

Integrating a Lightning Protection System into a Roof System

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KEY WORDS

Air terminals, Franklin rod system, lightning protection system, lightning rods, roof system, wind performance.

ABSTRACT

Lightning protection systems are commonly installed on roofs in locations prone to frequent lightning strikes. A roofing contractor typically does not install a lightning protection system. Rather, a separate contractor installs these items after a roof system has been installed. When not adequately integrated into a roof system, a lightning protection system can damage the roof, and/or become displaced and no longer be capable of providing lightning protection.

Manufacturers of lightning protection system components, roofing material manufacturers and roof system designers typically provide vague or inadequate details for securing a lightning protection system to a roof and/or protection of a roof from damage by the lightning protection system.

This paper provides an overview of a typical lightning protection system; discusses currently available design guidance for integrating a lightning protection system into a roof system; documents examples of roof damage caused by inadequate protection from and securement of a lightning protection system; discusses issues pertaining to integration of a lightning protection system into a roof system; and provides recommendations pertaining to design, specification and installation of lightning protection systems for new construction and reroofing projects.

AUTHOR BIOGRAPHY

Mr. Smith is president of TlSmith Consulting Inc. He specializes in architectural technology and research, with an emphasis on roof systems. Smith is a licensed architect and a registered roof consultant. His interest in roofing began in 1974. From 1988 to 1998, he was the research director for the National Roofing Contractors Association (NRCA). Prior to that time, he was in private practice in California and Alaska. He has designed roofs from the arctic to the tropics.

Smith has strong theoretical understanding and practical experience with many materials, systems and issues associated with roof performance. He is an internationally recognized expert on roofing technology.

INTRODUCTION

Lightning can strike anywhere in the world. In the United States, lightning storms occur as few as five times per year in some areas to as many as 100 times a year in others. [1] Lightning is the visible discharge of static electricity within a cloud, between clouds, or between the earth and a cloud. [1]

The most common lightning protection system is the traditional "Franklin rod" system, which is based on the lightning rod that Benjamin Franklin invented in 1752. This type of system does not prevent lightning from striking a building; rather, it provides a means for controlling a lightning strike and preventing damage to nonconducting parts of a building by providing a low-resistance path for the discharge of the lightning energy. [1]

The Franklin rod system consists of air terminals (commonly referred to as *lightning rods*) located around the perimeter of a roof (and also in the field of the roof on large roof areas) and along ridges of steep-slope roofs. The air terminals are connected together with either copper or aluminum conductors (*cables*). Metal bodies, such as mechanical equipment and roof hatches, often need to be "bonded" to the lightning protection system by attaching secondary conductors to the metal body and connecting the secondary conductor to the primary conductors that interconnect the air terminals. There are also instances where the metal body needs to be protected by air terminals and primary conductors that form part of the lightning protection system.

The conductors are attached to the roof and/or parapet with various types of conductor connectors (*clips*), spaced at a maximum of 3 feet (915 mm) on center (per Reference 2). The roof conductors are connected to through-roof or through-wall connectors, which are specially made bolted assemblies. Down conductors are connected to the interior side of the through-roof or through-wall connectors and then connected to ground rods.

To protect electrical equipment, surge arresters are installed at the electrical and telephone service entrance panels. Surge arresters are also installed on lead-in wires of antenna and satellite dishes. Transient voltage surge suppressors are installed in receptacles in which computers or other electronic equipment are connected.

Until recently, air terminals had sharp, pointed tips. However, because research has shown that blunt tips (see Figure 1) are better lightning strike receptors than conventional sharp-tipped terminals, blunt-tipped terminals are becoming more commonplace. [3] In addition to their strike receptor properties, blunt-tipped terminals offer a safety advantage to people on the roof. If someone on the roof were to accidentally fall or step on a terminal, impalement is less likely with a blunt-tipped terminal. Additional impalement protection may be provided by blunt-tipped terminals that have spring-mounted bases. Spring-mounted terminals may be advantageous on roofs that experience enough snow accumulation to cover the terminals. If a blunt-tipped, spring-mounted terminal is stepped on, the possibility of impalement should be

reduced. Blunt tips are available for retrofitting existing sharp-tipped terminals (see Figure 2).

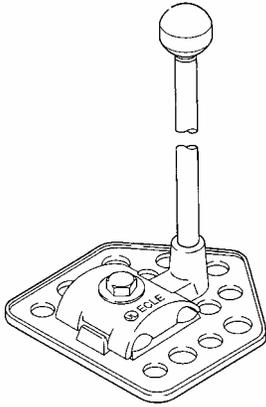


Figure 1. *Blunt-tipped air terminal.*

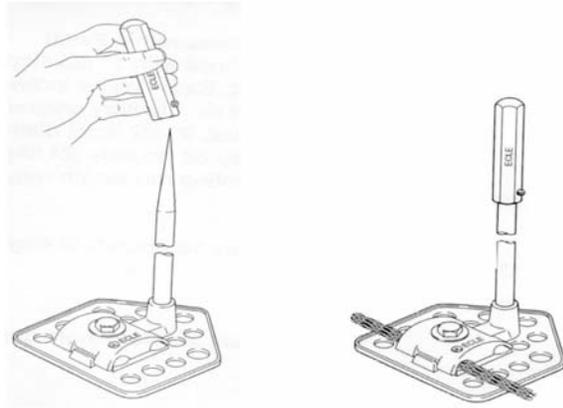


Figure 2. *Retrofitting an existing sharp-tipped air terminal with a blunt tip. (Figure 1 and 2 courtesy of East Coast Lightning Equipment Inc.)*

Underwriters Laboratories Inc. (UL) has a Master Label Program for lightning protection system installations. The program requires the use of UL Listed lightning protection components which undergo periodic factory testing and inspection.

References 2 and 4 through 6 pertain to traditional Franklin rod systems.

DESIGN AND INSTALLATION GUIDANCE

Lightning protection equipment manufacturers and references 2 and 4 through 6 provide information regarding the design and installation of a lightning protection system, with respect to dissipation of lightning energy. However, very little guidance pertaining to integration of a lightning protection system into a roof system is given. Reference 2 advises that copper lightning protection materials are not to be used on aluminum roofing materials, and aluminum lightning protection materials are not to be used on copper roofing materials. This requirement pertains to separation of dissimilar materials to avoid corrosion problems. Reference 2 also specifies the maximum spacing of conductor connectors, and it notes that galvanized or plated steel nails, screws or bolts are not acceptable for securing conductor connectors or air terminal bases.

A guide specification by a major lightning protection equipment manufacturer states, "The roofing contractor will be responsible for sealing and flashing all lightning protection roof penetrations as per the roof manufacturer's recommendations." It also states, "Lightning protection penetrations and/or attachment procedures should be addressed in the roofing section of the specifications."

When the author queried the manufacturer about specific recommendations for attachment of the air terminal bases and conductor clips to the roof membrane, the manufacturer advised that when attaching with adhesive, the adhesive should be compatible with the roof membrane. Furthermore, the equipment manufacturer stated that most roof membrane manufacturers have specifications pertaining to attachment of the lightning protection equipment, and that a lightning protection contractor can track down the criteria for a specific type of roof system.

Another lightning protection equipment manufacturer's specification states that air terminal bases shall be "fastened to the structure in accordance with code requirements." However, there are no code requirements that specifically address attachment of air terminal bases. When the author queried the manufacturer, the manufacturer's representative stated that for adhesive attachment, contact the roof membrane manufacturer for adhesive recommendations. This equipment manufacturer offers air terminal bases and conductor connectors that can be bolted to some metal standing-seam panel systems.

UL 96A (Reference 5) states that air terminals shall be secured to membrane roofs with an adhesive that is compatible with the roofing material, or if prescribed by the membrane manufacturer, shall be secured to "concrete blocks" (provided they are not porous). The conductors are to be secured by looping strips of the roof membrane material around the conductors and securing the strips to the roof with a compatible adhesive (similar to Figure 3). Or if prescribed by the membrane manufacturer, the conductors should be secured to "nonporous bricks."



Figure 3. *The conductors on this PVC membrane roof were attached with narrow strips of PVC sheet that were placed over the conductors and then welded to the roof membrane. In this area of the roof, the attachment strips were peeled off the roof membrane (the plane of failure occurred within the membrane, wherein the PVC matrix separated from the reinforcement).*

Many manufacturers of roofing materials also provide some guidance pertaining to the interface between the roof membrane and lightning protection system. Some examples of membrane manufacturers' recommended details are as follows:

- EPDM membrane manufacturer: A sufficient number of conductor connectors must be installed to "assure" the conductor does not contact the membrane. If the conductor contacts the membrane, install a strip of batten cover material under the conductor. For mechanically attached systems, place the conductor parallel and within 8 inches (200 mm) of the batten strip. Where the conductor falls between or is perpendicular to batten strips, install an additional batten and cover-strip under the conductor. The detail shows splice adhesive on the membrane and the air terminal base sitting in pourable sealer. The detail notes that the manufacturer "assumes no responsibility for attachment of lightning rods or damage to the roof system because of failure or detachment."
- PVC membrane manufacturer: To anchor the conductor, half the unspecified length of a minimum 2 inch (50-mm) wide strip of roof membrane material is welded to the membrane. The conductor is then placed over the strip, and the strip is folded over the conductor and welded to the previously welded portion of the strip. The strips are to be installed 12 inches (300 mm) on center. To anchor the air terminal, a pad of membrane material is heat-welded to the membrane. Then, the air terminal is placed on the membrane, and a strap (of unspecified length and width) of roof membrane material is placed over the base and welded to the pad.

The manufacturer notes that the conductor shall be "cleaned free of asphalt contamination" prior to installation. If it cannot be cleaned, a continuous layer of flashing material is to be located under the conductor and heat-welded in place.

- SBS-modified bitumen membrane manufacturer: Install a pad of cap sheet (3 inches [75 mm] wider in all directions than the air terminal base or conductor connector) in hot asphalt, asphalt roof cement or by using a torch. Attach air terminals and conductor connectors in asphalt roof cement. Figure 4 illustrates a similar detail.



Figure 4. A pad of cap-sheet material was adhered to the mineral-surfaced membrane. The conductor was set in and covered with sealant.

On aggregate-surfaced roofs, install cap-sheet pads prior to application of final surfacing. Run final surfacing up to the edge of the pad. If surfacing has been applied, spud off the aggregate and prime with asphalt primer prior to adhering the pad.

- SBS-modified bitumen membrane manufacturer: Set a minimum 9 inch by 9 inch (230-mm by 230-mm) pad of walkway material in asphalt roof cement over the roof membrane. Adhere the air terminals and conductor connectors per the lightning protection equipment manufacturer's requirements.
- Standing-seam metal panel manufacturer: Does not have a standard detail, but verbally recommended that adhesive not be used to attach air terminal bases or conductor connectors. Rather, it was recommended that a proprietary clip that is commonly used to attach various items to roof panels be used. The proprietary clip is anchored to the panel ribs and then somehow attached to the air terminal bases and conductor connectors.

- TPO membrane manufacturer: Offers two details. One detail specifies a 6-inch by 6-inch (150-mm x 150-mm) pad of membrane heat-welded, with the air terminals and conductor connectors sitting on the pad. The membrane manufacturer makes no recommendation regarding attachment of the air terminals and connectors to the pads. The second detail specifies a minimum 4-inch (100-mm) wide strip of roof membrane impaled over the air terminal and heat-welded. The detail does not specify the length of the strip, and it shows the air terminal resting directly on the membrane. To anchor the conductor, half the unspecified length of a minimum 2-inch (50-mm) wide strip of roof membrane material is welded to the membrane. The conductor is then placed over the strip, and the strip is folded over the conductor and welded to the previously welded portion of the strip.

Standard roof details produced by the Metal Building Manufacturers Association (MBMA), National Roofing Contractors Association (NRCA) and Spray Polyurethane Foam Alliance (SPFA) do not include details pertaining to integration of lightning protection systems into roof systems.

OBSERVED PROBLEMS

When not adequately integrated into a roof system, a lightning protection system can damage the roof, and/or become displaced and no longer be capable of providing lightning protection, as discussed below:

- Bitumen displacement: In hot climates, conductors resting directly on smooth- or mineral-surfaced built-up (BUR) or modified bituminous membranes can sink into the membrane, thereby displacing the bitumen above the reinforcement (see Figure 5). Bitumen displacement has the potential to shorten the service life of the membrane.



Figure 5. *This conductor occurred on a white cap sheet in Florida. The conductor had previously been located to the left where marked by the arrow. At the previous location, the conductor had sunk into the membrane, thereby displacing the bitumen above the reinforcement.*

- Roof surface abrasion. Conductors resting directly on the roof surface can abrade the roof surface. On metal roofs, abrasion can result in loss of the corrosion protection and subsequent corrosion-induced penetration of the metal. Loss of protective granules or wearing away of polymer matrices can shorten the roof's service life. Surface abrasion can be accelerated if the distance between conductor connectors is excessive due to lack of connectors (see Figure 6) or if a connector was not attached (see Figure 7) or becomes detached from the roof (see Figure 8). Accelerated abrasion can also occur on roofs located in areas prone to frequent or prolonged wind events that are sufficient to cause movement of the conductors between connector points.

Surface abrasion is typically not a problem when conductors bear on pavers or over aggregate surfacing.

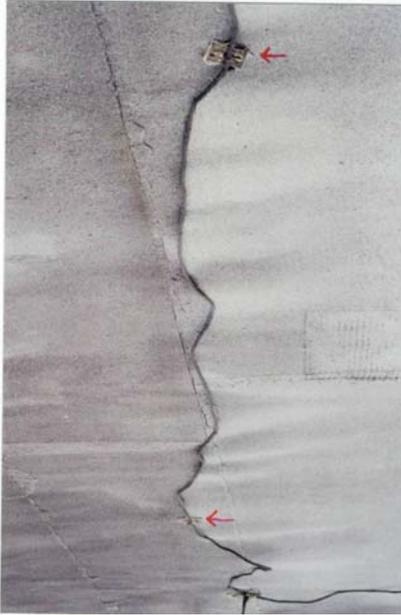


Figure 6. The spacing between these conductor connectors (shown by arrows near the top and bottom of the photo) greatly exceeded the 3 foot (915 mm) maximum requirement.



Figure 7. This is the upside-down base of an air terminal (the terminal rod is missing). The base had previously been adhered to a built-up membrane -- it had not been adequately cleaned and readhered to the new SPF roof.



Figure 8. *This conductor connector had been adhered in asphalt roof cement to an aggregate-surfaced BUR. Because the cement was applied to loose aggregate, the conductor could be easily moved.*

- Membrane puncture: When conductors rest directly on a roof surface, frayed conductor strands, protrusions from splice plates and bolts protruding from cross-run clips can puncture membranes (see Figures 9 through 11).



Figure 9. *Frayed conductor strands at a conductor splice. In this condition, the roof membrane is vulnerable to puncture.*



Figure 10. This conductor splice is upside down. One of the prongs of the splice plate was not clamped to the conductor -- the prong is resting on the roof membrane. As with the condition shown in Figure 5, the membrane is vulnerable to puncture by the frayed strands and splice prong.



Figure 11. The bolts through this cross-run clamp are resting on the roof membrane. A conductor connector occurs near the top of the photo. It was attached to the membrane with sealant.

Air terminals that become dislodged during wind storms can also puncture the membrane (see Figure 12).



Figure 12. This air terminal was dislodged and whipped around during a hurricane. The single-ply membrane was punctured by the sharp tip in several locations.

- Membrane tearing and blow-off: Conductors that become dislodged during wind storms can tear membranes. During prolonged high winds, repeated slashing of the membrane by loose conductors and puncturing by air terminals can result in lifting and peeling of the membrane (see Figures 13 and 14).

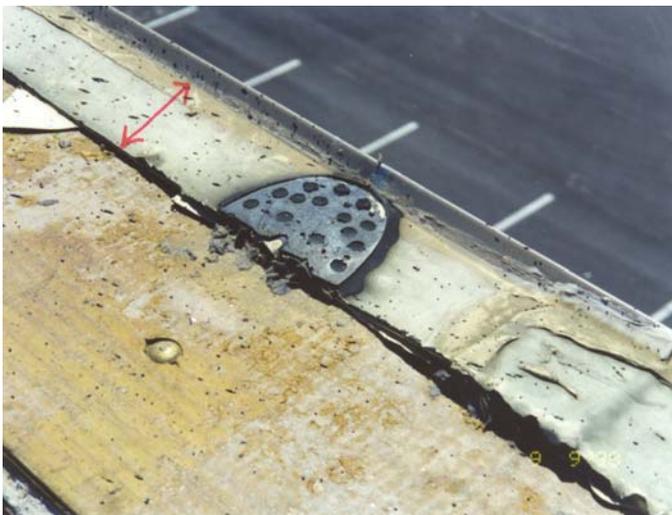


Figure 13. View of location where an air terminal base was adhered to an EPDM membrane. The arrows indicate the horizontal flange of the metal edge flashing. The conductor became dislodged during a hurricane. The loose conductor whipped and tore the membrane. The torn membrane was eventually lifted and peeled off the roof insulation. See Figure 14.

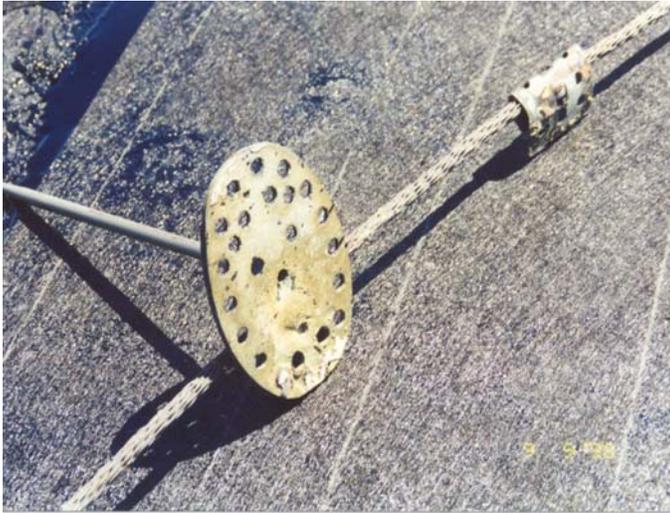


Figure 14. View of the underside of a dislodged air terminal. The failure plane was between the base plate and adhesive (i.e., an adhesive failure). See Figure 15.



Figure 15. In this area, the conductor pulled out from the conductor connector. The connector was adhered to the EPDM membrane.

- Loss of lightning protection system integrity: When air terminals are blown toward the center of the roof or blown off the roof, the building no longer has adequate lightning protection.

DISCUSSION

Integration of a lightning protection system into a roof system has received inadequate attention from both the lightning protection and roofing industries. The lightning protection industry in general provides very little guidance on integration issues. Many roofing material manufacturers provide some guidance, but often the guidance is inadequate or the manufacturer does not stand behind that guidance. In addition, some roofing manufacturers refer back to the equipment manufacturer, which results in a vacuum where neither party provides guidance.

Typically, there is a lack of coordination between the roof system and lightning protection system specifications, as well as a lack of detailed direction from the designer regarding issues pertaining to protection of the roof system from damage by the lightning protection system and adequate anchorage of the lightning protection system. These design issues are exacerbated by a lack of specific guidance for use by designers. Lack of coordination is particularly illustrated by those projects wherein a lightning protection system is installed without the roofing contractor being made aware of the work.

The bitumen displacement, roof surface abrasion and membrane puncture from frayed conductors and various types of connectors is easily mitigated by incorporation of a continuous strip of extra membrane material underneath the conductors, or in the case of metal roof systems, by adequate elevation of the conductor above the surface. However, to avoid wind-induced detachment of conductors, research needs to be conducted to further understand the loads induced on the conductors, which are then transferred to the connectors and air terminal bases. A test method needs to be developed to evaluate the strength and long-term effectiveness of the attachment.

RECOMMENDATIONS

- Standard details pertaining to the integration of a lightning protection system into a roof system should be developed by MBMA, NRCA and SPFA. In the interim, the following are recommended:
 - Provide a continuous strip of extra membrane material underneath the conductors, or in the case of metal roof systems, elevate the conductor above the surface.
 - In lieu of adhesive attachment, attach air terminal bases and conductors with strips of membrane. The width and length of the strips should be a function of the material properties of the strips, the strength of their attachment to the membrane and the design wind loads.

- At conductor splices, install a strip of membrane over the conductor near either side of the splice plate to minimize conductor movement and avoid the possibility of the conductors from becoming disconnected.
- For mechanically attached single-ply systems, it is recommended that conductors be placed near rows of fasteners (as mentioned in the discussion of the EPDM membrane manufacturer's details). This may require additional rows of fasteners to accommodate layout of the conductors. This should be addressed in the contract documents.
- Specify that when air terminals and conductor connectors are attached to the roof with strips of membrane the application of the strips be performed by the roofing contractor.
- Specify that penetrations through the roof (such as through-roof connectors) be flashed by the roofing contractor. In the author's opinion, fasteners through vertical faces of base flashings and copings should be permitted to be installed by the lightning protection contractor, but provisions for ensuring long-term watertightness of the fastener penetration should be specified by the designer. When attaching through copings, the designer should also evaluate thermal movement ramifications.
- Specify that blunt-tipped terminals be used. In addition to the advantages discussed previously, if an air terminal does become dislodged, it is less likely to cause damage if it has a blunt tip.
- Specify that a lightning protection contractor attend the preroofting conference.
- After completing the lightning protection system installation, it is recommended that the designer and/or roofing contractor inspect the roof. The purpose of the inspection is to look for membrane damage caused during installation of the lightning protection system and to visually attempt to assess whether the attachment/penetration details compromise the integrity of the roof system.
- When reroofing a building that has an existing lightning protection system:
 - Notify the building owner in writing that the system will be disconnected and nonfunctional during the reroofing work.
 - It is recommended that a lightning protection contractor remove the existing lightning protection system. (Note: Some roofing contractors also perform lightning protection system work.)
 - If the existing system is UL Master Labeled, the reinstallation must be performed by a contractor that is Listed by UL. (Note: Several roofing contractors are Listed for lightning protection system work.)

Master Labeled systems have a UL Mark, which is a tag that states that the lightning protection system is Listed by UL. The tag also provides the Master Label number. UL recommends that the tag be installed in close proximity to the installer's nameplate. It also can be determined if a building has a Master Label system by requesting UL to search its database.

Upon completion of the work, the Listed contractor must submit a request to UL for a Reconditioned Installation (sometimes called a Reconditioned Master Label). If the existing system is not UL Master Labeled, it is still recommended that the work be performed by a lightning protection contractor rather than the roofing contractor (unless the roofing contractor is knowledgeable and routinely provides lightning protection work).

- It is recommended that research be conducted to further understand the wind loads induced on the conductor connectors and air terminal bases, and that a test method be developed to evaluate the strength and long-term effectiveness of attachments. The test method should include provisions to evaluate dynamic loading and aging influences.
- It is recommended that UL consider expanding the scope of their Master Label Program by investigating the attachment (including its long-term integrity) and compatibility of the lightning protection components with different types of roof systems.

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