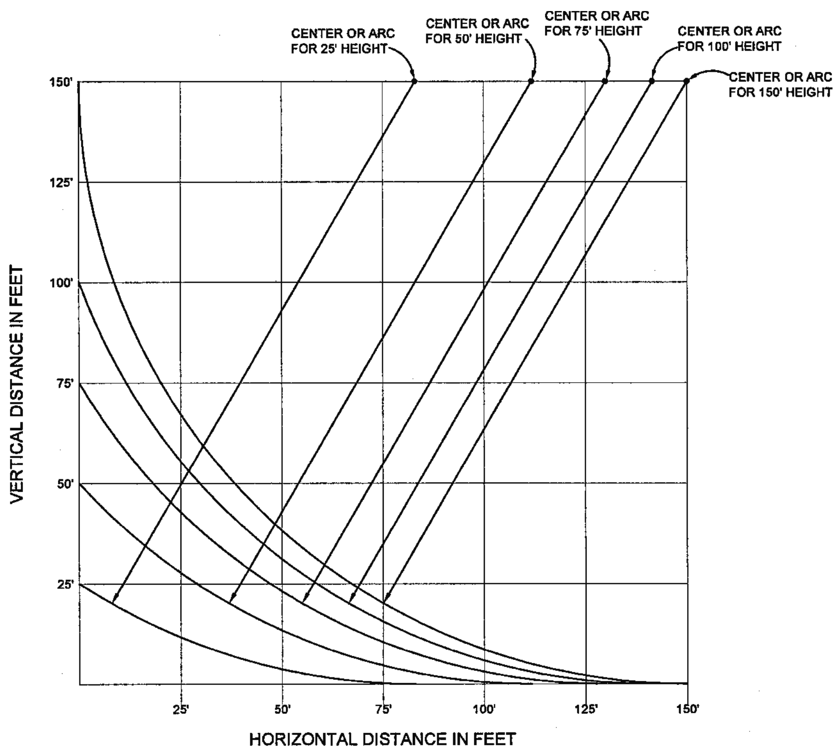


FIGURE 21

92) The protected distance for the 150 ft. (45 m) radius sphere method may also be calculated by the formula:

$$d = \sqrt{h_1(2R - h_1)} - \sqrt{h_2(2R - h_2)}$$

Where: d = horizontal protected distance
h_1 = height of the higher strike termination device on protected roof level
h_2 = height of the lower roof or object under consideration for protection
R = rolling sphere radius – 150 feet or 45 m

93) The distance (d) represents the horizontal distance on the lower level (h_2) protected by the system on the higher level (h_1). Above grade areas beyond this distance (d) shall be treated as unprotected roof areas or objects, and require a determination for placement of additional strike termination devices to complete the lightning protection system.

94) When calculating zone of protection between roof levels, you will first strike an arc equal to the 150 ft. (45 m) radius sphere model tangent to the higher protected roof or vertical wall and grade (or calculate d) to see if the lower roof extends beyond the zone from the high roof. If the lower roof requires protection, reset the radius as tangent to the higher roof (or vertical wall) and the lower roof height to determine the proper distance for the first strike terminal(s) on the lower roof. This can be done mathematically using the formula in paragraph 55 above substituting the height differential for h_1 and using 0 (zero) for h_2 to calculate d.

95) When the protection (strike termination device or protected roof level) is higher than 50 feet (15 m) but no higher than 150 feet (45 m) above grade or a lower roof level, the zone of protection is the space located beneath a 150-foot radius arc, which is:

A. Tangent to earth and a strike termination device at roof level, or
B. Resting on two or more strike termination devices on different height roof levels
C. Resting on 3 strike termination devices on top of a roof area

96) When the protection (strike termination device or protected roof level) is more than 150 feet (45 m) above grade or the lower roof area under consideration, the zone of protection is the space located beneath the arc when it is resting against the vertical wall of the higher roof area of the structure and is:

A. Resting on a lower strike termination device, or
B. Tangent to (resting on) the earth.

Optional Zone of Protection Calculation for Site Surveys

97) When the protection (strike termination device or protected roof level) is no higher than 25 feet (7.5 m) above grade or a building level under consideration, the zone of protection replicates a line at a 1 to 2 (27°) angle **(See Figure 22).**

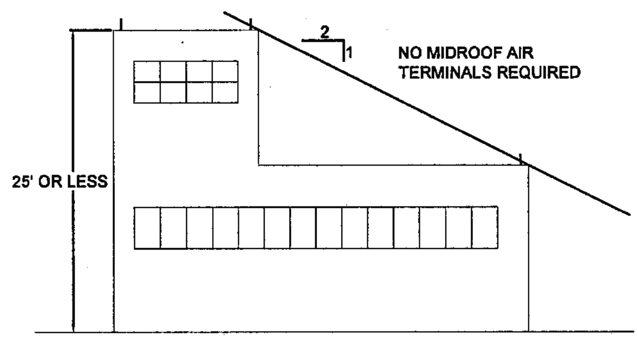


FIGURE 22

98) A 150 ft. (45 m) radius protected distance calculated from the graph or formula may yield a larger protected zone. As an example, a 3 ft. (1m) tall strike termination device would yield a protected radius of 29 ft. (9 m) using the graph or formula, but only a 6 ft. (2 m) radius at a 1 to 2 angle. The 27° angle for protected areas 25 (7.5 m) feet or lower can be used for convenience in fieldwork and inspection, because it fits within the model and is easier to calculate on site.

99) When the protection (strike termination device or protected roof level) is higher than 25 feet (7.5 m) but no higher than 50 feet (15 m), the zone of protection can be conveniently determined by striking a line at a 1 to 1 (45 °) angle. A larger inclusive area may be calculated, see paragraph 57 above, but 1 to 1 is considered appropriate for field calculation and review **(See Figure 23).**

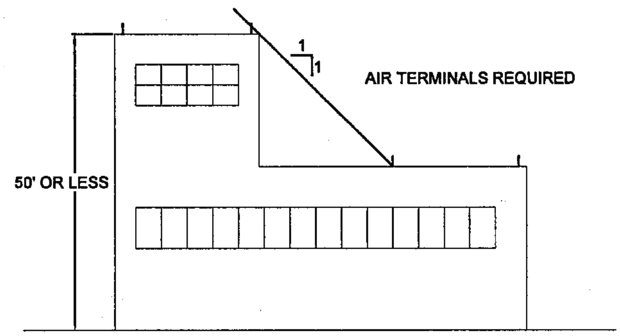


FIGURE 23

MAIN CONDUCTORS

100) All conductors used for LPI Certified System installations shall be approved for the purpose by an independent testing agency. Main (current carrying) conductors shall be sized according to the height of the structure, either Class I or Class II **(See TABLE 2 below).**

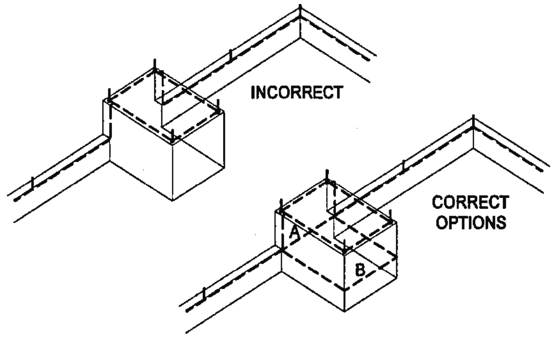
TABLE 2

MAIN SIZE CONDUCTORS - MINIMUM MATERIAL REQUIREMENTS

Classification	Product	Description	Copper		Aluminum	
Class I	Cable	Size each strand	17 AWG	(1.04 mm²)	14 AWG	(2.08 mm²)
		Weight per length	187 lbs./1000 ft.	(278 g/m)	95 lbs./1000 ft.	(141 g/m)
		Cross section area	57,400 cir. mils.	(29 mm²)	98,600 cir. mils.	(50 mm²)
	Solid Strip	Thickness	0.051 in.	(1.3 mm)	0.064 in.	(1.63 mm)
		Cross section area	57,400 cir. mils.	(29 mm²)	98,600 cir. mils.	(50 mm²)
Class II	Cable	Size each strand	15 AWG	(1.65 mm²)	13 AWG	(2.62 mm²)
		Weight per length	375 lbs./1000 ft.	(558 g/m)	190 lbs./1000 ft.	(283 g/m)
		Cross section area	115,000 cir. mils.	(58 mm²)	192,000 cir. mils.	(97 mm²)
	Solid Strip	Thickness	0.064 in.	(1.63 mm)	0.102 in.	(2.61 mm)
		Cross section area	115,000 cir. mils.	(58 mm²)	192,000 cir. mils.	(97 mm²)

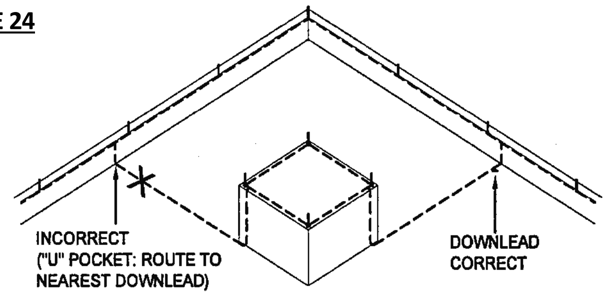
101) Main roof conductors shall be coursed along ridges of gable, gambrel, and hip roofs, around the perimeter of flat roofs, behind or on top of parapets and across large roof areas as required to interconnect all strike termination devices. Main circuit conductors shall be coursed through or around obstructions (e.g., cupolas, ventilators, penthouses) in a horizontal plane.

102) Main roof conductors shall be used to interconnect the strike termination devices. Main roof conductors shall afford two or more paths from each strike termination device downward, horizontally, or rising at no more than ¼ pitch to connections with the grounding electrode system **(See Figure 24)** subject to dead end rules allowed in paragraphs **103-104.** It is permitted to use one rising path not to exceed 50 ft (15 m) in length on pitched roofs, or a single rising path not exceeding ¼ slope on flat or gently sloping roofs.



"A" & "B" CABLE PATH COURSING METHODS ARE ALTERNATE WAYS OF MAINTAINING TWO PATHS TO GROUND FOR EACH AIR TERMINAL.

FIGURE 24



103) ***Exception*** - A main conductor drop from a higher to a lower roof level interconnecting strike termination devices on the lower roof is permitted without an extra downlead provided the horizontal run of conductor on the lower roof does not exceed 40 feet (12m). **(See Figure 25)**

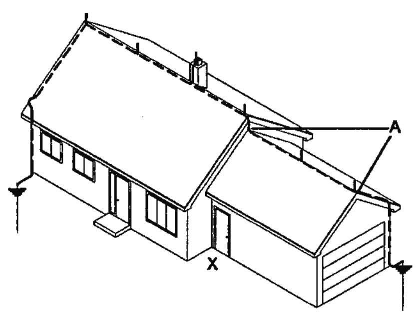
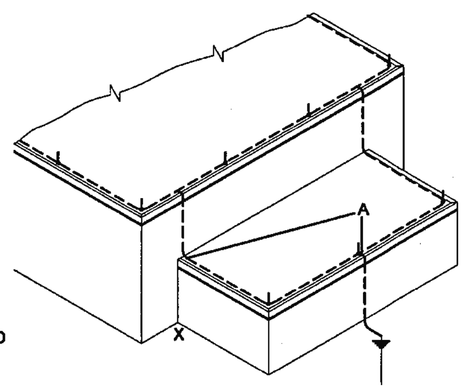


FIGURE 25

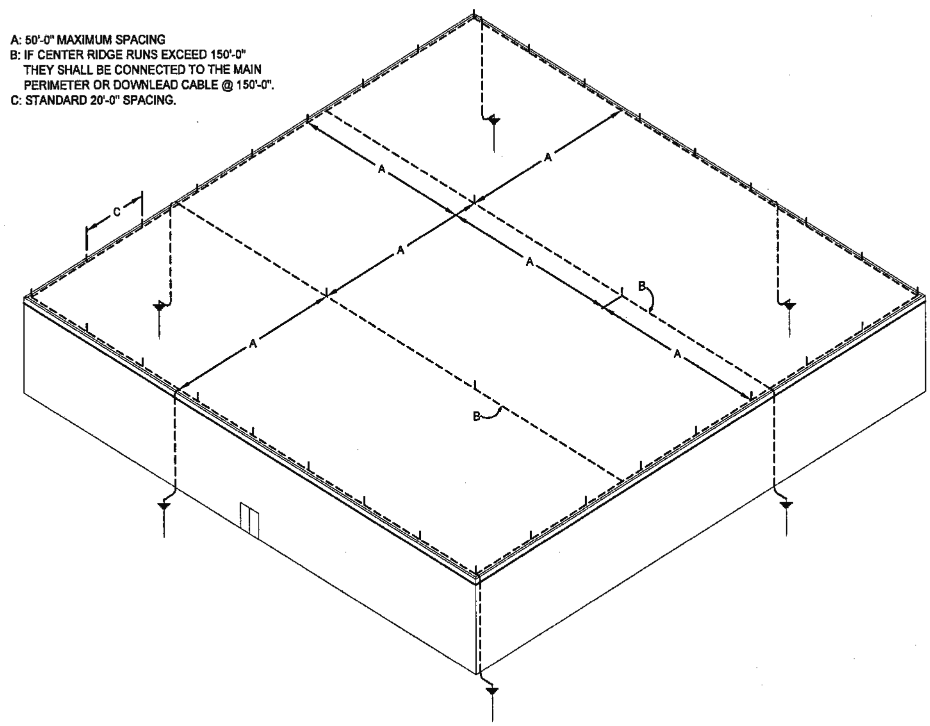
IF LOWER ROOF DISTANCE (A) IS MORE THAN 40'-0", ADDITIONAL DOWNLEAD & GROUND REQUIRED AT LOCATION "X".



104) ***Exception*** - A “dead ended” main conductor shall be permitted between a single strike termination device or full sized bonding fitting and a main sized conductor run under all of the following conditions:

1) The main sized conductor run to which the “dead-end” lead is connected must have a two-way path to ground. It may be a mid-roof run, a perimeter circuit, or a downlead.
2) At the main protected roof level when the horizontal portion of the dead-end conductor is not more than 8 feet (2.4m) in total length.
3) On a roof below the main protected level when the dead-end conductor is not more than 16 feet (4.9m) in total length.
4) All dead end runs shall maintain a horizontal or downward course from the strike termination device to the connection point with the conductor run.

FIGURE 26



105) Cross run conductors are coursed over flat or gently sloping roofs that exceed 50 feet in width to interconnect strike termination devices required in these areas. For example, a roof from 50 to 100 feet in width requires one additional run; roofs 100 to 150 feet in width require two runs, etc. These cross run conductors shall be connected to the main perimeter cable at intervals not exceeding 150 feet (45 m). **(See Figure 26)**

106) Conductors shall maintain coursing free from "U" or "V" (down and up) pockets. Such pockets, often formed at low-positioned chimneys, dormers, or other elevations on the slope of a roof and at coping walls, shall be provided with a down conductor from the base of the pocket to ground, or to an adjacent downlead **(See Figures 24 & 27)**.

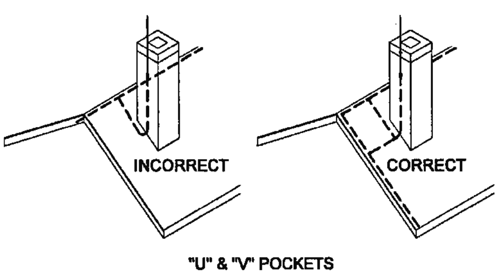


FIGURE 27

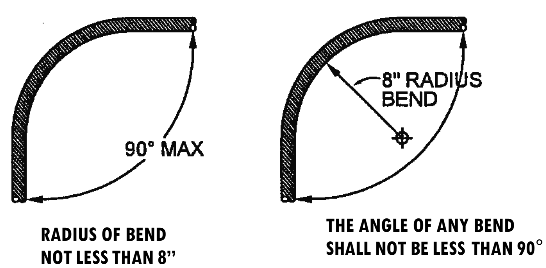


FIGURE 28

107) Conductors shall be permitted to be routed in an upward coursing for a vertical distance of no greater than 8 in. (200 mm) at through-roof or through-wall connections only, in order to mitigate tripping hazards, provided that the coursing complies with paragraph 108.

108) 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 inches (203 mm). This radius requirement is not applicable where listed clamps or fittings ("Tee" fittings) are used to accomplish cable connections **(See Figure 28).**

109) Exposed conductors shall be fastened to the structure at intervals no greater than 3'-0" (1 m). Concealed main conductors should be anchored as required to maintain the proper coursing of the conductor. Conductors may be coursed through the air without support for a distance of 3 feet or less. When conductor coursing through air would be for a greater distance, the conductor shall be provided with a positive means of support to prevent damage or displacement.

110) Metal roofing and siding having a thickness less than 3/16 inches (4.8 mm) shall not be substituted for the main lightning conductor. A lightning conductor system shall be applied to a metal clad building in like manner as on a building without such metal coverings **(See Figure 29)**.

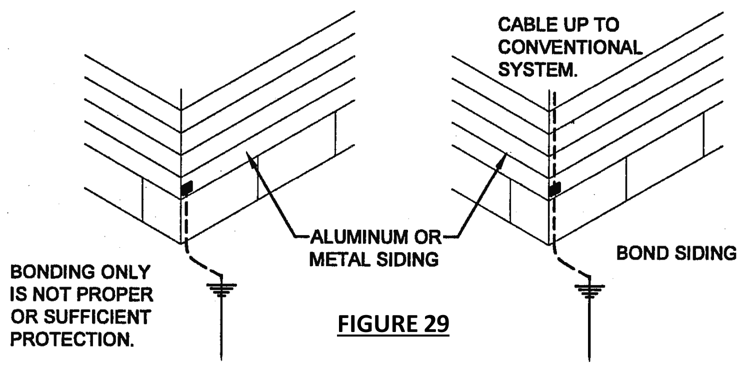


FIGURE 29

111) Ancillary metal, such as eave troughs, downspouts, chutes, door tracks or other metal parts considered to have a shorter replacement cycle than a main size conductor shall not be used as a substitute for main conductors**.** Metal roofing and siding shall not be substituted for main conductors, because mechanical fastenings of sections are not considered suitable for lightning conduction.

112) Permanent, electrically continuous exterior metal handrails and ladders shall be permitted to be substituted for a main conductor where the minimum thickness is 0.064 in. (1.63 mm). Metal rails outside a zone of protection having a wall thickness of 1⁄8 in. (3.2 mm) thick or greater shall only require connection to the lightning protection system in accordance with Paragraphs **102-104**. Where handrails are employed as part of the lightning protection system, it is important to caution that touch potential and sideflash issues could result. Signage or other methods should be provided to warn the public not to touch or stand near the handrails when lightning is probable, and that the handrail is an integral part of the lightning protection system.

DOWN CONDUCTORS

113) Down conductors (downleads) shall be sized as main conductors according to the height of the structure, either Class I or Class II **(See TABLE 2)**. Down conductors (continuation of roof conductors) shall be as widely separated as practical, preferably at diagonally opposite corners on square or rectangular structures and diametrically opposite on cylindrical structures or irregularly shaped structures **(Figures 30 – 33)**. Placement of down conductors is contingent upon the size of structure, most direct coursing, security against displacement, locations of strike termination devices, location of metallic bodies requiring bonding, and grounding conditions.

114) Not less than two down conductors shall be provided on any kind of structure, including freestanding steeples, chimneys, spires, bell towers, viewing platforms, etc. **(See Figure 30)**

115) Structures exceeding 250 feet (76 m) in perimeter shall have a down conductor for every 100 feet (30m) of perimeter or fraction thereof. The down conductors on larger structures shall be spaced not to exceed an average distance of 100 feet (30 m) between all down conductors along the protected perimeter of the structure **(See Figure 31).**

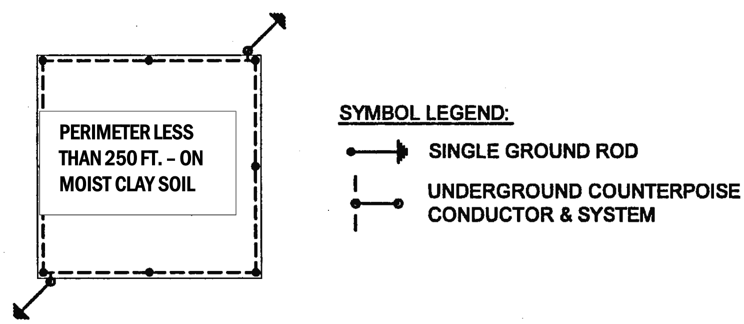


FIGURE 30

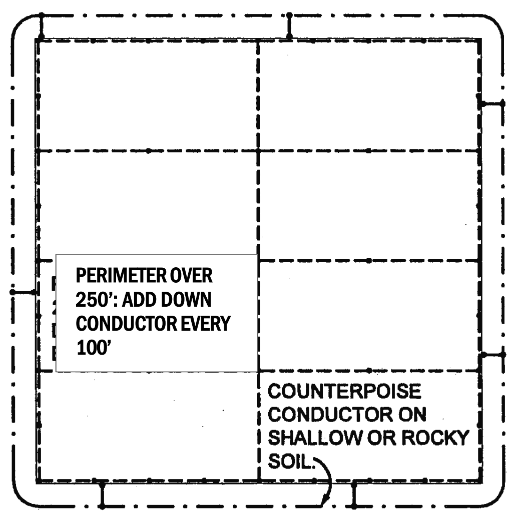


FIGURE 31

116) Irregular-shaped structures shall have additional down conductors to provide a two-way path from the strike termination system to the grounding electrode system. When an obstruction (a hangar door, loading docks, etc.) will not allow even placement of downleads on the structure perimeter, the proper total number shall be provided and spaced along the balance of the perimeter as far apart as practical **(Figure 32).**

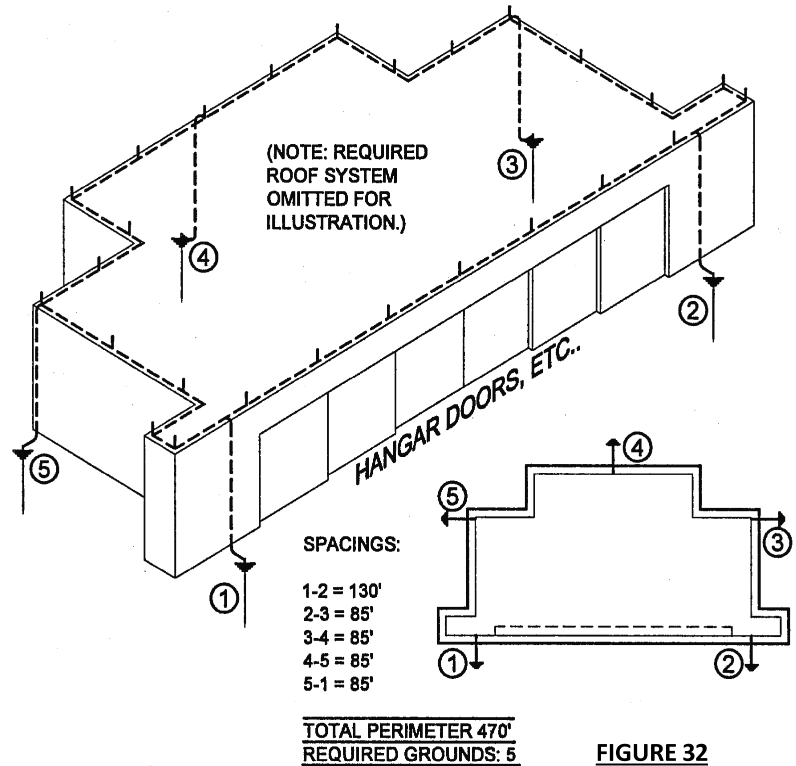


FIGURE 32

117) When figuring the perimeter to determine the required number of down conductors, measure only the "protected" perimeter; that is, those roof areas requiring protection, and exclude low roofs and projections fully under the zone of protection of a higher roof. On pitched roof structures the perimeter shall be taken as comparable to the eave line or horizontal footprint of the protected roof area(s) **(Figure 33).**

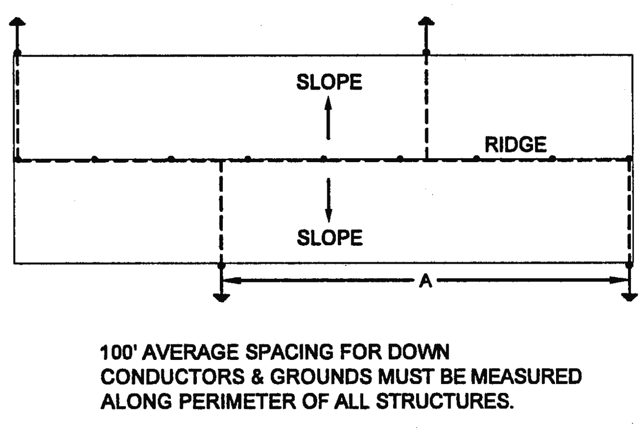


FIGURE 33

118) Down conductors located near driveways, school playgrounds, livestock areas, public walks, or other locations subject to physical damage shall be guarded to prevent damage or displacement. If the conductor is run through pipe or tubing of iron, steel, copper, or any conductive metal, the conductor shall be bonded to the top and bottom of the pipe or tubing. Guards of wood, plastic (PVC rigid), or metal laid over the conductor and securely fastened, are acceptable. Guards shall afford full protection of the down conductor for a distance of not less than 6 feet (1.8 m) above grade level.

119) 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 their entire length below grade.

120) Down conductors coursed in reinforced concrete columns or coursed on or within the calculated bonding distance of reinforced concrete columns or structural steel columns shall be bonded to the reinforcing steel or the structural steel member at its upper and lower extremities. When cable down conductors are used in lieu of metallic (structural steel) columns, the metallic column members shall be bonded to the downlead at their upper and lower extremities. In the case of extremely long vertical down conductor runs, an additional connection shall be made between each down conductor and the reinforcing steel or metallic column at intervals not exceeding 200 feet (60 m). Where these bonding requirements are not satisfied because of lack of access in retrofit installations, some provision shall be made to ensure the required interconnection of these parallel vertical paths.

121) Use of PVC conduit or any other nonmetallic chase shall not eliminate the need to satisfy the bonding required by this Standard.

122) It is preferable to mount down conductors at or near the exterior perimeter of the structure. This routes the lightning away from interior building systems and personnel. When pipe chases, shafts or stairwells provide the only possible downlead locations for retrofit systems on existing structures, downleads shall be as widely separated as possible and should be limited to one downlead per chase, shaft or stairwell. Consideration should be given to avoiding close proximity to other building grounded systems. Bonding vertical metallic grounded systems is even more critical for this type installation.

123) Future testing of the integrity of the structural grounding system is recommended for any system. Questionable soil conditions or extended system life requirements may make this a necessity. System design parameters and job site conditions will dictate the best location for disconnects to be located in the downleads or between the downlead cables and the grounding electrode system. It is most appropriate to make the disconnect points as low as practical on the building, because as you rise up the building's elevation interconnections with structural metallic members and bonding to other grounded systems will lower the ground test results giving false readings.

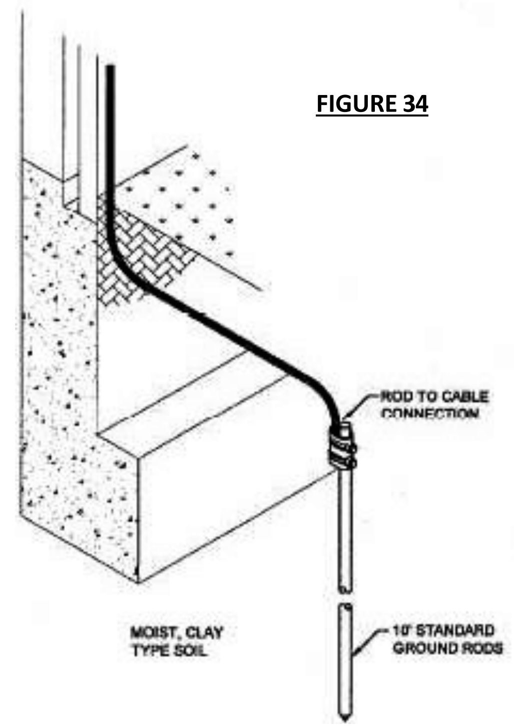
124) System disconnects may be provided in ground wells where connections from downleads to terminals are located, in junction boxes which access downlead cables concealed within the construction, or on exposed downlead cables above grade. Approved fittings used for connecting down conductors with driven grounding electrodes, main conductor to main conductor splicers, or bimetallic fittings used to interconnect aluminum conductors to copper conductors are acceptable disconnect devices.

GROUNDING

125) In general, the extent of the grounding arrangement will depend on the character of the soil, ranging from single ground rods in the earth where soil is deep and of excellent conductivity, to an elaborate buried wire network where the soil is dry or of poor conductivity. Ufer grounds, connections to rebar, isolated pilings, etc. are not acceptable as substitutes for the grounding methods outlined in this Standard.

126) Each down conductor shall terminate at one or more grounding electrodes dedicated to the lightning protection system or to a grounding electrode system. Individual electrical system and telecommunication grounding electrodes shall not be used in lieu of lightning ground electrodes. This does not prohibit the required bonding together of grounding electrodes of different systems.

FIGURE 34



127) In the case of a building, structure, or facility that has multiple grounding electrodes that are bonded together with a ground ring electrode or a single ground ring electrode for all systems, connection of the downleads to the ground ring shall fulfill the requirement without the addition of separate lightning protection electrodes. The ground ring electrode shall meet or exceed the size of a main lightning conductor for the Class of structure being protected. (See paragraph **134**)

128) Down conductors shall be attached permanently to the grounding electrode system by bolting, brazing, or welding connectors listed for the purpose, and clamps shall be suitable for direct burial. All clamps used for LPI Certified Systems shall be subject to in-factory inspection by an independent testing agency to UL 96 requirements. Clamps used to connect down conductors to driven ground rods shall make contact with ground rods for a distance of 1 ½ inches, measured parallel to the axis of the ground rod and with the cable itself for a distance of 1 ½ inches. Clamps shall be secured with at least two bolts or cap screws.

129) Whenever practical connections to ground electrodes should be made at a point not less than 1 foot below grade level and not less than 2 feet away from the foundation wall or far enough away to avoid buried footings, pipe caps, etc. **(Figure 34)**

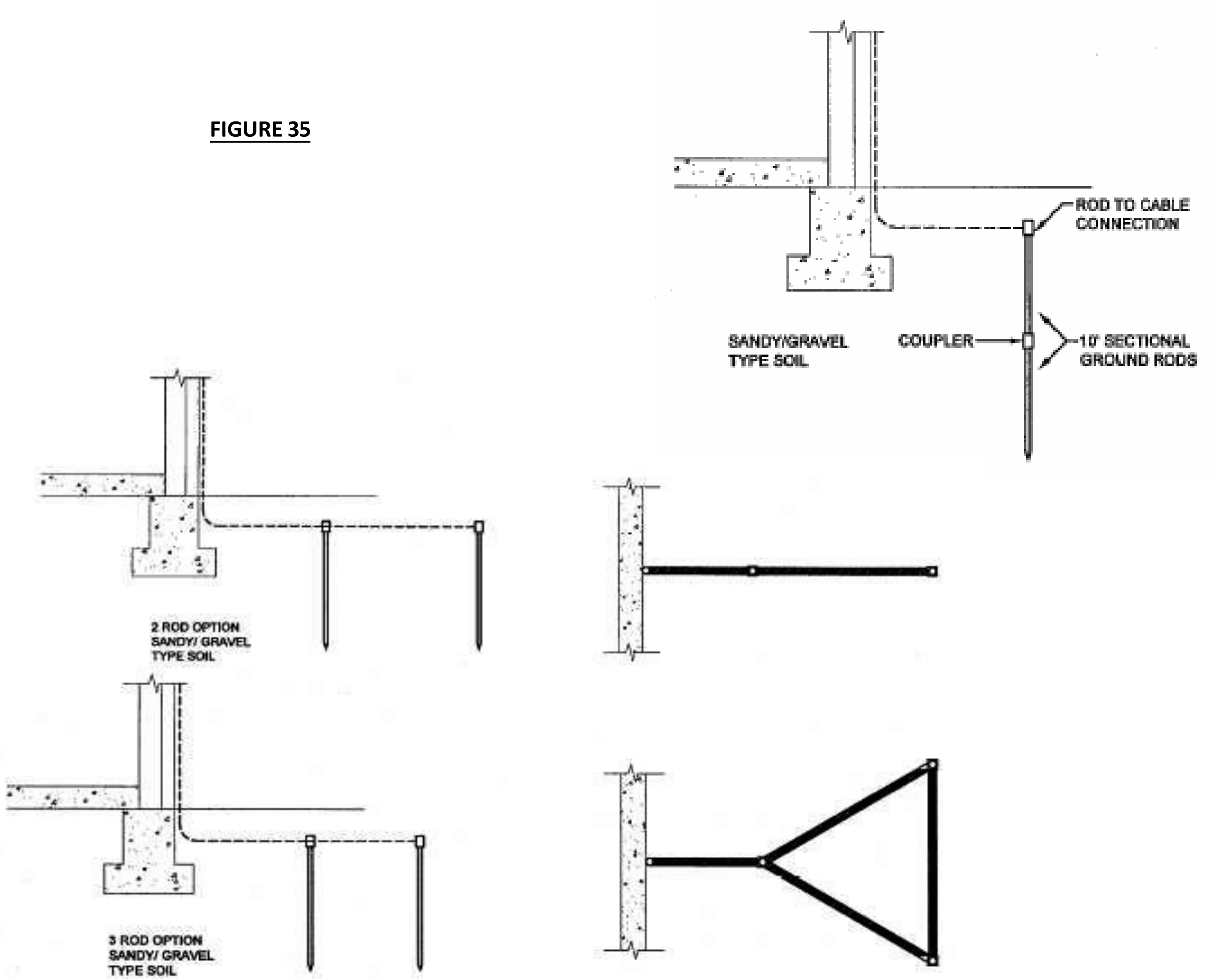
130) During a discharge of lightning current on a system of conductors, the grounding electrodes are to be thought of as the points through which the heavy current flows between the air terminals and the earth about the structure. Therefore, they should be distributed or located with the view of carrying the flow of current in the most advantageous manner. This will be realized generally by placing them at the outer extremities, such as corners and outside walls of the structures, and avoiding as far as possible the flow of current under the building.

131) Grounding electrodes shall be installed below the frost line where possible to maintain good connection with the soil for the full range of conditions throughout the year.

Grounding Electrodes

132) Ground Rods – shall be not less than ½ in. (12.7 mm) in diameter and 8 ft. (2.4 m) long. Rods shall be free of paint or other nonconductive coatings. The ground rods shall extend vertically not less than 10 ft. (3 m) into the earth. Rod grounding electrodes shall be copper-clad steel, solid copper, or stainless steel. Consideration of the corrosive environment is necessary in the selection of an appropriate stainless steel alloy as a material. (Hot-dipped galvanized steel rods have been deleted as a grounding electrode option because of concerns about longevity in various soil conditions and connections with copper main conductors.) The earth shall be compacted or made tight against the length of the rod.

FIGURE 35



133) Multiple Ground Rods – Where multiple ground rods are used, the separation between any two ground rods should be at least the sum of the rod lengths or their driven depths where practical to maximize the benefit. Configurations shown in **Figure 35** are permitted.

134) Ground Ring Electrode – The ground ring electrode shall be a main size copper lightning conductor for the Class structure being protected, or a grounding conductor of equivalent or greater cross-sectional area. A ground ring electrode shall encircle the structure and preferably be in direct contact with the earth at a depth of 18 in. (457 mm) or more. A ground ring electrode may be encased in a concrete footing in accordance with paragraph **137** below.

135) Radials – A radial electrode shall consist of one or more main size copper conductors, each in a separate trench extending outward from the location of each down conductor. A radial electrode shall be not less than 12 ft. (3.7 m) in length and not less than 18 in. (0.5 m) below grade.

136) Ground Plate Electrode – A ground plate electrode shall be made of solid copper and have a minimum thickness of 0.032 in. (0.8 mm) and a minimum surface area of 2 sq. ft. (0.18 m²). The ground plate electrode shall preferably be buried not less than 18 in. (0.5 m) below grade **(See Figure 36)**.

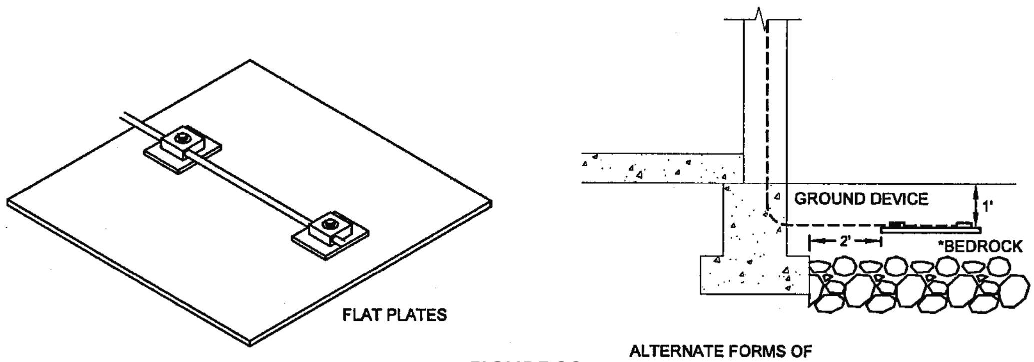


FIGURE 36

ALTERNATE FORMS OF GROUNDING IN SHALLOW OR ROCKY SOIL.
* DEPTH REQUIREMENT WAIVED IF ROCK IS CLOSER TO SURFACE.

137) Concrete Encased Electrodes – A concrete encased electrode shall be located at the bottom of a concrete foundation or footing that is in direct contact with the earth in new construction. The electrodes shall be encased by not less than 2 in. (50 mm) of concrete. An accessible connection point shall be provided for each concrete encased electrode to enable future maintenance testing. The concrete encased electrode may consist of any of the following:

a) A ground ring electrode (paragraph **134** above)
b) Not less than 20 ft. (6.1 m) of bare copper main size conductor.
c) At least 20 ft. (6.1 m) of bare or electrically conductive coated steel reinforcing bar or rod not less than ½ in. (12.7 mm) in diameter. If more than one steel bar is used they shall be effectively bonded together by either welding or overlapping 20 diameters and wire tying.
d) Nonconductive or resistive coatings on steel reinforcing bars shall not be permitted.

Field experience has demonstrated that a copper conductor could experience accelerated corrosion at the point where the copper conductor exits the concrete. Concrete and soil composition could have a direct impact on the amount of corrosion, if any. Investigation of existing installations at the proposed site or chemical analysis of the concrete and soil composition would provide a basis to determine if additional corrosion protection is warranted. Each installation should be evaluated to determine the need for any additional corrosion protection. Tinned copper conductors or installation of a nonmetallic sleeve over the conductor where the conductor exits the concrete are two methods that could mitigate corrosion. The nonmetallic sleeve should extend 6 in. (150 mm) on each side of the transition from concrete to soil.

138) Combinations – The use of combinations of grounding electrodes listed above to achieve desired results in various soil conditions is permitted.

Selection Criteria Based on Soil Condition

139) Moist Clay Soil – Moist clay or loam soils are characterized by superior (low) soil resistivity. It is standard practice to use ground rods according to paragraph **132** above. It may be suitable under differing circumstances to use any type grounding electrode (paragraphs **132 – 137**) or combination for this soil type.

140) Grounding in Sandy or Gravelly Soil – Sandy or gravelly soil conditions are characterized by poor (high) soil resistivity. Multiple ground rods should be provided in accordance with paragraph **133**. If there is no suitable area to locate multiple grounds in the configurations shown **(Figure 35)**, then individual grounds should be extended by use of sectional rods to a depth of 20 feet (6.1 m) into the earth.

141) When the depth of these poor resistivity soils will not allow driven ground rods, the ground ring electrode is preferred connecting all downleads and building grounded systems. If the ground ring is not possible because of construction conditions, longer radials or multiple ground plates suitable to the application shall be used. Multiple ground plates at each downlead location shall be separated as widely as practicable. A radial only configuration for grounding each downlead should include a total buried horizontal conductor length of 33 ft. (10m) minimum. This may be accomplished using a crow's foot radial configuration, having a combined total length of buried conductors meeting the requirement at each downlead location (**See Figure 37**).

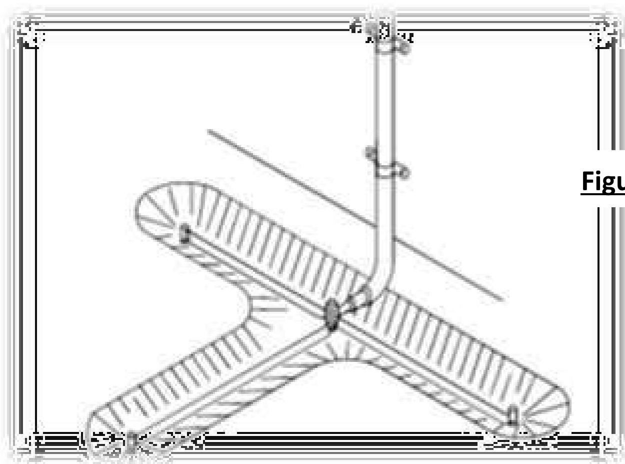


Figure 37

Crow's Foot Radial Configuration

142) Grounding in Shallow Top Soil – Conditions of shallow top soil can be divided into three different situations –

a) Soil a minimum of 18 in. – If the soil is at least 18" (457 mm) deep, then the following grounding electrodes would be acceptable. The ground ring (paragraph **134**), the radial (paragraph **135**), the ground plate (paragraph **136**), or a combination of these electrodes would be suitable.
b) Soil less than 18 in. deep – For soil less than 18" (457 mm) deep, a ground ring, ground radials, or ground plates (paragraphs **134 - 136**) shall be installed at maximum depth in contact with the soil. Combinations of the above may be used to improve the grounding electrode system **(See Figure 38).**
c) No soil (solid rock) – A ground ring electrode may be laid directly on bedrock extending a minimum distance of 2 ft. (0.6 m) from the foundation or footing. The ground ring system may be improved by attachment to ground plate electrodes or radials at each downlead location.
d) If no soil is available and a continuous ground ring cannot be installed because of construction conditions, a radial electrode configuration shall be used. A total horizontal length of 65 ft. (20m) shall be used at each downlead location, and may include a multiple crow's foot configuration to

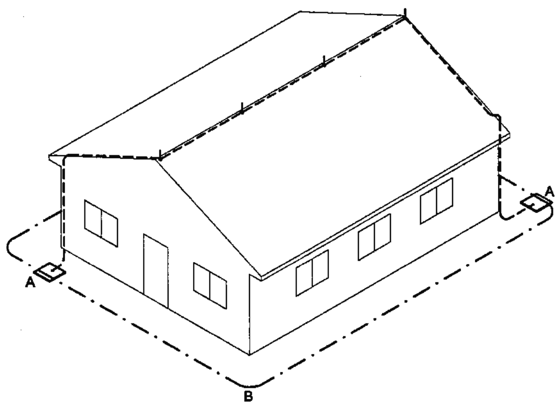
reach the combined horizontal footage. The exposed conductor shall be anchored every 3 feet (1 m) to protect against movement. Consideration should be given to using solid strip conductors for these exposed location radials.

143) At locations where there is no access to property outside the building footprint (zero property line condition) additional considerations for the grounding system are required:

a) Grounding electrodes may be located under basement slabs or in crawl spaces and shall be installed as near as practicable to the outside perimeter of the structure.

b) Ground rods in accordance with paragraph **132**, ground ring electrodes in accordance with paragraph **134**, radials in accordance with paragraph **135**, or ground plate electrodes in accordance with paragraph **136** shall be installed below the structure in earth compacted tight against the electrode.

c) Where earth depth under the building is insufficient for electrode placement depths, concrete encased electrodes (paragraph **137**) or the requirements for shallow topsoil (paragraph **142**) shall be applied.



A: OPTIONAL GROUND PLATES
B: ENCIRCLING COUNTERPOISE
(GROUNDING IN SOIL LESS THAN 1'-0" DEEP)

FIGURE 38

144) Using an exterior ground ring (paragraph **134**) is a suitable method for providing a grounding electrode under any soil conditions. It will improve the ground system when added to all of the above types. The ring will equalize ground potential for the downleads, and allow for interconnection with other building grounded systems. A concrete encased electrode system (paragraph **137**) may be suitable for any soil condition above. It should be considered most often when there is no soil or very shallow soil around the structure.

INTERCONNECTION (BONDING)

Common Bonding of Grounded Systems at Grade Level

145) All grounded media and buried metallic conductors (including underground metallic piping systems) that can assist in providing a path for lightning currents in or on a structure shall be interconnected to the lightning protection system within 12 ft. (3.6 m) of the base of the structure to provide a common ground potential.

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

147) All ground level connections may be made below grade. Providing a ground loop in contact with the earth will greatly enhance the effectiveness of the grounding electrode system. Construction circumstances may dictate these interconnections be made interior to the building in a basement, crawl space, subterranean garage, first floor ceiling, etc.

148) A ground loop conductor is considered to be a complete or closed loop around the perimeter either outside or inside the structure. If existing conditions will not allow for the installation of a closed loop, a main conductor run interconnecting every downlead and all other grounded media can be considered as an alternative.

149) This interconnection shall include all building system ground devices including lightning protection, electric service, communications, and antenna system grounding electrodes.

150) Interconnection of underground metallic piping systems shall include, but not be limited to, water service, well casings located within 7.6 m (25 ft.) of the structure, gas piping, underground conduits, underground liquefied petroleum gas piping systems. Plastic pipe shall not be connected to the lightning protection system. However, when a plastic service line feeds an internal metallic piping system and fixtures the metallic piping system shall be bonded. If plastic pipe sections interrupt a generally all-metallic pipe system, then they shall be bridged using main size conductors to ensure electrical continuity between grounded systems.

151) When the building grounded systems noted above are interconnected at a common accessible point in or on the structure, the lightning protection system shall have only one main size conductor connected to the common bonding point. This common bonding point shall include a ground bar, a section of water pipe, or the metallic structural frame as identified in the National Electrical Code (NFPA 70).

The interconnection of incoming services to the lightning protection system should be performed as near the service entry as reasonable and not meander greatly through the structure before its interconnection. For larger structures with services entering the structure at different locations, multiple equipotential ground bus bars (EGB) should be considered. In these cases, the interconnection of the multiple EGBs is best accomplished through interconnection with a ground ring electrode.

152) Where bonding of the lightning protection grounding system, grounded media, and buried metallic conductors has not been accomplished at a common point, interconnection shall be provided according to the following:

A. Grounded media and buried metallic conductors inherently bonded through construction to the lightning protection grounding system shall not require further bonding.
B. Grounded media and buried metallic conductors shall be bonded to the lightning protection grounding system or downlead below a height 12 ft. (3.6 m) vertically above the base of the structure or as near as practical to their entrance to the building.
C. The continuous metal framework of a structure shall be connected to the lightning protection system (See paragraphs **120, 179** and **182 - 189**).
D. Main size lightning conductors shall be used for direct connection of grounded media and buried metallic conductors to the lightning protection system.
E. A ground bar designed for interconnection of building grounded systems shall have one connection to the lightning protection system.
F. A continuous metal water pipe system designed for interconnection of building grounded systems shall have one connection to the lightning protection system.
G. Interconnection to a gas system shall be made to the customer's side of the meter.

NOTE: A4.14.6.1(6) of NFPA 780 has determined "Where lightning protection is installed on a structure containing corrugated stainless steel tubing (CSST), the CSST should be bonded to the lightning protection system in more than one location to lower the probability of arcing. The CSST should be bonded as close to the gas service entrance as possible, at any appliance supplied by the CSST, and at any manifold present in the gas piping system. In addition, the length of any bonding conductor between the CSST gas piping system and the lightning protection grounding system should be as short as possible. Shorter bonding lengths limit the voltage drop between CSST and other metal components, lowering the probability of the development of an electric arc. Shorter bonding lengths conduct a larger amount of current to ground and reduce voltage differences between the CSST and other metallic components. A bonding length of 25 ft. (7.6 m) or less is likely to be effective in preventing arcing due to induced currents. Bonding clamps should not be installed directly on the CSST or its jacket. The means of bonding the CSST should be installed in accordance with the CSST manufacturer's instructions. Maintaining a separation between metal bodies (except appliances and bonding connections) and CSST piping could also mitigate arcing. A separation distance of 6 in. (150 mm) or more is recommended."

H. Where galvanic corrosion is a concern or where a direct bond is prohibited by local code, an isolating spark gap shall be used for bonding building grounded systems.

Interconnection to Internal Building Systems

153) A side-flash or flash over from the lightning conductor system to another building grounded system can lead to physical danger or possible fire or explosion damage to a structure. 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 interconnected with the lightning protection system **(See Figure 39).**

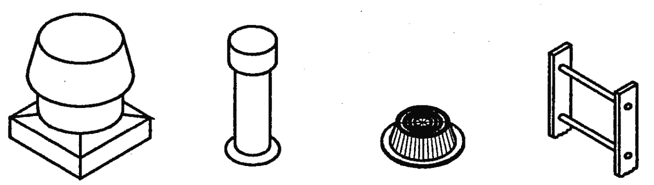


FIGURE 39

154) Metal bodies may be inherently interconnected with the lightning protection system through construction, as in the case of systems mounted directly to the structural metallic frame of a building. When the lightning protection system is installed using the structural metallic frame as a conductor or the metallic frame is grounded as required by paragraphs **120, 179 and 182 - 189**, most metal bodies will need no further bonding. Grounded metal bodies shall not require additional bonding if the measured dc resistance between the inherently bonded, electrically conductive materials and the nearest lightning protection component is less than 200 milliohms.

155) A metallic water pipe system is required to be interconnected to the lightning conductor system at grade level as are all other building grounded systems. When electrical continuity is achieved for the plumbing system it may serve as a common grounding point for other systems. Continuity shall be confirmed by testing, in particular across joints or fittings which may use pipe dope or tape, in effect insulating system sections. Metal bodies may be connected to the continuous water pipe or other grounded systems, the nearest lightning conductor, or to another metal body already connected to the system at additional vertical intervals to accomplish required bonding. Metal bodies grounded automatically through their structural connection to the continuous water pipe system require no additional bonding.

156) Prominent metal bodies located exposed on roofs or walls of the structure are to be interconnected using main size conductors and may serve as strike termination devices. In cases where strike termination devices and main size conductors are mounted on metal bodies, a bond shall be included for each conductor run from the metal body if not inherently provided by direct contact or system fasteners and fittings.

Potential Equalization

157) Potential equalization is the bonding together of grounded systems at different building height (vertical) intervals to eliminate side flashing between systems. Interconnection of these systems causes them to rise and fall together so there is no potential difference and no flash over between systems.

Structures exceeding 60 feet (18 m) in height

158) Ground-Level Potential Equalization – See paragraphs **145 - 152** above.

159) Roof-Level Potential Equalization – Structures exceeding 60 feet (18 m) in height shall have all grounded media in or on the structure interconnected within 12 feet (3.6 m) of the main roof level. The main roof conductors are considered to be the loop conductor for interconnection of all downleads to building grounded systems.

160) Roof mounted grounded media need to be considered individually for bonding connections. Multiple vent items may be connected together just below roof level making one bonding connection sufficient. On the other hand, vents may be the extension of long vertical building systems that diverge near grade level requiring individual connections to several separate vents.

161) In cases where steel (metallic) framing just below the roof surface is interconnected with all the lightning protection downleads and the grounded roof level media, no additional bonding is required. If it is not continuous through construction, building grounded media penetrating the roof may be either interconnected with this grounded structural roof framing, or bonded directly to the lightning protection system.

162) Intermediate-Level Potential Equalization – Structures exceeding 60 feet (18m) in height shall have interconnections between the lightning protection system down conductors and other grounded media at intermediate levels between roof and grade based on their construction according to A. through D. below:

A. Steel Framed Structures - Intermediate loop conductors and interconnections shall NOT be required for steel framed structures where the framing is electrically continuous and bonded as required to the lightning protection system.
B. Reinforced Concrete Structures – Where the reinforcement is interconnected and grounded at the top and bottom of each downlead conductor in accordance with paragraphs **120 and 179**, 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).
D. Long Vertical Metal Bodies - Grounded and ungrounded metal bodies exceeding 60 ft. (18 m) in vertical length in or on reinforced concrete structures, where the reinforcement is interconnected and grounded in accordance with paragraphs 118 and 177, shall be bonded to the lightning protection system as near as practicable to their extremities unless inherently bonded through construction at those locations.

163) A system, with proper bonding between grounded systems and the lightning protection system at grade, roof and intermediate levels as described above provides very good side-flash protection for all intermediate vertical areas. This equates to an extremely large denominator for calculation as described in the formula shown in paragraph **167** (n approaches the total number of downleads for the entire building) and results in an extremely small bonding distance at intermediate heights. This generally eliminates bonding considerations at intermediate vertical intervals for system branches (See **166B**) with the exception of systems run contiguous to the lightning protection downleads. When possible internal building grounded systems in high- rise structures should be routed up through the interior core of the building with lightning protection downleads run at the perimeter to avoid proximity interaction. Consideration should be given to isolating perimeter contiguous systems by design from the lightning protection system by at least 1 foot (0.3 m) through solid building materials.

Structures up to 60 feet (18 m) in vertical height

164) Ground-Level Potential Equalization – See paragraphs **145 - 152** above. All ground level connections may be made below grade, or construction circumstances may dictate these interconnections be made interior to the building as stated above. A ground loop will enhance the system, but is not required on these structures.

165) Roof-Level and Intermediate-Level Potential Equalization – Additional interconnections of metal bodies shall be based on a bonding distance. For convenience, consider bonding all grounded metal bodies within 7 feet (2 m) of the lightning protection system to stop side flash through air, and those within 3.5 feet (1 m) to stop side flash through building materials. This assumes a connection between the lightning protection system and the grounded building systems within 60 vertical feet (18 m), and two downleads located within a 100 feet (30 m) radius zone of the bonding point under consideration. This would provide adequate bonding for most typical installations. Further calculation, as detailed below, could provide a reduced bonding distance with fewer interconnections required.

Bonding Calculations

166) Grounded Metal Bodies – Bonding of grounded metal bodies not covered by previous sections shall be considered according to the following~~:~~

A. When grounded metal bodies have been connected to the lightning protection system at only one extremity (as required at the base for all structures), possible bonding of the other extremity (top) may be calculated. This is the condition at the upper extremities of any building 60 feet (18 m) tall or less, which is the height at which a top potential equalization loop is required bonding all systems.
B. When branches of grounded metal bodies connected at their extremities (top and bottom) change vertical direction more than 12 ft. (3.6 m), possible bonding of branches needs to be calculated.

167) Bonding distance requirements can be determined by a technical evaluation of the number of down conductors and their location, the proximity of grounded metal bodies to the lightning conductors, and the flashover medium, either air or solid materials. Bonding distance may be calculated by the following formula:

$$\mathbf{BD} = \left(\frac{\mathbf{h}}{\mathbf{6n}}\right) * \mathbf{Km}$$

Where:

BD = calculated bonding distance

h = vertical distance between the bond being considered and the nearest lightning protection system bond. (For simplification on buildings under 40 feet tall, h may be considered to be the building height from the main roof level to grade.)

n = a value related to the number of down conductors that are spaced at least 25 ft. (7.6 m) apart; located within a zone of 100 ft. (30 m) radius from the metal body in question;

n = 1 where there is only one downlead in the 100 ft. (30 m) radius zone.
n = 1.5 where there are only two down conductors in the zone.
n = 2.25 where there are three or more down conductors in this zone

Km = a value of 1 if the potential flashover is through air, and 0.50 if through any solid building material such as concrete, brick, wood, and so forth.

A bonding connection shall be required where the grounded metal body lies within the calculated bonding distance from a lightning protection system component or another interconnected grounded metal body.

168) Some sample bonding distances (rounded to the nearest 0.5 foot) are calculated from the formula in Table format below:

TABLE 3
SAMPLE BONDING CALCULATIONS
BD = (h / 6n) * Km

height (ft.)	Km	n = 1	n = 1.5	n = 2.25
		Bonding Distance (feet)		
10	1	**2**	**1.5**	**1**
20	1	**3.5**	**2.5**	**1.5**
30	1	**5**	**3.5**	**2.5**
40	1	**7**	**4.5**	**3**
50	1	**8.5**	**6**	**4**
60	1	**10**	**7**	**4.5**
10	0.5	**1**	**1**	**0.5**
20	0.5	**2**	**1.5**	**1**
30	0.5	**2.5**	**2**	**1.5**
40	0.5	**3.5**	**2.5**	**1.5**
50	0.5	**4.5**	**3**	**2**
60	0.5	**5**	**3.5**	**2.5**

height (m)	Km	n = 1	n = 1.5	n = 2.25
		Bonding Distance (meters)		
3	1	**0.5**	**0.5**	**0.25**
6	1	**1**	**0.75**	**0.5**
9	1	**1.5**	**1**	**0.75**
12	1	**2**	**1.5**	**1**
15	1	**2.5**	**1.75**	**1.25**
18	1	**3**	**2**	**1.5**
3	0.5	**0.5**	**0.25**	**0.25**
6	0.5	**0.5**	**0.5**	**0.25**
9	0.5	**0.75**	**0.5**	**0.5**
12	0.5	**1**	**0.75**	**0.5**
15	0.5	**1.25**	**1**	**0.75**
18	0.5	**1.5**	**1**	**0.75**

169) Long horizontal grounded metal bodies on roofs exceeding 60 ft. (18m) in horizontal length shall be bonded to the lightning protection system as near as practicable to their extremities unless inherently bonded through construction at those locations. Horizontal grounded metal bodies that are parallel to a main lightning conductor and that are within the bonding distance calculated in paragraphs **166 – 167** shall be bonded to the main conductor at intervals averaging not more than 100 ft. (30m) along the main conductor unless inherently bonded through construction at those locations. Horizontal grounded metal bodies that cross a main conductor shall be bonded to the main conductor where they cross the conductor unless inherently bonded through construction at that location.

170) Ungrounded Metallic Bodies – Bonding between the lightning protection system and other grounded metal bodies is critical to eliminate side-flash. The influence of an ungrounded 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 interconnection to the lightning protection system. An ungrounded metallic body will influence bonding requirements only if the total of the distances between the lightning conductor and the ungrounded metal body, and between the ungrounded metal body and a grounded metal body is equal to or less than the calculated bonding distance per paragraph **166**.

171) Bonding connections where required shall be permitted to be made directly from the lightning protection system to the grounded metal body, or from the lightning protection system to the ungrounded metal body and from the ungrounded metal body to the grounded metal body.

172) Grounded metal bodies that maintain a separation distance from the lightning protection system components that is greater than the distance calculated using the bonding distance formulas (paragraphs **166-167**) are considered isolated and require no further bonding.

Potential Equalization Materials

173) Horizontal loop conductors used for the interconnection of lightning protection system downlead conductors, grounding electrodes, or other grounded media shall be sized no smaller than that required for the main lightning conductor **(TABLE 2).**

174) Interconnections of prominent metal bodies to the lightning protection system to create strike termination devices requires the use of main size conductors. Interconnection of the building structural steel or reinforcing steel requires the use of main size lightning protection conductor and bonding fittings (**TABLE 2**).

175) All other required interconnections between the lightning protection system and grounded or ungrounded metal bodies are considered to be secondary bonding connections (non-current carrying), and secondary size conductors and bonding devices may be used **(TABLE 4)**. Connectors for equipotential bonding shall have a minimum surface contact area of 0.021 in^2 (0.133 cm^2) for copper and 0.032 in^2 (0.208 cm^2) for aluminum.

TABLE 4

BONDING CONDUCTORS - MINIMUM MATERIAL REQUIREMENTS

Classification	Product	Description	Copper		Aluminum	
Class I or Class II	Cable	Size each strand	17 AWG	(1.04 mm^2)	14 AWG	(2.08 mm^2)
		Number of strands	14		10	
		Cross section area	26,240 cir. mils.	(13.3 mm^2)	41,100 cir. mils.	(20.8 mm^2)
	Solid Wire	Size	6 AWG	(4.11 mm)	4 AWG	(5.19 mm)
		Cross section area	26,250 cir. Mils.	(13.3 mm^2)	41,740 cir. Mils	(21.1 mm^2)
	Solid Strip	Thickness	0.051 in.	(1.3 mm)	0.064 in.	(1.63 mm)
		Width	1/2 in.	(12.7 mm)	1/2 in.	(12.7 mm)

CONCEALED SYSTEMS

176) Lightning protection system components may be concealed in building construction. A lightning protection system is a low resistance continuous metallic path designed for the purpose of transferring lightning from the top of a structure into the earth. Although the electrical power of lightning may be massive, the time it is impressed upon a properly designed lightning protection system is negligible. This makes the possibility of damage to building components relatively low. In fact, it may be preferable to conceal portions of the lightning protection system for aesthetic reasons as well as to avoid weathering of materials, accidental damage, or improper removal of components by other trades.

177) All requirements covering exposed systems apply to concealed installations. Conductors are coursed in a similar manner, except that they may be coursed under the roofing material, under the roof framing, behind the exterior wall facing, and between the studding of partitions or outside walls. Copper conductors may be embedded directly in concrete.

178) Conductors may be coursed in concealed or embedded conduit. Cable in metallic conduit shall be securely bonded to the conduit at both ends, where it enters and emerges from the conduit, and at all locations where the conduit is not electrically continuous.

179) Where conductors are embedded in concrete, either directly or in conduit, the reinforcing steel shall be bonded to the cable or metallic conduit with a main size conductor. Reinforcing steel shall be bonded at the top and bottom of each embedded downlead (See paragraph **120**). If roof conductors are embedded, a connection to reinforcing steel shall be made at no less than 100' average intervals. Approved clamp type fittings are acceptable for cable to rebar connections.

180) Chimney terminals and conductors may be built into the masonry of a chimney, or may be attached to the outside of a chimney and carried through the roof to a main concealed conductor.

181) Continuity of all concealed conductors and connections shall be verified at time of installation. As-built drawings and photographs showing the location of the conductors, grounding electrodes, and required bonding interconnections shall be supplied to the owner or inspection authority as a record of concealed system components for purposes of inspection and future system additions.

STRUCTURAL STEEL OR METALLIC FRAME SYSTEMS

182) The metallic framework (steel) 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. Any framing members of metal that are 3/16" (4.8 mm) or more in thickness may be utilized as the main conductor of a lightning protection system.

183) A system employing the structural metallic framework may be considered preferable since the framework will normally provide top, mid-height and base interconnection loops. Bonding to other building systems may be inherently accomplished through standard interconnections from mounting these systems to the structural metal in this type construction. The entire lightning protection system is considered an improved "faraday cage" for the protection of the structure and contents when the structural metallic columns are connected to a properly installed grounding system.

184) Strike termination devices shall be connected to the structural metallic framing by direct connection (i.e. drilling and tapping), by use of individual vertical conductors routed through the roof or parapet walls to the metal framework, or by use of an exterior horizontal conductor interconnecting all strike termination devices and connected to the metal framework. Where an exterior horizontal roof or ridge conductor is used, it shall be connected to the metal framework of the structure at intervals not exceeding an average distance of 100 ft. (30m), as widely separated as possible **(See Figure 40).**

185) Conductor connections shall be made to areas of the metallic framework cleaned to base metal by use of bonding plates, drilling and tapping, welding, or brazing. Bonding plates shall have bolt pressure cable connectors and a surface contact area of not less than 8 square inches (5200 mm^2) to the metal frame. Plates may be bolted, welded, or brazed to the structural steel. Where corrosion protective paint or coatings are removed, the completed electrical connection shall have corrosion protection equivalent to the original coating **(See Figure 41).**

186) Drilling and tapping the metallic column to accept a threaded connector also shall be permitted. The threaded device shall be installed with at least five threads fully engaged and secured with a jam nut. The threaded portion of the connector shall be not less than ½ in. (12.7 mm) in diameter.

187) Grounding electrodes shall be connected to metallic columns around the perimeter of the structure at intervals averaging not more than 60 ft. (18m). Grounding electrodes shall be attached at the lowest available point according to paragraphs **185 or 186** above. Grounding electrode systems for metal framed structures shall comply with the requirements of paragraphs **125 to 144**.

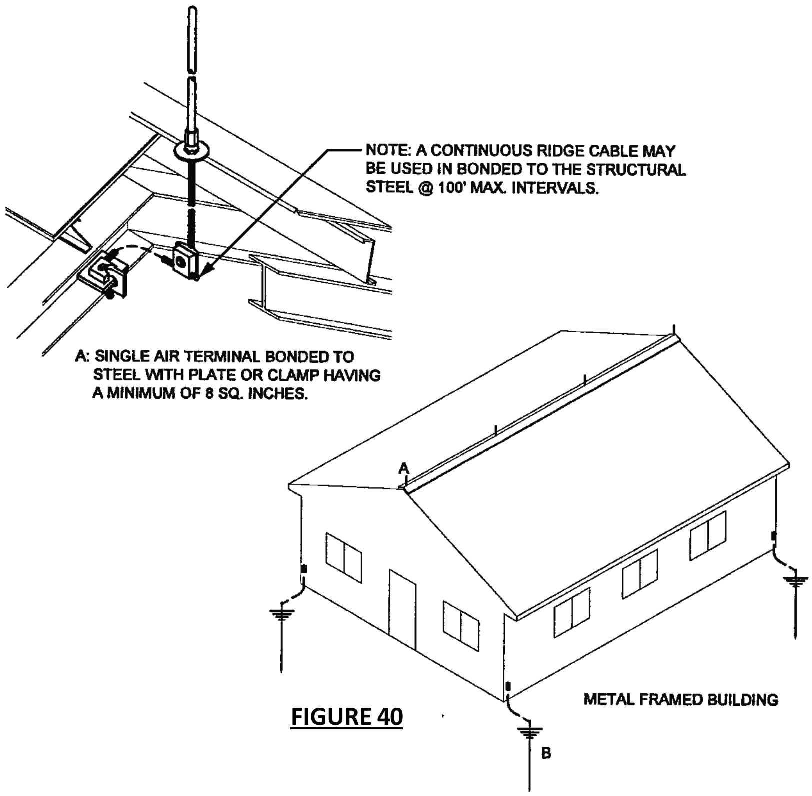


FIGURE 40

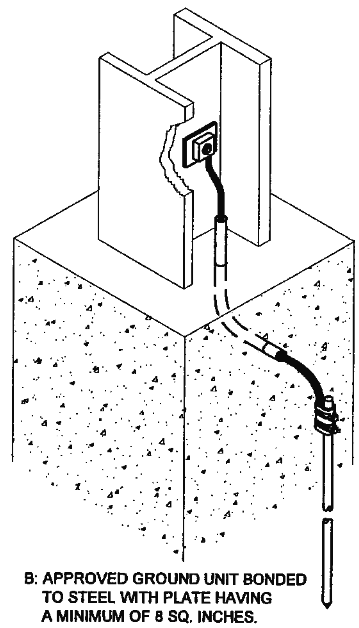


FIGURE 41

188) Where metal bodies located within a metallic framed structure are inherently bonded to the structure through construction, separate bonding connections shall not be required. Prominent metal projections connected to the metallic framework and electrically continuous with the lightning protection system through structural interconnection are considered to be bonded and an additional interconnection is not required. Prominent metal projections connected to grounded structural metal that are a minimum of 3/16" thick serve as strike termination devices. If these prominent grounded metal projections are not 3/16" thick, strike termination devices shall be added to place them within a zone of protection. Any prominent ungrounded metal body may be connected to the grounded structural metal using main size conductor to accomplish required bonding.

189) Where structural metallic framework is used as an element of a lightning protection system, all components (air terminals, conductors, fittings, etc.) necessary shall be Class I or Class II as dictated by the building section's height.

SURGE PROTECTION

190) A complete lightning protection system includes both direct strike and surge protection measures. Responsibility for compliance with these surge protection requirements rests with the engineer, owner or contractor responsible for the specific equipment, service or system involved. Surge protection alone is not intended to prevent or limit physical damage from a direct lightning strike to a facility or structure. Rather, it is intended to defend against indirect lightning effects imposed upon the service wiring to a structure as part of a coordinated lightning protection system installed in accordance with the requirements of this standard. SPDs also represent a bonding interconnection for potential equalization between these systems and the lightning protection grounding.

191) Services shall be protected from surges and over voltage transients created by direct or nearby lightning strikes. Surge currents and their corresponding over voltage transients can be coupled onto utility feeders in a number of ways. These mechanisms include magnetic or capacitive coupling from a nearby strike, or the more dramatic but much less frequent conductive coupling of a direct cloud-to-service discharge. These over voltage transients pose a significant threat to the structure for fire damage. Electrical and electronic equipment may require additional protection beyond these requirements for survival.

192) This section provides requirements for surge protection equipment installed for the facility electrical, communications (including but not limited to CATV, alarm, data), antenna systems or other electrical system hardware. The requirements included within this Standard are limited to permanently installed surge protective devices (SPDs). Surge arrestors shall be installed when a building, structure, or equipment operates over 1,000 V.

193) Surge protective devices shall not be required where, under engineering supervision, it is determined that surge threat is negligible or the lines are equivalently protected or where installation compromises safety.

194) Installation of surge suppression hardware shall conform to the requirements of NFPA 70, National Electrical Code. Resistance of the earth electrode system used in the grounding of surge protective devices shall comply with NFPA 70, National Electrical Code.

195) SPDs should not be grounded through a down conductor of a lightning protection system. SPDs shall be located and installed so as to minimize lead length, and interconnecting leads should be routed to avoid sharp bends, coils, or kinks. The SPD grounding conductor shall be installed in accordance with manufacturer's instructions.

196) All SPD components shall be accessible for inspection and maintenance. Some SPD units are provided with a failure indicator. This feature facilitates maintenance or test procedures. Where used, this indicator should be visible for periodic inspection or testing. The SPDs shall be protected in consideration of the operational environment and the manufacturer's instructions. Ancillary enclosures shall be listed for the purpose.

Electrical Power Entrance Surge Protection

197) Surge protection shall be installed at all power service entrances to structures.

198) The surge protective device (SPD) shall be listed for the protection of service entrances. The SPD shall protect against a surge produced by a 1.2/50 μs, 8/20 μs combination waveform generator.

199) Service entrance SPDs shall have a nominal discharge current (I_n) rating of at least 20 kA 8/20 μs per phase.

200) The short circuit current rating of the SPD shall be coordinated with the available fault current rating of the supply panel to which it is connected in accordance with NFPA 70, National Electrical Code. The maximum continuous operating voltage (MCOV) of the SPD shall be selected to ensure that it is greater than the upper tolerance of the utility power system to which it is connected.

201) The protection of service entrances shall use Type 1 or Type 2 SPDs in compliance with applicable standards such as UL 1449, UL Standard for Safety for Surge Protective Devices.

TABLE 5

Surge Protective Devices for Power Distribution Systems

Power Distribution System	Maximum allowed Voltage Protection Rating (VPR) per Mode: Line to Line	Line to Ground	Line to Neutral	Neutral to Ground
120v 2W + ground	-	700	700	700
240v 2W + ground	-	1000	1000	1000
120/240v 3W + ground	1200	700	700	700
120/208v WYE 4W + ground	1200	700	700	700
277/480 WYE 4W + ground	1800	1200	1200	1200
277/480v WYE 4W + HRG*	1800	1200	1200	1200
347/600v WYE 4W + ground	4000	1800	1800	1800
240v DELTA 3W + ground**	1000	1000	-	-
240v DELTA 3W ***	1000	1000	-	-
480v DELTA 3W + ground**	1800	1800	-	-
480v DELTA 3W ***	1800	1800	-	-

*** - high resistance ground**
**** - corner grounded**
***** - ungrounded**

202) Several modes of protection are possible to minimize voltage differences between the individual conductors:

a) Line-to-Line (L-L) protection places the SPD between the current carrying conductors in a power system.
b) Line-to-Neutral (L-N) places the SPD between the current carrying conductors and the grounded conductor (neutral) in a power system.
c) Line-to-Ground (L-G) places the SPD between the current carrying conductors and the grounding conductor (ground) in a power system.
d) Neutral-to-Ground (N-G) places the SPD between the grounded conductor (neutral) and the grounding conductor (ground) in a power system.

203) SPDs at grounded service entrances shall be wired in a line-to-ground (L-G) or line-to-neutral (L-N) configuration. Other modes, line-to-line (L-L), or neutral-to-ground (N-G) shall be permitted at the service entrance. For services without a neutral, SPD elements shall be connected line-to-ground (L-G). Additional line-to-line (L-L) connections are also permitted.

Additional Facility Electrical System Surge Protection

204) Surge protection should be installed at all points where a service leaves a structure to supply another structure if the conductor runs are over 100 feet (30m).

205) Surge protection shall be permitted for installation at sub or branch panels and at the point of utilization (receptacle or signal termination point), also termed supplementary protection.

206) Optional SPDs for these purposes shall be rated as follows:

a) Branch panels or subpanels – SPDs, where installed, at branch panels or subpanels, should have an I_n rating of 10kA, 8/20 μs or greater per phase.
b) Point of utilization or supplementary protection – SPDs, where installed, shall have an I_n rating of 5kA, 8/20 μs or greater per phase.

207) Branch panels over 100 feet (30m) from the service entrance should have L-G or L-N and N-G modes of protection. Additionally, L-L protection is also permitted (although this is usually achieved by the L-N modes across two phases.)

Signal, Data, and Communication Surge Suppression

208) Surge protection shall be provided for all conductive signal, data, and communication lines when they enter a facility.

209) Surge protection shall be installed at all points where electronic system conductors leave a structure to supply another structure if conductor runs are over 100 feet (30m). Surge protective devices may be placed on both ends of external signal lines connecting pieces of equipment or facilities to protect against surges coupled into the wiring or caused by ground potential differences.

210) SPDs shall be listed for the protection of signal, data, or communication systems and shall have an I_{max} rating of at least 10kA, 8/20 μs or greater when installed at the entrance.

211) SPDs shall be selected taking into consideration aspects such as the frequency, bandwidth, and voltage. Losses (such as return loss, insertion loss, impedance mismatch, or other attenuation) introduced by the SPD must be within acceptable operating limits.

212) SPDs protecting communications systems shall be grounded with the exception of devices that perform their surge protection function through isolation . Grounding shall be accomplished in accordance with National Electrical Code (NFPA 70) Chapter 8. If this point of grounding is greater than 20 ft. (6m) away from the main electrical service grounding electrode, a supplementary ground reference point shall be installed at the SPD location. A supplementary ground reference shall consist of an equipotential ground bus bar, the structural steel building frame, or the ground reference at a secondary power distribution panel in compliance with NFPA 70, National Electrical Code and this document.

213) SPDs for data and signal line protection shall provide common mode protection with the exception of devices that perform their surge protection function through isolation.

214) Proprietary utility-owned communication equipment shall be provided with SPDs by the communication utility provider or the tenant communication utility. SPDs are not required for these systems when the service provider has made other provisions for lightning surge threats.

ELEVATED STORAGE STRUCTURES (SILOS)

215) Industrial and farm silos, storage tanks and other elevated storage structures are classified as standing alone if more than 6 ft. (2 m) away from the main building structure and not physically attached (**Figure 42**). Adjacent storage structures are 6 ft. (2 m) or less from the main building but not attached. Attached storage structures are physically connected to the main structure with, for example, a reinforced concrete ramp or covered passageway, regardless of distance from the main structure. For convenience, such elevated storage structures are hereafter termed “silos”.

216) Silo protection shall comply with the general requirements for the protection of structures (paragraphs **26 to 214**) along with the following requirements:

217) Silos standing alone need not be protected to obtain certification for the lightning protection system on another nearby structure. However, adjacent and attached silos must be protected, and the systems must be interconnected to the systems on the adjacent or attached structures for certification under the LPI program.

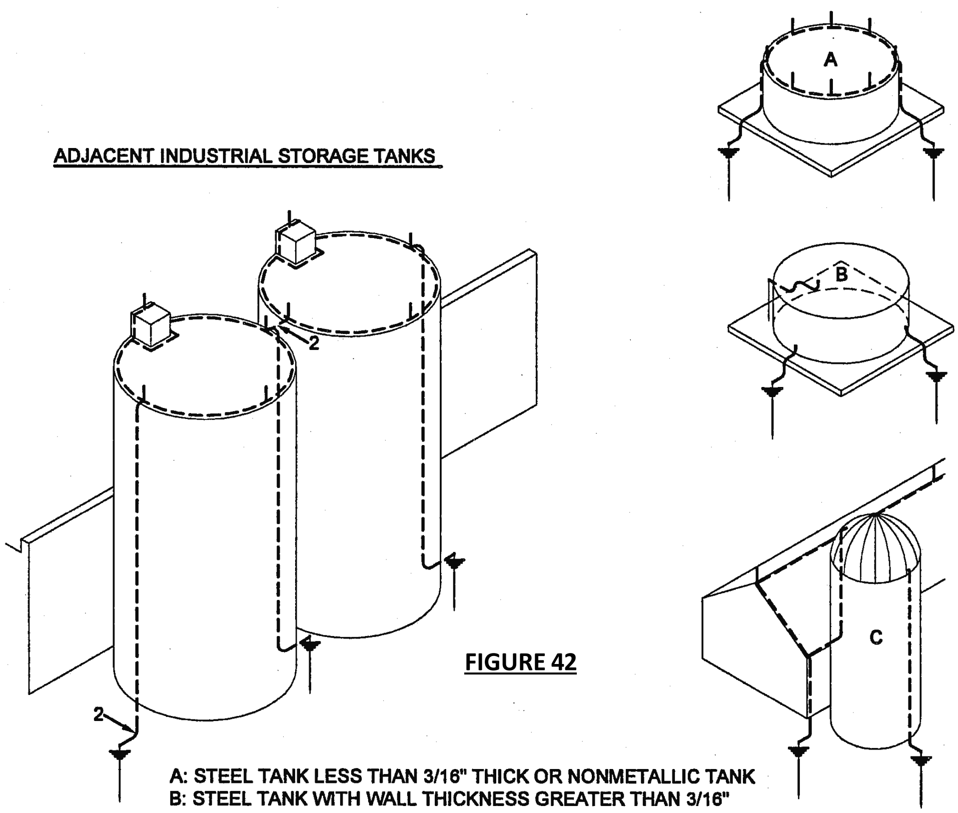


FIGURE 42

A: STEEL TANK LESS THAN 3/16" THICK OR NONMETALLIC TANK
B: STEEL TANK WITH WALL THICKNESS GREATER THAN 3/16"
C: NON-CONDUCTIVE SILO WITH CONTINUOUS METAL ROOF.

NOTE 1: INTERCONNECT WITH BUILDING SYSTEM
NOTE 2: SYSTEMS CAN BE INTERCONNECTED IF SPACING BETWEEN DOES NOT EXCEED 4'. IF FURTHER APART, SEPARATE DOWNLEADS MUST BE RUN.

218) Strike termination devices shall be equally spaced around the top edge of open, flat roofed, or gently sloping roofed silos in accordance with the requirements for ordinary structures. A main size conductor coursed around the silo near the top edge, forming a closed loop, shall interconnect the strike termination devices.

219) Peak or dome-roofed silos shall have at least one strike termination device at the peak, and additional strike termination devices as required to create a zone of protection for the silo perimeter.

220) Prefabricated all metal silo tops or domes at least 3/16 in. (4.8mm) thick and electrically continuous may serve as the strike termination device and the top circuit conductor. Two down conductors shall be securely bonded to the lower edge of a metal silo roof using bolt pressure fittings having a surface contact area not less than 8 sq. in. (5200 mm²).

221) Silos standing alone shall be equipped with not less than two down conductors for up to 200 ft. (67 m) circumference. One additional down conductor shall be added for each additional 100 ft. (33 m) of perimeter or fraction thereof.

222) Adjacent and attached silos need to be equipped with only one separate down conductor with a second connection to a down conductor on the adjacent structure. The distance from a strike termination device to a connection with the main conductor on the adjacent structure shall not exceed 16 ft. (4.9 m), and the top of the silo must be lower than the adjacent protected structure. If this distance exceeds 16 ft. (4.9 m), or if the top of the silo is higher than the adjacent structure, two down conductors are required for the silo with an interconnection to the system on the adjacent structure.

223) The lightning protection system on adjacent or attached silos shall be interconnected to the system installed on the adjacent or attached structure. This interconnection may be made at roof level, between downleads, or underground between system components. A system on a silo standing alone within 25 ft. (7.6 m) of a protected structure shall include an interconnection between the two systems.

224) Twin silos with separate roofs shall be equipped with not less than three down conductors, the center conductor may be a common downlead for both silos.

225) The grounding system for silos shall comply with the grounding requirements of paragraphs **125 – 144.**

226) Permanent metal parts of a silo, such as bands, chutes, ladders, conveyors, etc. may be used as substitutes for main conductors, if they are a minimum of 3/16 in. (4.8 mm) thick and electrically continuous. All metal bodies associated with a silo shall be interconnected or bonded with the lightning protection system in accordance with paragraphs **145 – 175**.

HEAVY DUTY STACKS

227) LPI Certification will be issued for installations on heavy-duty stacks if they are a stand-alone or separate structure, a minimum of 6 ft. (2 m) from any other building or structure. Stacks that protrude through buildings, or are attached to the side of a building will receive certification only as part of the protection for the entire structure **(Figure 43)**.

228) Heavy-duty stacks include large commercial and industrial stacks of brick, reinforced concrete, fiberglass and other non-conductive materials or metal construction, used for purposes of power generation, heat, process control, etc. A heavy-duty stack has a height greater than 75 ft. (23 m) above grade level and has a single cross-sectional flue area exceeding 500 sq. in. (0.3 m²) **(Figures 43 & 44)**. Similar structures that do not comply with this height or size requirement are termed chimneys and protected according to the general requirements.

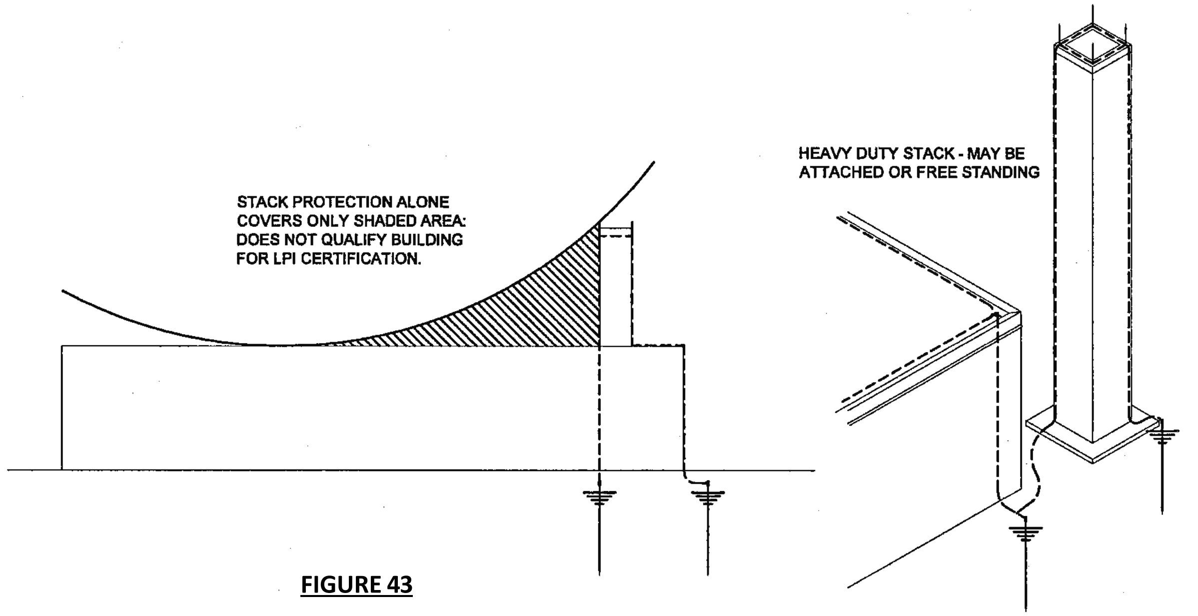


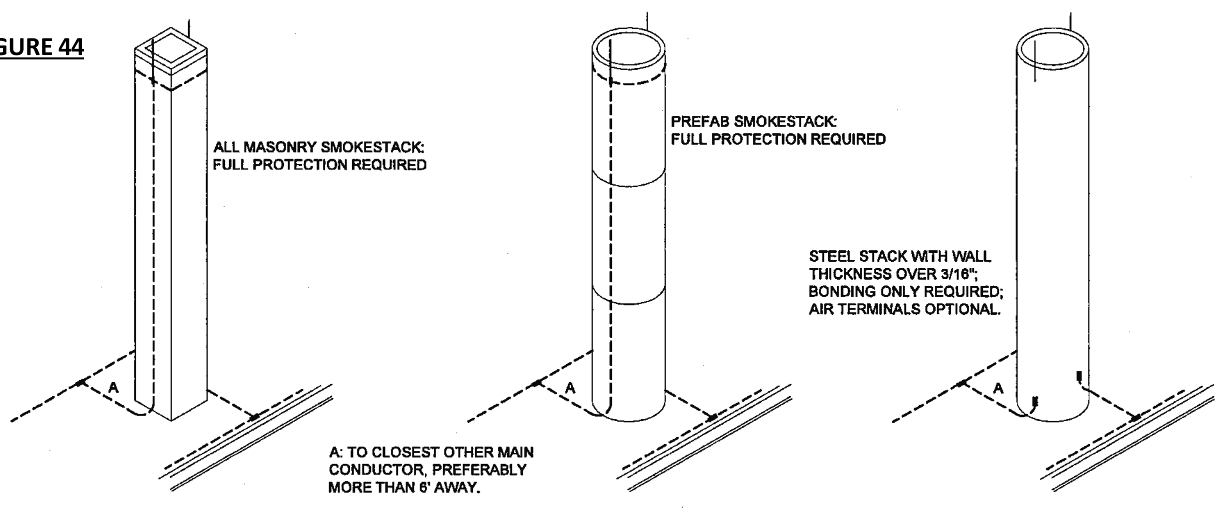
FIGURE 43

Stack Materials

229) All materials shall be Class II size in accordance with **TABLE 2** without the corrosion protection.

230) All copper and copper alloy materials used on the upper 25 ft. (7.6 m) of a heavy duty stack shall have a continuous covering of lead having a minimum thickness of 1/16 in. (1.6 mm) or approved corrosion-resistant material or coating for protection against corrosive gases or exhausts. Such system components shall include cable conductors, air terminals, connectors, bonding fittings, splicers, fasteners, and lay-in attachments. Aluminum components shall not be used for the protection of heavy-duty stacks.

FIGURE 44



231) Stacks that protrude through a roof and extend less than 25 ft. (7.6 m) above the roof shall have lead covering only on the materials above the roof level. Materials embedded in masonry need not be lead covered. System components run concealed from the exterior, such as downlead cables run concealed in the annular space below a roof deck, need not be provided with additional corrosion protection.

Stack Strike Termination Devices

232) Strike termination devices shall be uniformly distributed about the rim of cylindrical stacks at intervals not exceeding 8 ft. (2.4 m). Square or rectangular stacks shall have strike termination devices located not more than 24 in. (600 mm) from the corners and not more than 8 ft. (2.4 m) apart along the perimeter.

233) Air terminals shall be made of solid copper (lead covered), stainless steel, or Monel metal. Air terminals shall extend above the top of the stack not less than 18 in. (460 mm) nor more than 30 in. (760 mm) and shall be at least 5/8 in. (15 mm) diameter exclusive of corrosion protection. Stainless steel and Monel air terminals do not require additional corrosion protection. Top mounted air terminals shall not extend more than 18 in. (460 mm) above the surface they are mounted on. They shall not be mounted on chimney caps constructed of brick or on caps made of metal less than ¼-in. (6.4 mm) thick.

234) Side mounted air terminals shall be secured to the stack at not less than two locations. The anchored base can be considered one fastening, and the point shall be additionally fastened to the stack as near the top of the stack as practical, preferably anchored into the concrete or metal cap.

235) Stacks equipped with hoods of electrically continuous metal not less than 3/16 in. (4.8 mm) thick which provide a zone of protection for the lining and column shall not require additional strike termination devices. The hood shall serve as the strike termination device and as the top main size conductor. The hood shall be connected to a minimum of two down conductors using a securely fastened bonding plate of not less than 8 sq. in. (5200 mm^2).

Stack Conductors

236) The strike termination devices shall be connected together at their lower ends using a main size conductor to form a closed loop around the stack perimeter.

237) Not less than two down conductors shall be provided on opposite sides of the stack for up to 200 ft. (67 m) circumference as equally spaced as practical leading from the top circuit conductor or metal hood to the grounding system. One additional down conductor shall be added for each additional 100 ft. (33 m) of perimeter or fraction thereof.

238) Main size cable loop conductors at the following locations shall interconnect all down conductors, the structural reinforcing steel, a metal liner, and any other continuous grounded metallic system:

a) Within 12 feet (3.6 m) of the top of the stack
b) At equidistant intermediate intervals not to exceed 200 ft. (67 m) vertically
c) Within 12 feet (3.6 m) of grade level at the base of the stack or below grade

239) Down conductors shall be protected from physical damage and displacement for a minimum of 8 ft. (2.4 m) above finished grade as detailed in paragraph **118**.

240) Attachments and fasteners shall be of copper, bronze, or stainless steel. Acceptable masonry anchors or lay-in attachments shall anchor the fastener firmly to the stack. Fastener shanks (anchor size) shall be not less than ½-in. (13 mm) diameter for air terminals and 3/8-in. (10 mm) for conductors. All conductors shall be fastened at intervals not exceeding 4 ft. (1.2 m) vertically and 2 ft. (0.6 m) horizontally.

241) Joints or splices in conductors shall be as few as practical and constructed to provide 200 lbs. (890 N) of pullout strength. All connectors and clamps shall be approved bolt-pressure type and shall contact any cable for a minimum of 1-1/2 in. (38 mm) measured along the conductor length. Bonding devices for the interconnection of metal bodies shall provide a contact surface of at least 3 sq. in. (1940 mm^2). Exothermic connections may be used.

Stack Interconnection of Metal Bodies

242) All interior and exterior metal bodies that are not inherently bonded through construction, including ladders, elevators, breechings and liners, piping, or conduit, that exceed 60 ft. (18 m) in vertical height shall be interconnected to the lightning protection system at a minimum of their upper and lower extremities. When these metal bodies exceed 200 ft. (67 m) in vertical height, they shall also be bonded to the lightning protection system at intermediate levels at the location of mid-height main conductor loops interconnecting the downleads.

243) All ungrounded metal bodies located outside of the zone of protection described by the 150 ft. (45 m) radius sphere model on the exterior of the stack and protruding outward 18 in. (460 mm) or more from the column wall shall be considered to be subject to a direct strike and shall be bonded to the lightning protection system with main size conductor. Examples of such metal bodies are jib hoists and rest platforms.

244) Stacks constructed partly or entirely of reinforced concrete shall comply with the requirements of this section and, in addition, the reinforcing steel shall be made electrically continuous through construction. Standard tying or clipping of reinforcing steel is acceptable to insure continuity.

245) The continuous reinforcing steel shall be bonded to the lightning protection system within 12 ft. (3.6 m) of the top level, within 12 ft. (3.6 m) of grade level, and at any location of an intermediate ground loop interconnecting the downleads.

Stack Grounding

246) The downleads from the lightning protection system shall terminate below grade with a connection to a grounding electrode or system per paragraphs **125 – 144**. If there is a plant ground grid available, connection to the grid is preferable to interconnect all system grounds. Any grounding electrode installed for the lightning protection system shall be interconnected with all other system grounds.

247) If driven grounds are used as electrodes, they shall be the equivalent of a copperclad rod having a diameter of 5/8 in. (16 mm) and shall be at least 10 ft. (3 m) in length.

248) Metal stacks made of continuous metal more than 3/16 in. (4.8 mm) thick shall have two bonding connections from the base of the stack to the ground system. If the metal stack is less than 3/16 in. (4.8 mm) thick or is not electrically continuous, a full system of strike termination devices and conductors shall be installed.

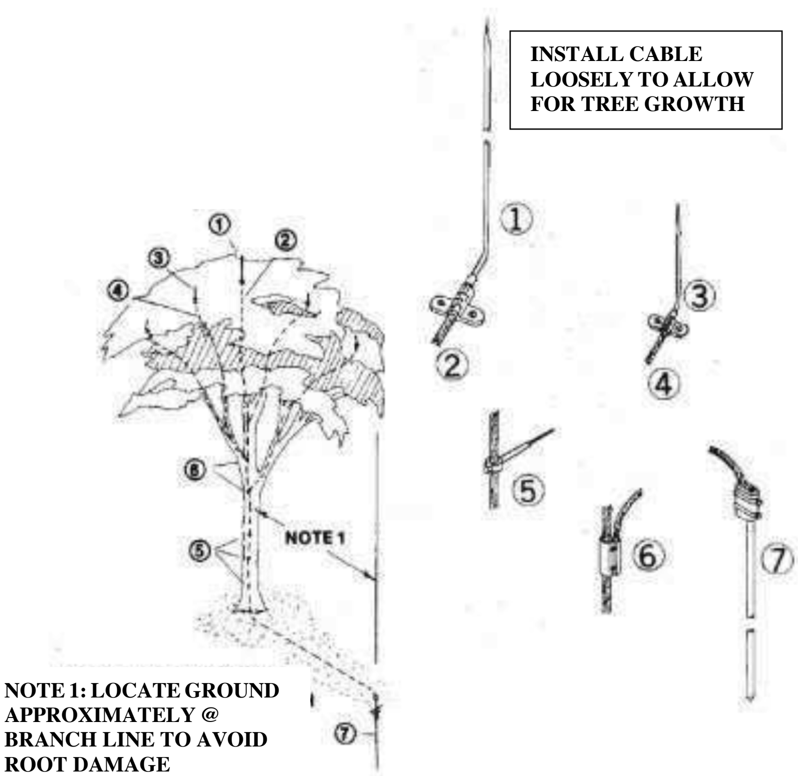
249) A metal water pipe system within 25 ft. (7.6 m) of the stack or metal breeching shall be interconnected using a main size conductor.

250) Metal guy wires and cables used to support a stack shall be grounded at their upper and lower extremities. Grade level anchors set in concrete require grounding electrodes or connection to the grounding system. Attachments to a building roof or other non-conductive surface require main size conductor runs to a lightning protection system component or grounding system connection.

TREE PROTECTION

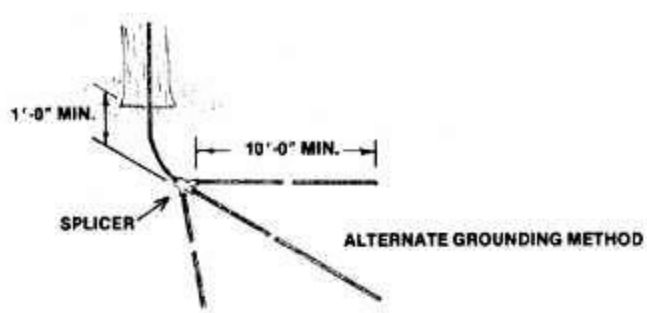
251) Lightning protection for trees should be considered by an owner because of historic or aesthetic value or when trees are adjacent to a residence or other structure. Trees do not afford protection for nearby buildings and a building equipped with a lightning protection system does not provide protection for nearby trees. It is recommended that trees, which have trunks, located within 10 ft. (3 m) of a protected building and branches extending to a height above the building be equipped with lightning protection. This will not only protect a tree but helps avoid the possibility of lightning striking the tree and side flashing or grounding to a nearby structure. A lightning strike to a tree may cause fire or superheating of the moisture of a tree resulting in splintering of the tree.

252) Adding protection to trees according to this section does not ensure the safety of people seeking shelter under a tree during a thunderstorm. Problems with side flashing, step potential, or touch potential can still exist near protected trees (see paragraphs **260 – 263**).



1. MAIN TRUNK AIR TERMINAL
2. MAIN SIZE CABLE CONDUCTOR
3. BRANCH AIR TERMINAL
4. BONDING SIZE CABLE CONDUCTOR
5. DRIVE TYPE CABLE FASTENER
6. SPLICER
7. GROUND ROD AND CLAMP

FIGURE 45



253) Strike termination devices should be located in a tree at the upper most extension of the main trunk and on outer peripheral branches in an umbrella effect. The height and type of tree will determine the total number of air terminals. For example, a pine or similar conical shaped tree may require only one primary standard air terminal to place it under a zone of protection. Other species of trees may require one or two primary standard air terminals and from three to eight secondary (miniature) air terminals on main branches **(See Figure 45)**. A rule of thumb for large trees would be to protect main branches extending upward at a 45° angle or greater from the trunk.

254) One main size tree cable conductor should be coursed from the primary air terminal at the top of the main trunk or main branch extension to ground. Secondary bonding conductors should be coursed from the miniature branch points, located as far out on the branches as possible, back to the primary conductor on the tree trunk. Conductors should conform to the minimum requirements for main or bonding conductors listed in **TABLES 2 and 4**. Conductors should be loosely coursed following the contour of the branches to allow for tree movement and future growth.

255) Conductors should be attached to the tree with drive type fasteners allowing for movement in the wind and tree growth without danger of damage. A distance between fasteners not exceeding 3 ft. (0.9 m) will maintain the conductors in position.

256) To provide low resistance grounding in a moist area and to avoid possible injury to tree roots, the down conductor should extend out away from the base of the tree in a shallow trench (8 inches (0.2 m) deep minimum) to a distance of 12 ft. (3 m) minimum from the tree trunk. A radial system of grounding would be established consisting of 12 ft. (3.6 m) of trenched conductor, or the conductor may terminate at a ground rod or plate as described in paragraphs **132 - 138**. Keep in mind that usually the underground spread of roots is equal in area to the spread of the branches above ground. Terminals installed outside the area of the root spread will minimize damage.

257) A grounding system on a protected building within 25 ft. (7.6 m) of a protected tree should include an interconnection between these two systems. If the tree or grounding system for the tree is within 25 ft. (7.6 m) of a metallic water pipe or deep well casing connection should be made between them.

258) When there are several major trees in a row requiring protection, the grounding electrodes of two or more trees may be interconnected by a trenched conductor coursed to the base of each intermediate tree. The down conductor of each intermediate tree may connect with the trenched interconnecting conductor. This practice avoids making independent groundings for each tree and provides common system grounding.

259) Aluminum materials should not be used for tree installations since aluminum will oxidize when in contact with moisture and wet decaying matter.

PROTECTION FOR OPEN SHELTERS

260) The lightning protection design concerns for open shelters include step potential, touch potential, and sideflash to persons or animals. Lightning protection systems should comply with the requirements of this standard for ordinary structures with additional considerations detailed below.

261) Step potential reduction is accomplished by establishing an electrically equipotential plane beneath the shelter. A ground grid should be installed below the structure, consisting of main size copper conductors spaced at 3 ft. (0.9 m) intervals. The grid perimeter and cross points should be interconnected. The grid under the shelter should extend to the full footprint of the structure perimeter, and may extend beyond when there is reasonable expectation that persons may stand near but outside the perimeter. A ground ring (paragraph **134**) should be installed encircling the structure, and radials (paragraph **135**) extending outward from the ground ring are recommended. All structural system down conductors, the grid, and any utility entrance grounds or metallic pipes entering the structure should be connected to the ground loop to create common potential. This is the best possible method for step potential reduction for any open structure whether the floor is concrete or dirt (no floor). In retrofit projects where it is not possible to site an under structure grid, the ground loop and radials should be required. Isolation techniques such as insulated floors, insulated mats, or other technologies to reduce the threat of step potential shall be permitted.

262) Measures to reduce sideflash within the structure should include providing additional down conductors from the strike termination system. The use of down conductors at each corner is recommended (4 for a square or rectangular structure) even when the perimeter is less than 400 feet. The splitting of the lightning along more current carrying paths reduces sideflash potential. Structures of irregular shape or with many sides should use no fewer than four downleads if it is impractical to install one at every corner. Downlead conductors should still be spaced a minimum of 25 ft. (7.6 m) apart where they enter the soil to serve the current splitting function, so very small footprint shelters may use less than 4. See the factor n in paragraph **167** of the bonding (sideflash) distance formula and note the improvement with additional down conductors (See also **TABLE 3**).

263) Touch potential reduction involves shielding down conductors to at least 8 ft. (2.4 m) in height above grade with electrically insulating material (PVC conduit or wood molding are examples) that is resistant to climatic conditions, impact, or accidental damage. Any other element of the lightning protection system that may be exposed to direct human or animal contact should be covered in like manner. Providing non-metallic shielding for the down conductors also reduces sideflash potential (See factor K_m in the formula in paragraph **167**).

264) When structural metallic framing is used as part of a shelter, it should be bonded to the ground loop. If the metallic framing is not a qualified substitute for main conductor downleads (3/16” (4.8 mm) thickness or greater), then it should be bonded to the system down conductors. When the structural metallic framework is properly interconnected to a grid and ground loop, electrical insulation is less critical for touch potentials due to the typically larger size of the structural metallic framework and its lower inductive reactance. Insulation of the metallic framework will further reduce the possibility of sideflash and touch potential hazards.

265) Open areas may be sheltered from direct lightning strikes by the use of masts and overhead ground wire systems placing the area in a zone of protection (See paragraphs **80 – 88**). The step potential, sideflash, and touch potential must be considered for the area included in the protected zone as detailed above for protection of open structures. In particular, the ground grid must be installed for the entire area considered protected by a mast, overhead line or any substitute like a properly grounded flag pole, light standard or protected tree. Without precautions to address step potential and touch potential, the hazard to persons in the vicinity of tall bodies more likely to be struck is potentially greater.

Lightning Protection Institute

The Lightning Protection Institute was founded in 1955, chartered as a not-for-profit corporation.

The aims and objectives of the Lightning Protection Institute are:

- Promote the use of ANSI accredited lightning protection systems to protect life and property
- Provide educational programs for installers, designers, and other interested parties such as, but not limited to, building owners, architects, engineers, and safety professionals
- Provide programs to participants in the lightning protection industry, including, but not limited to, certification of installers, designers, inspectors, and ANSI accredited lightning protection systems
- Initiate, support, and conduct lightning protection research and development in advancement of the industry

The Lightning Protection Institute has adopted the latest edition of the NFPA 780 Standard as its reference for this document. This document and any updates, or revisions to this document are intended as an installation guide for LPI System Certification.

Specification. Installation. Inspection.

LPI-175
2023 Edition

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