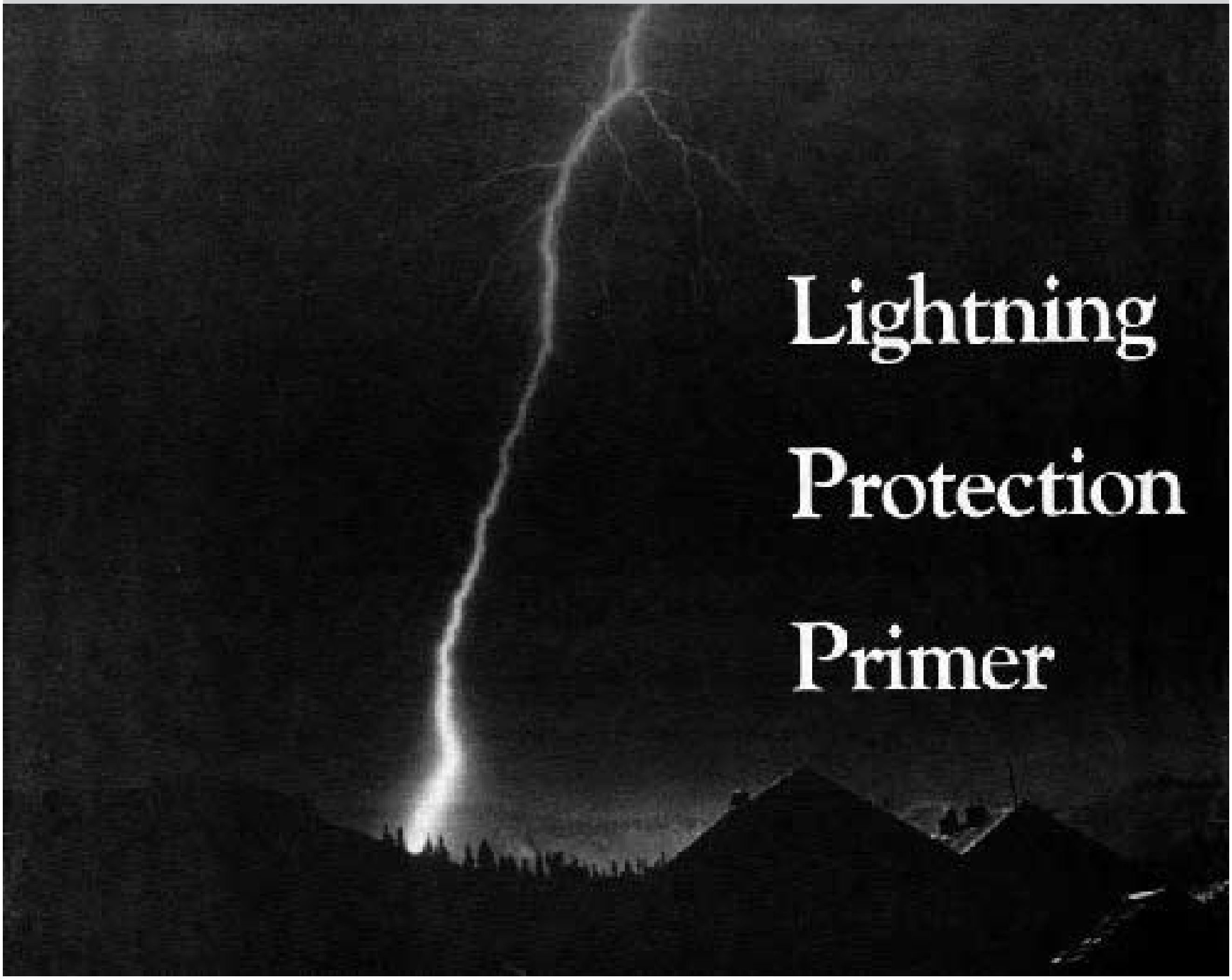
Lightning Protection Primer



Within this bright flash, positive and negative charges interact between sky and ground–generating up to 50 million volts and 50,000 degrees of heat.

Engineered lightning safety is gaining ground due to the rise of plastic plumbing and home electronics

by Marvin Frydenlund

Lightning protection used to be a high priority in lightning-prone parts of the country. But changes in insurance-premium credits and building techniques contributed to its demise. Now it is making a comeback due to new construction materials that make buildings vulnerable and to the increased use of electrical and electronic equipment in households.

PVC (polyvinyl chloride) is widely used today for piping. But when PVC is used today for metal soil stacks, underground waste lines, and cold-and hot-water pipes, only the electrical-wiring system in the building is left to conduct the lightning discharge downward to electrical ground.

Aside from this potential danger with non-metal piping, the contents of households have changed too. Microwave equipment, VCRs, and home computers can be knocked out by lightning currents conducted over power lines. Sometimes, a nearby lightning discharge can cause a damaging electrical surge simply by induction through the air.

Whenever you substitute plastic piping for metal or use electronic devices, you increase a building's vulnerability to lightning currents. This just adds to the risk any structure naturally faces in a lightning-prone area.

For the builder, this situation presents both opportunities and responsibilities. During construction, the builder has the opportunity to offer the customer protection against lightning. A protection system generally costs the least during construction, and this is also when the system can be largely concealed from view and weather (see Figure 1). It is the builder's responsibility to make sure that the lightning-protection system is effective and will remain so through the years.

Accordingly, you should know what lightning is and how it behaves. You should also know something about a protection system's design and installation.

What Is Lightning?

Lightning is a gigantic electric arc, a discharge of current between two oppositely charged electrical fields. The average lightning flash consists of three sequences of exchanges between negative charges, originating in the air, and positive charges, originating from high points – a tree or building – on the ground.

When this sequence of exchanges begins, negatively charged "leader" strokes – streams of negative charges – reach down to the ground in 150-foot leaps. Positively-charged strokes, in

Figure 1. *During construction, a lightning-protection system can be concealed from view and weather. The built-in system on this house shows only the 10-inch "air terminals" along the house's ridge.*

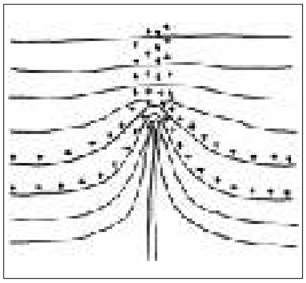


Figure 2. *When a pointed objection – part of a building or a tree – protrudes upward, a positive charge gathers around the tip of the object.*

turn, stream up to the sky. The current that flows during each stroke can range from a few thousand amperes to more than 100,000 amperes, with a potential of a million to over 50 million volts. This exchange of positive and negative charges, stroking back and forth in very rapid succession, is what we call lightning. Lightning flashes vary in length from a half mile to as much as five or six miles.

Lightning strikes along a path of "ionized" or electrically charged air. As lightning rapidly travels along this path, it generates heat up to 50,000∞F. This heat explodes air molecules, and thunder is the noise of the exploding air.

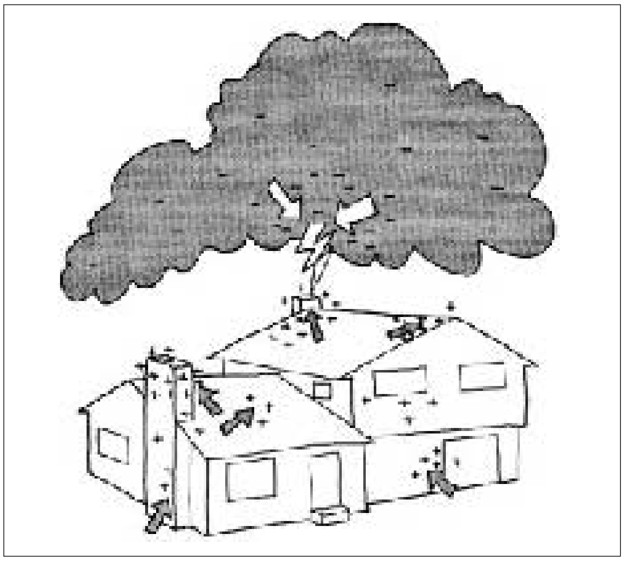


Figure 3. *If a negatively charged cloud comes within 150 feet above a house, positively charged "streamers" flow upward off the building. Lightning may result.*

Lightning can exert a tremendous mechanical force as it strikes. This force is an outward thrust, a blast effect. The mechanical force exerted by a large-magnitude discharge can severely damage a building.

Lightning causes fire too. A lightning fire is the result of a multiple-stroke flash that contains at least one stroke where current flows for a long period. This sustained flow of current transfers enough heat to ignite wood or asphalt shingles, framing, and other building materials.

Although lightning flows to the earth in a millionth of a second, it can cause severe structural damage, even death, unless the buildings struck are equipped to conduct it safely from roof to ground. This requires an effective lightning-protection system – one that meets or exceeds the codes and standards determined by the Lightning Protection Institute (LPI).

Lightning Protection Principles

It is important to understand four basic principles of lightning.

First, when a pointed object – such as a building or a flag pole – protrudes upward, it distorts the natural electric field. This distortion causes a positive charge to gather and intensify around the tip of the object (see Figure 2).

Second, all sharp objects that can conduct electricity will emit such positive streamers when a large negatively charged mass passes overhead.

Third, when cloud banks encounter one another, the heat transfer or "convection" of this movement intensifies the electrical field and sets the stage for a discharge. As the negative leader stroke approaches a point about 150 feet or so above a house (or other grounded object), positive-charged streamers strain upward off the building's corners, its chimneys, and other roof-top objects (see Figure 3). This distance of 150 feet is the most attractive range for lightning. When a leader is 150 feet away, the air can no longer act as a resistor. The sequence of leader stroke and return stroke begin and lightning results.

Where the lightning discharges to the building – the "strike point" – varies and is determined by the relative height and location of the various sharp objects.

It is important to remember this practical limit of about 150 feet. That's the average flash's "striking distance," and it is used in lightning protection standards to determine the locations of air terminals. This striking distance is also used to determine the amount of protection a high roof will provide for a lower roof (see Figure 4).

The fourth and final principle is that lightning will follow a low-resistance path, and if the path is sufficiently conductive, the lightning will be confined within that channel. However, only lightning currents of small electrical magnitude will confine themselves to a single conductor.

Protection System Components

There are five sub-systems within a proper protection system. I've listed critical points for each. The sub-systems are listed in the order a lightning discharge would encounter them.

1. Roof System. Air terminals – small vertical rods of metal – should extend a minimum of 10 inches above protected objects (Figure 5). They should be placed at 20-foot intervals on high points along the roof. If the roads are more than 24 inches high, this interval increases to 25 feet. Rods should also be placed along flat-roof edges, within 2 feet of corners (gable ends and other sharp building features), and at 50-foot grid spacings in mid-roof areas. Special braided conductors should interconnect all air terminals. On flat roofs, conductors should form a closed loop that is then "downconducted" or connected to ground. On large roofs, cables should be run at 150-foot intervals across the pattern to provide two horizontal or downward paths from each air terminal (except code-permitted "dead ends").

2.Conductor System. Conductors cables used to connect the air terminals to each other – are sized by weight according to the height of the protected structure. Their size may change depending on whether steel building columns are used in lieu of downconductors. For Class-I structures (75 feet high or less), you must use copper conductors that weigh at least 187.5 pounds per 1,000 feet, or aluminum conductors that weigh 90 pounds per 1,000 feet. For Class-II structures (structures over 75 feet high or those whose steel framing is used in lieu of downconductors), conductors must weight at least 375 pounds per 1,000 feet for copper and 190 pounds per 1,000 feet for aluminum.

All buildings with perimeters up to 250 feet require two downconductors or diagonally opposite corners. An additional downconductor is required for each additional 100 feet of perimeter. Downconductors are best located at roof corners, where lightning strikes most often (see Figure 6).

When steel columns are used as downconductors, you can reduce the spacing of grounds and downconductors to every other perimeter column or 60 feet, whichever is greater.

3. Grounding System. You must ground every downconductor with a grounding-system connection (see Figure 7). You must also interconnect the lightning-protection grounding system with utility grounds. The type and configuration of a grounding system depends on the "resistivity," moisture content and penetrability of the soil, and the sensitivity of the building's contents. Electronic equipment or sensitive substances (like explosives or unstable gasses) are vulnerable to heightened electric fields during a lightning discharge to the building.

There are techniques for lowering ground resistance. All of them aim to expand the area for dissipation or to increase its conductivity. For instance, you may have to increase the moisture content of the soil you are grounding to, or you may have to add clay to rocky soil.

Aside from these special considerations, here are standard grounding requirements

• In moist, easily penetrated soil like clay loam, drive individual 8-foot copper, copper-clad, or stainless-steel

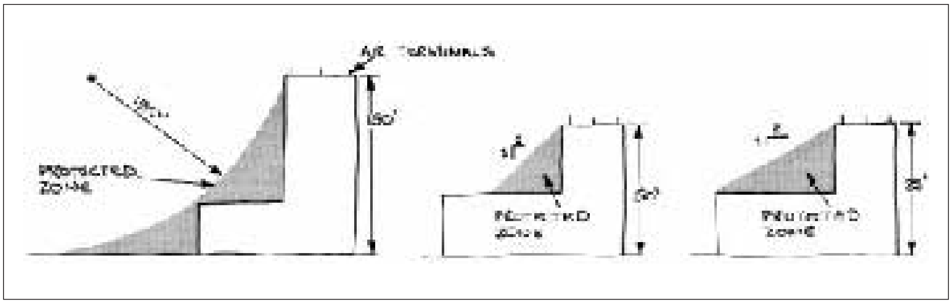


Figure 4. *For buildings over 50 feet high, a theoretical "rolling ball" with a 150-foot radius (left) determines what area is protected by air terminals on a higher roof. A building section from 25 to 50 feet high (center) offers a one-to-one protection zone for a lower roof. For buildings less than 25-feet high (right), the lower roof is protected if it is within a two-to-one diagonal line as shown.*

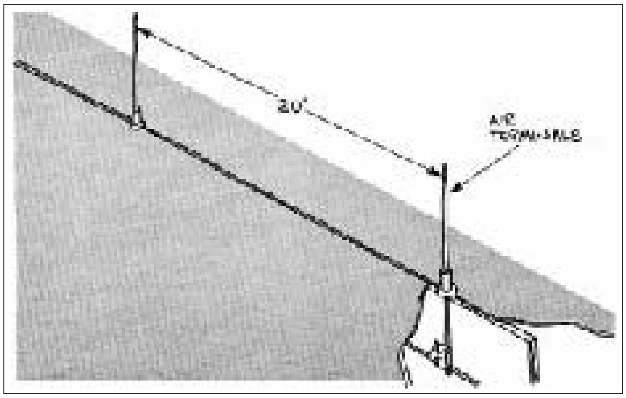


Figure 5. *Air terminals – small vertical rods of metal – should extend a minimum of 10 inches above protected objects and be placed at 20-foot intervals on high points of the roof, along flat roof edges, and within 2 feet of corners.*

ground rods to 10-foot depths. Class-I buildings require 1/2-inch-diameter rods, Class-II structures call for 5/8-inch-diameter rods.

- Sandy or gravelly soil may require additional ground rods. These should be driven to 10-foot depths, placed in-line or triangularly.
- Where bedrock near the surface prohibits driven rods, lay copper conductors in 12-foot-long, minimum 1-foot-deep trenches, extending out from the wall in clay soil. In sandy or gravely soil, make the trenches 24 feet long.
- In shallow soil, a Class-I copper or a large encircling "counter-poise" cable should be laid in trenches, rock crevices, or directly on the bedrock to completely circle the building.
- In extreme cases, extra metal – preferably copper or, alternatively, stainless steel – can be placed in hollows or depressions to enhance grounding.

4. Bonding System. Bonding is the process of protecting a conductive object by attaching it to ground. Metal objects such as roof-top vents, stacks, and below-roof air-handling units can contribute to lightning hazards because they provide an easy path to ground for lightning currents. Therefore, such metal bodies need to be bonded to the lightning-protection system. Objects like vents and stacks are called "primary metal bodies." Objects like below-roof air-handling units are called "secondary metal bodies."

Primary metal bodies – objects located at or above roof level and not within the protective zone of an air terminal – may be struck directly and must therefore be bonded with a conductor (see Figure 8). If such an object has a metal skin less than 3/16 inch thick, it can be punctured by lightning's tremendous heat and must be fitted with an air terminal.

A secondary metal object – one located below the roof and ungrounded – is generally safe from a direct lightning discharge. It is a hazard only if it contributes to a short-circuit between lightning conductors and/or grounded-conductive bodies.

Whether or not you should bond a secondary object depends on a number of factors. First is ground resistance. Second is induction, which is related to building height and the amount of interconnection between grounded conductors present at a certain height. For instance, a disproportionately well-grounded section at one end of a building may require the bonding of a distant secondary object that would otherwise be safely left unbonded. Finally, you must consider the possibility of a side-flash, which is current that jumps from one object to another after the initial discharge. Sometimes a secondary metal body acts as a short circuit that contributes to a sideflash. To determine whether primary and secondary bondings are needed, refer to the current edition of the LPI's Installation Standard LPI-175. Though there are rarely any local codes for lightning protection, this serves as the nationwide standard. It also corresponds with the National Fire Protection Association's guidelines for lightning protection.

5. Surge-Suppression System. After electrical power was introduced as a commodity in the 19th century, gas or air-gap type arresters were introduced. These arresters intercept and shunt to ground damaging waves of current induced into power lines by distant lightning strikes. Such arresters are recommended as integral parts of modern lightning-protection systems.

Many of today's electronic devices and systems may be sensitive even to air-borne transient voltage charges from distant lightning flashes. To protect against these, you need extremely fast-response wave-shaping and suppression devices. Such devices are now standard in total lightning-protection systems.

The LPI's Standard of Practice LPI-175, calls for surge suppression equipment where services enter the structure. The LPI cites the IEEE/ANSI Standard C62.41 as the document to use. The telephone service, cable-TV service, and all TV or radio antennas require surge suppressors in order for a lightning-protection system to be certified by the Institute.

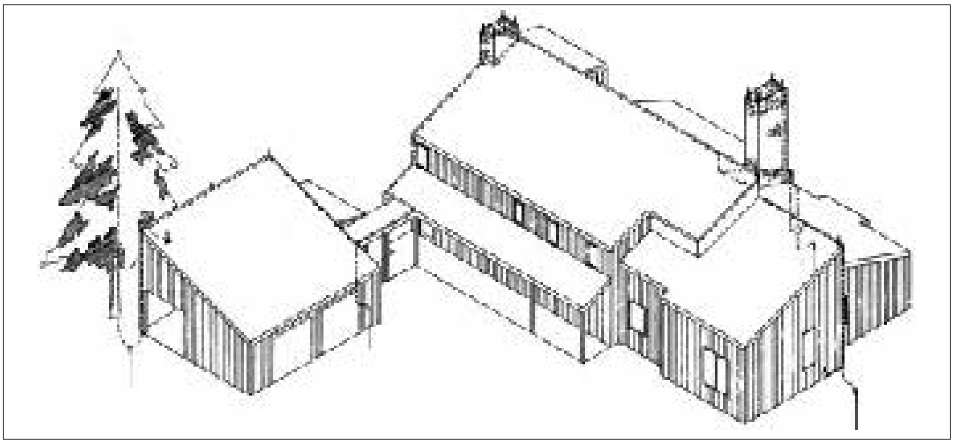


Figure 6. *Two downconductors at diagonally opposite corners are required for all buildings with perimeters up to 250 feet They are best located at roof corners, because corners are most often struck.*

System Certification

The biggest problem confronted by the Institute in recent history is quality control. While once maintained through a small group of lightning-protection specialists nationwide, it has since become an industry concern.

LPI has addressed the problem by establishing the "LPI Certified System" program for residential and other light construction. The program requires supervision by "LPI Certified Master Installers" who must go over the plans and the installation with the protected building's owner or a designated representative of the owner, such as the builder or architect.

When all requirements dictated by the Installation Standard LPI-175 are met, LPI issues a certificate. In addition, the installer can purchase a brass plate to attach to the building, to certify that it is protected.

Installation Costs

Lightning protection is labor-intensive and installation costs depend to a large degree on the building and roof shape, height, and soil conditions. Where there is high bedrock and sandy or gravely soil, for example, costs are higher than where ground rods can be driven into moist clay or loamy soil.

Labor costs also depend on prevailing rates, which may be considerably higher in northern-metropolitan areas than southern-rural areas, for example.

In New England, LPI-certified master installers reported these costs for residential installations.

- 1,000 square-foot single-story ranch with a straight roof: $900.00 - $1,200.
- 2,000 square-foot L-shaped ranch: $1,200 - $1,500.
- 3,000 square-foot two-story house: $1,500 - $2,000.

As modern building techniques and the use of sensitive electronic equipment become more popular, it is even more important for builders to know about lightning-protection systems and how they work. An informed builder has the opportunity to offer lightning-protection systems and the obligation to see that they are properly installed.

For more information…

The Lightning Protection Institute's *Installation Standard LPI-175* is available for $13 from the Lightning Protection Institute, P.O. Box 1039, Woodstock, IL 60098-1039; 815/ 337/0277. ■

Marvin M. Frydenlund is director of the Lightning Protection Institute, Woodstock, Ill.

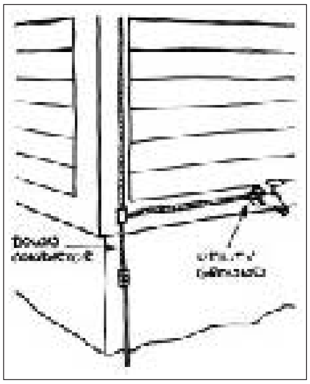


Figure 7. *Each downconductor needs a grounding connection, which must be interconnected with utility grounds.*

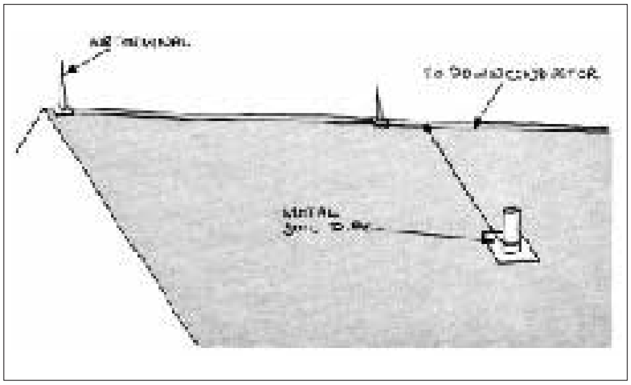


Figure 8. *Unprotected metal objects on the roof, such as soil pipes and vents, may be struck directly and must be wired to a downconductor.*