PDHonline Course E367 (2 PDH)

Designing to Lightning Standard, NFPA-780-2011

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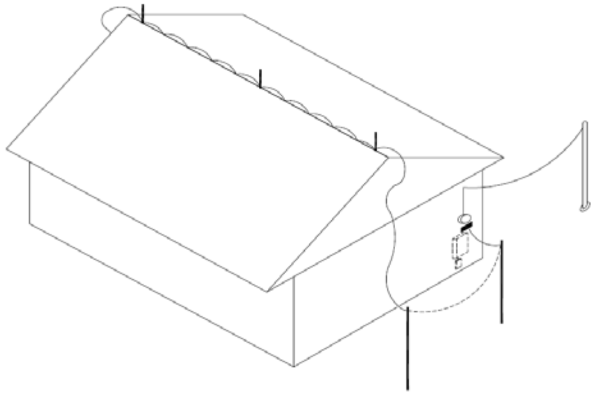
Designing to Lightning Standard, NFPA 780-2011

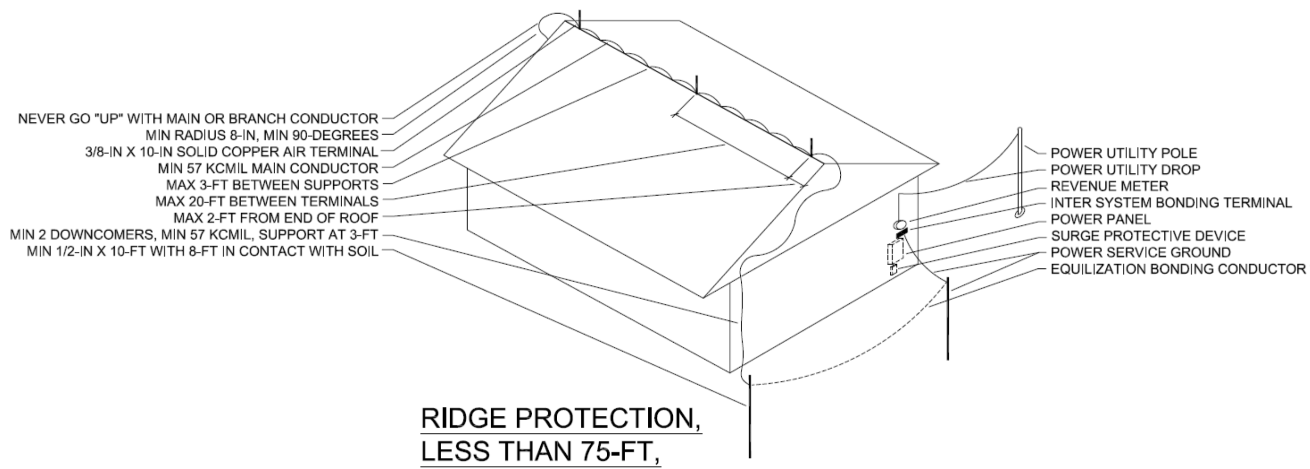
Thomas Mason, PE

The goal of this course is to learn how to design lightning protection systems. Fortunately, it is very easy. Please consider the following four examples:



RIDGE PROTECTION,
LESS THAN 75-FT,
FACE DOWNCOMER

This illustration is for orientation.



RIDGE PROTECTION,
LESS THAN 75-FT,
CORNER DOWNCOMER

This illustration identifies the components and introduces the basic rules for an NFPA 780-2011 lightning protection system. To the left are the air terminals, conductors, supports, and ground rods.

To the right are electric power service components which are essential to lightning protection. If they do not already exist, they must be added at the time of lightning rod installation. Note especially the intersystem bonding terminal and surge protective device (SPD). The equilization bonding conductor is part of the lightning protection system. IEEE says that you must place an additonal surge protective device at each critical, sensitive equipment, such as television, personal computer and microwave.

Why is this course organized this way and what is this box and who cares about IEEE ?
First, the box. This course contains *hard content*, as materials requirements, minimum and maximum dimensions, counts and spacing. It also contains *asides*, interesting useful information that is not central to complying with the Standard. Such asides will be placed in boxes like this, called *sidebars*, to offer the opportunity to skip them completely, if you wish. Now, regarding the examples. To convince you that this course provides immediate value in your job, we are giving examples of the product we promise to deliver. If you wanted to learn to do calculations or fill out requirements forms, this is the wrong course. We will refer to our examples to show how to apply the hard content. Regarding additional surge protective devices and IEEE recommendations. NFPA 780 requires a surge protective device (SPD) at the electric power service. It recommends additional downstream SPD at branch panels (commercial and industrial) and at critical sensitive equipment. The IEEE Emerald Book, dedicated to protecting equipment from surges, requires SPD at the critical, sensitive device and recommends upstream SPD at the branch panel and at the service. If your goal is to protect the structure and its contents, do put in more than the minimum SPD. (And that does not mean you should buy a premium single unit. It means you should buy multiple good units.)

Referring to the illustration, *Ridge Protection, Less than 75-ft, Corner Downcomer*, let us examine each detail. First, the title, *Ridge Protection*. We normally think of lightning as coming down from the sky, so the highest point on the structure has the most exposure. And, normally this is correct. The *ridge* is the line along the top of the roof, sticking up highest into the sky. This is correct placement only as first approximation.

There is a very common circumstance in which a storm front rapidly approaches. You can see the clouds coming at you. Sometimes, you can see an actual edge of the rain approach. What you don't see is the change is the electric charge coming at you. This is easily measurable, using high school physics laboratory equipment (gold leaf electrometer or electronic equivalent). As the charge front approaches, it is common to get a side flash to the gutters of a building or to the extended branches of a tree.

The intuitive approach would say, "That is only a few moments in a thunderstorm that can last for hours or days. It can't be much of a statistical hazard." Wrong. Just driving around, you can see the soot, damaged masonry and crispy branches, usually about midway up the tree, with a clear path to the main stalk and down to the trunk.

Ridge protection is the first line of defense, but perimeter protection is a close follow-up, and the normal protection for commercial and industrial structures.

Back to the illustration. *Less than 75-ft* distinguishes tall structures from short structures, within the definition by NFPA. There are three differences between *less than 75-ft* and *more than 75-ft*, as follows:

NFPA 780-2011		
Item	**Less than 75-ft**	**More than 75-ft**
Name	Class I	Class II
Air Terminal	min 3/8-in dia	min 1/2-in dia
Main / Downcomer	57 kcmil (between #2 and #3 AWG)	115 kcmil (between 1/0 and 2/0)
Earthing	Rods	Rods and Loop

Corner Downcomer introduces two critical concepts - earth potential and current dissipation. Earth potential is the voltmeter reading between where you are measuring and *remote earth*. It is non-intuitive, but the local value of ground changes by several hundred volts as a storm approaches and passes over.

Why do you say that local ground value changes ?
I could cite publications, but I would rather cite personal experience. In the 1980's I was tech support for a large petrochemical research facility. As we kept building more laboratories, we kept extending our RS-232 data network (the best available at that time). When the runs exceeded 500-lf, we started blowing RS-232 receiver chips. RS-232 is defined as +12, -5 V pulses, 1200bps to 56kbps (personal computers use +5, 0 V, but that is another story). The OEM receiver chips were rated to 50 V input. After many, many failures of these chips, we found a 300 V input chip that was a pin-for-pin replacement. Today, we would use opto-isolators and surge protective devices. As part of troubleshooting the RS-232 problem, I lifted ground leads and saw them spark and measured 50-100VDC with a digital meter, but 0VDC with a Simpson analog meter. It was high voltage with tiny current. On the other hand, I have seen the #22 AWG ground wires burned off, probably associated with a nearby strike rather than a ground shift.

Current dissipation is what happens when the lightning rods does its duty. A current of 50,000 – 500,000A (short duration) will travel across the main, use the downcomer and ground rod. From the ground rod, it *dissipates* into the contacting earth. This subject has been extensively researched for high-voltage electric substation faults. Those longer duration current flows create a lethal voltage, or *step potential* at the point of entry to the earth, which diminishes exponentially as you move away from the point of entry.

For lightning current dissipation, the massive current flow boils the moisture at the rod and it expands away from the rod. The earth adjacent to the rod is now dry and non-conductive.

Between the two, differing ground potentials and no-longer-functional ground rods, you can see why it is required to have a minimum of two ground rods and they should be placed as far from each other as possible.

But not far from the building. The ideal position of the ground rod is at the downcomer, 24-30-in from the foundation. More distance is bad. Lightning is very quirky. Three characteristics should be introduced immediately - it doesn't like to go *up*; it doesn't like to go far; and, it does what it wants to do regardless of what you do.

You will note that I am anthropomorphizing. After a while, people who study lightning start to do that. The laws of high school physics and undergraduate electrical engineering work only grossly with lightning. NASA is still having a hard time figuring when they dare fire off a rocket and when it would be better to wait. We put in a nice, thick copper downcomer and the lightning jumps off the side to the brick building, runs a few feet, then jumps back on the downcomer. This has been repeatedly observed and photographed. The soot stains and cracked masonry remain.

Let us review the notes on the *Corner Downcomer* illustration. The first two say, *Never go "up" with main or branch conductor* and *Minimum radius 8-in with a minimum 90-degree bend*. The never-go-up is my inference from examples later in NFPA-80 on right and wrong installation of branch conductors on dormers. It matches my intuition for the phenomenon, as a current flow trying to equalize the voltage from the bottom of the cloud to the earth. There is a voltage gradient. The flow is trying to follow the gradient. The forces involved are against contra-gradient flow.

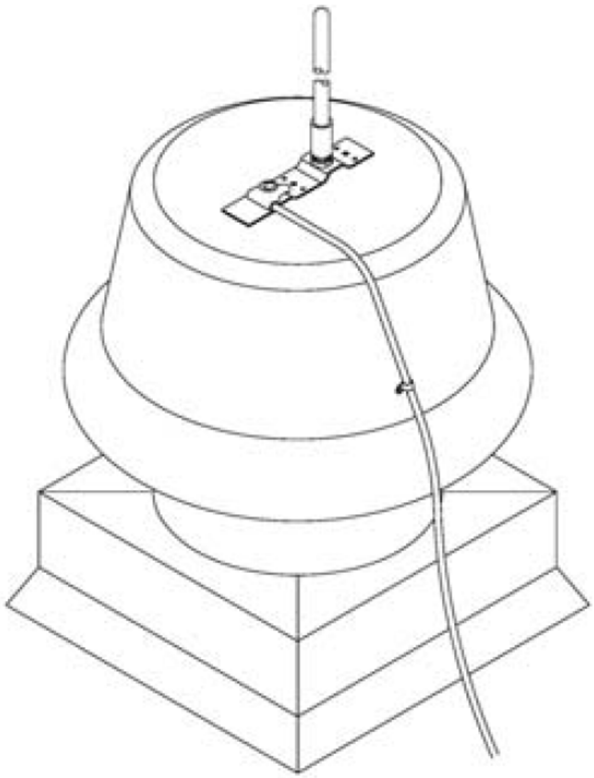
The rule to keep sweeping bends and not too sharp is clearly stated in the Standard. Again, this matches my mental picture of the driving voltage gradient and the current flow. A sharp bend or an acute bend will have the leading edge of the flow fighting the trailing edge. Photographs and soot marks indicate where lighting jumps off the downcomer because the bend was too tight.

This introduces a complication. Architects and sensitive Owners don't like prominent lightning protection systems (though some like glass baubles on the terminals). NFPA responds to this by offering two alternatives - concealed downcomers and using building steel or handrails as downcomers.

The goal of this course is to put you into a position where you can discuss lightning protection intelligently with Architects and Owners. You should know the NFPA version and your instructor's version and decide for yourself. My experience is that neither steel nor aluminum is as good conductors as copper. I specify copper terminals, main cables and downcomers. We both specify copper clad ground rods (or stainless steel in corrosive soil).

NFPA-780 has tables of "equivalent" aluminum and copper. NFPA-780 accepts continuous building steel columns as downcomers. NFPA-780 accepts continuous steel handrails as downcomers. I have field experience that disputes the "equivalence". But my field experience, in turn, is disputed by experts in the field whom I respect.

The requirements of the Standard as shown on the *Corner Downcomer* illustration reference the sizing of the main conductor on the roof and the size of the downcomers. This is reiterated in the table distinguishing short and tall buildings. No branch conductors are shown on this illustration. An example would be a rooftop HVAC unit or exhaust fan vent, if it rises above the ridge. It is preferable to loop a main-size conductor into and out of the metal housing, each with a 3 sq-in bare metal plate bonded to the unit and an air terminal on top of the unit. There is permission in 4.9.2 for a dead-end (single lead) of main-size to the bonding plate and air terminal, if it is less than 8-ft. Cross-connect cables, to be discussed later, must be main-size. A branch conductor and exhaust fan protection are shown below. The wide plate supporting the terminal provided the enclosure bonding.

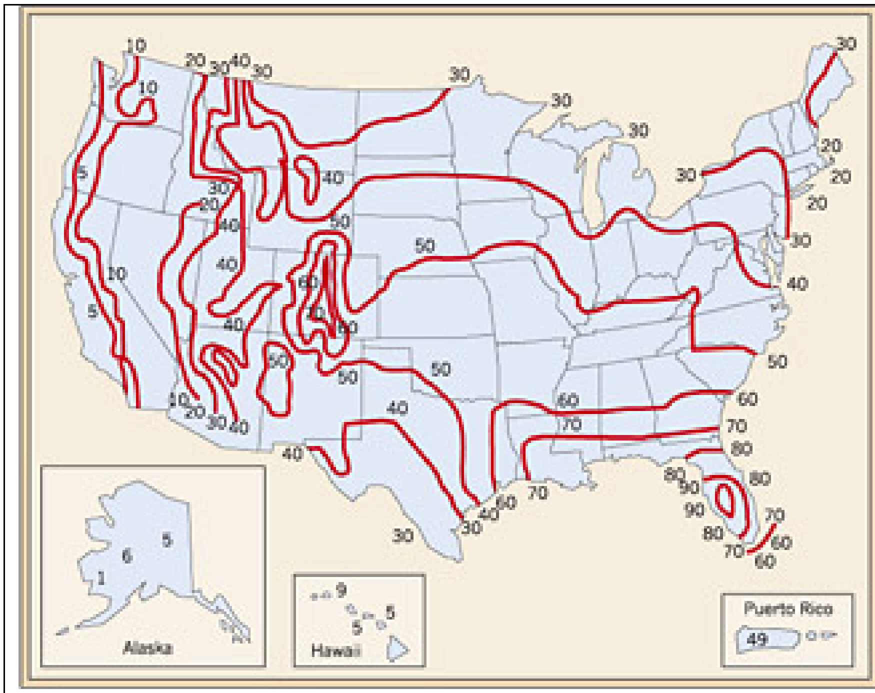


The location of the air terminals on the building ridge are at the discretion of the designer, so long as they are not closer than 2-ft to the end of the ridge and are spaced no more than 20-ft apart. Note that this is a LOT of terminals. That is what the Standard requires. Main cable and downcomer supports must be at 3-ft intervals or less.

The ground rod was mentioned previously. First choice is a 10-ft copper-clad steel rod with at least 8-ft in contact with earth, located at least 2-ft from the foundation, but not much farther. If there is a hazard of damage to the downcomer, it must be protected by conduit a minimum of 8-ft above finished grade. It is very, very common to find the section of the downcomer between the wall and the rod missing. Best installation is to place the short horizontal section below grade.

There are parts of the country where topsoil, or overburden, as it is called in the Standard, is very shallow. It is permitted to drive the ground rod diagonally or even lay it in a trench, horizontally. In the extreme, the rod can be attached by anchors or epoxy to bed rock. It is pointed out that these are not good grounds. If you want a good ground under these conditions, you must lay a ground loop of main-size cable around the perimeter of the building. We will see ground loops again as the preferred grounding for tall buildings.

What about the missing piece of downcomer ? Why all the fuss about a *good ground* ?
The underlying question is, “Why are we putting in a lightning protection system?” In Tampa, there will be hundreds of nearby lightning strikes each year. In Florida, all schools and State buildings must have lightning protection systems. In the rest of the country, not so much. See Isokeraunic Map, below:



Number of Days with Thunderstorms, http://ecmweb.com/mag/electric_lightning_strikes/

Beyond Florida, I am aware of no requirement for lightning protection. Real-world application is spotty. It is common for public utilities to have two substations, side-by-side. One with lightning protection towers and catenaries and the other without

I often suspect that requests for lightning protection systems immediately follow a perceived catastrophic loss.

My favorite example is a meter shed adjacent to a 500-ft incinerator stack. The stack had an excellent lightning protection system. The 6-ft x 6-ft shed had two terminals and two ground rods. In the terminology of NFPA-780, the shed was within the *zone of protection* of the stack. None of the other buildings at the plant had lightning protection.

We design lightning protection systems to NFPA-780 when a Client asks for lightning protection. We do not guarantee effectiveness, only that it complies with the Standard and we require a *Master System Label* from the installer.

Returning to the *Corner Downcomer* illustration, utility grounding is required by the National Electrical Code (NEC). The requirements have evolved to presently requiring an intersystem ground terminal. It is not required retroactively, but is required by the lightning protection standard. All copper utilities, power, data, telephone, cable, must be grounded and connected to the building power ground. There are three reasons the NEC requires this - fire safety, equipment survival and human safety. There is no SCOPE section in NFPA-780, though it is listed in the Table of Contents.

Fire safety is closely related to NFPA-780, but the lightning standard has been moving towards equipment survival since 2008. The lightning standard now REQUIRES surge protective devices on power and each incoming copper service.

I say again, “Provide tiered surge protection. *Big SPD* at the service and *small SPD* at critical, sensitive loads."

One of my Clients, a public housing authority, is providing *small SPD* to its residents so that they can use their vacuum cleaners on AFCI protected circuits. They are paying less than $5 each for single circuit, plug-in SPD. Below is the current ad from one of the discounters I deal with. SPD at bargain prices are a bit volatile, so I will not give you the link. But, they are available.

The power service ground is part of NEC compliance, and over 60-years a requirement. The NFPA-780 requirement is to bond this to the lightning ground with a main-size equalization conductor. Below grade is best. This will NOT bring lightning back into your house.

Just another really keen flash map, copied from the last issue of this course. Link not verified.

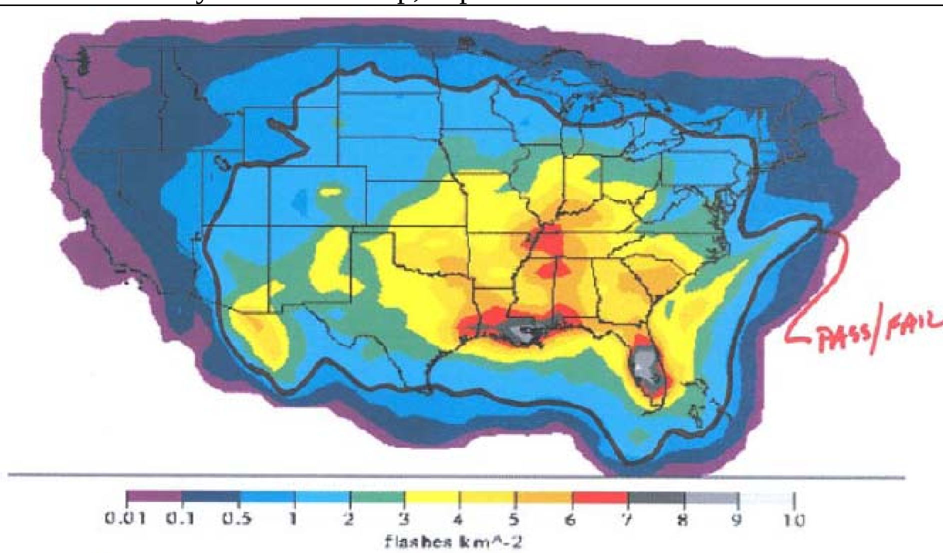
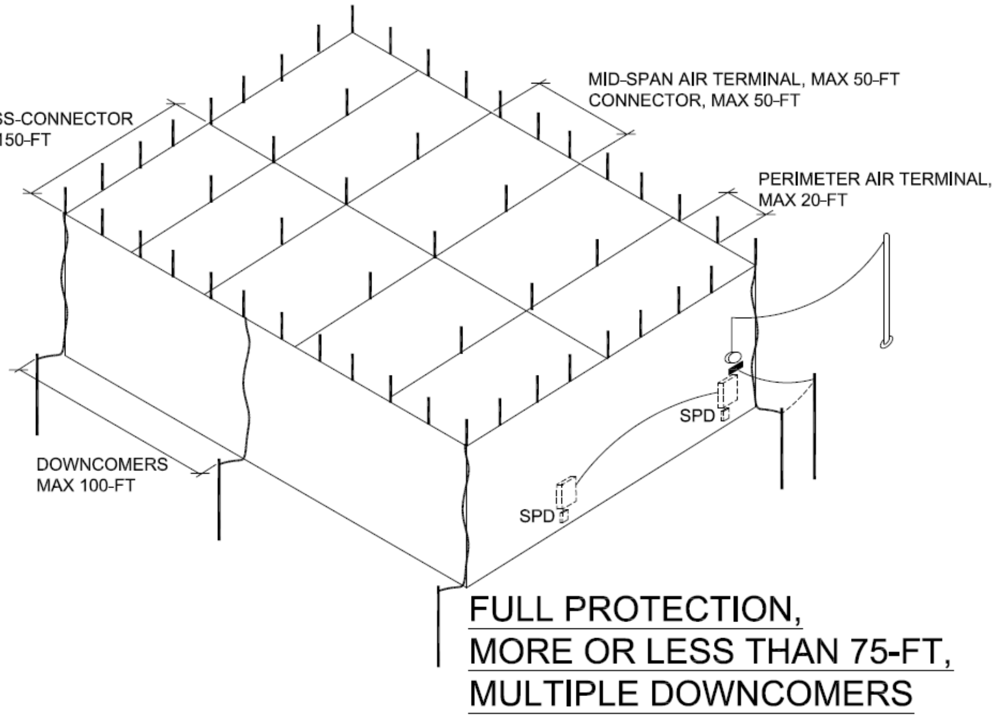


Fig. 10, NFPA-780 SPD-Required Localities, from
http://rammb.cira.colostate.edu/visit/lightning/afdmapsli.asp

The Pass / Fail threshold has been eliminated from the 2011 revision of the Standard.

Let us continue with the examples.



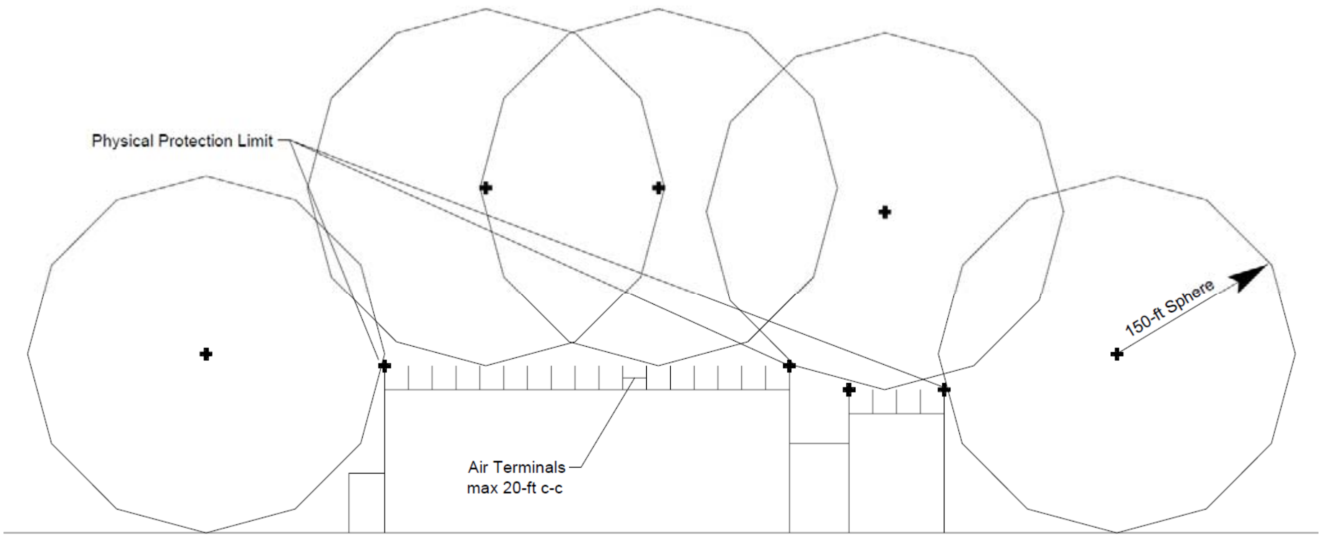
This example uses the same symbols as before. The only ambiguity is the main cable and downcomer sizing, which is determined by the height of the building. Multiple panels, each with a Type 2 SPD, are shown. Individual *Small SPD* are recommended, but not shown. A large building has a more complex main switchboard, possibly multiple services and more complicated data services. The concepts, however, are identical.

Concealed downcomers or use of steel columns as downcomers are permitted, but not recommended.

We will examine the rolling ball method after the next sidebar.

Do you space the terminals for the lightning protection installer ? No.
The purpose of the graphic associated with the lightning protection specification is to communicate design intent and it should be labeled such. The specification must reference NFPA-780-2011 and require a UL Master System Label. It is the responsibility of the installer to pick out the hardware and choose the mounting locations. It is the responsibility of the Electrical Inspector, Construction Manager (if present) and commissioning agent to approve or critique the selections.

Both the old version and the current revision of the Standard present a graphic similar to the following, to introduce the rolling ball method of analysis:



Zone of Protection, 150-ft Rolling Sphere Model

The Standard tells us that a zone of protection is provided under the chord of a 150-ft rolling sphere.

Before we elaborate on the rolling ball method and horizontal terminals, let's review the cone of protection method which was replaced by the rolling ball.

The following are illustrations of the discarded cone of protection method for 50-ft and 100-ft towers:

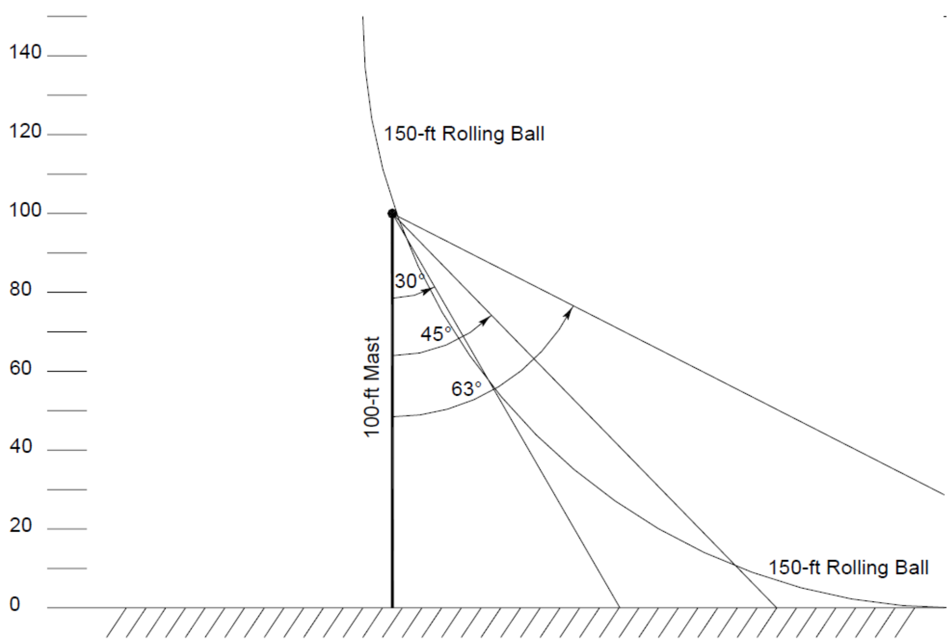


Fig 15 - 100-ft Mast
150-ft Rolling Ball;
30°, 45°, 63° Cone of Protection

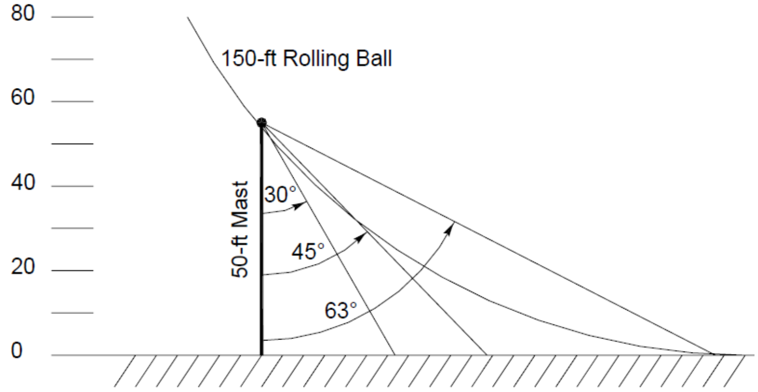
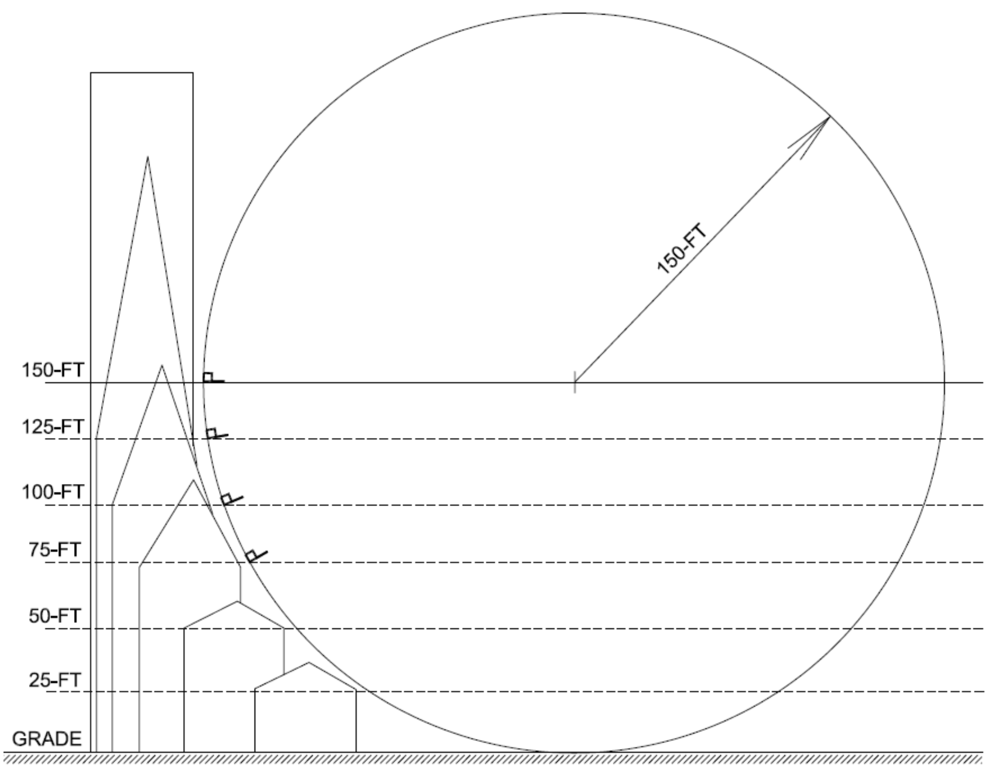


Fig 16 - 50-ft Mast
150-ft Rolling Ball;
30°, 45°, 63° Cone of Protection

The following illustration is a legal parody of Figure 4.8.2 in NFPA-780-2011:



ROLLING BALL METHOD, TALL STRUCTURE, FOLLOWING FIG 4.8.2

The reference to Figure 4.8.2 says that building eves 50 – 150-ft above grade may omit air terminals if the roof pitch is steeper than the arc of the ball at that point. It is possible that the unlabeled bold-d is a mathematical symbol relating to the tangent.

Appendix F, Lightning Protection for Trees

This sidebar is included for two reasons - to acknowledge the economic and cultural value of trees and to communicate what might be a very valuable lightning protection concept. The following is a published example. Note use of conductors as terminal devices, including guy as terminal.

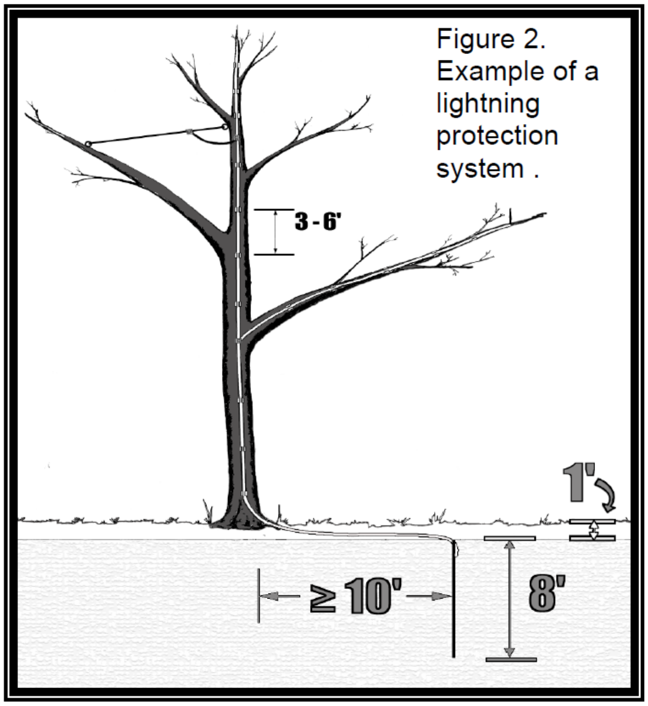
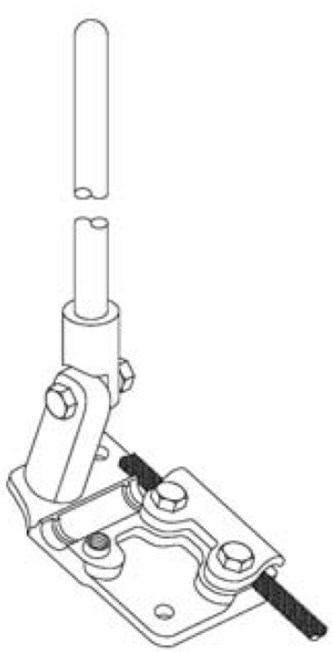


Figure 2. Example of a lightning protection system .

The source text emphasizes the importance of placing ground rods at least 10-ft fron the trunk. NFPA-780 offers an alternate horizontal radial grounding scheme to avoid root damage. NFPA-780 says to go at least 2-ft from the trunk then provide three radials, minimum 12-ft each. They show only a single downcomer, but five conventional terminals, including one horizontal.

An adjustable terminal mount is shown below:



Bad Sample Lighting Protection Specification #1

SECTION 26 4113 - LIGHTNING PROTECTION FOR STRUCTURES

PART 2 PRODUCTS

1.01 LIGHTNING PROTECTION SYSTEM

A. Lightning Protection System: Provide complete system complying with NFPA 780, including air terminals, bonding, interconnecting conductors and grounding electrodes.
   1. Provide system that protects:
      a. The entire structure.
      b. Open air areas within 100 feet (30 meters) of exterior walls at grade level.
      c. Open air areas within building footprint.
   2. Coordinate with other grounding and bonding systems specified.
   3. Provide copper, bronze, or stainless steel components, as applicable; no aluminum.

1.02 COMPONENTS

A. All Components: Complying with applicable requirements of UL 96.

B. Strike (Air) Terminals: with adhesive bases for single-ply roof installations.

C. Grounding Rods: Solid copper.

D. Ground Plate: Copper.

E. Conductors: Copper cable.

F. Connectors and Splicers: Bronze.

END OF SECTION

Course Comments

1) This spec is not CSI format, even though it comes from a national spec-providing service.

2) Always give year of Code or “latest edition”.

3) Should require *UL Master Label Certification.*

4) Requiring lightning protection 100-ft away from the building involves masts and catenary cables or something weird. I have never seen anything like this installed. It is unworkable.

5) *Coordinate with other grounding and bonding* should reference NFPA-70, the National Electrical Code.

6) The spec lacks internal coordination. Ground Plate is loosely specified but there is no requirement for installation.

7) There is no mention of surge protective devices (SPD), an essential part of lightning protection and complying with the Standard. Recommend mentioning here requiring service SPD, branch panel SPD and expensive, sensitive device SPD’s.

8) The downcomer system required must be described. Copper main-size cables at NFPA-780 intervals is recommended. If steel column downcomers are acceptable, say so. If steel handrail downcomers are acceptable, you are not going to get any Christmas presents this year.

9) The ground system is not described.

10) There is no mention of connection means - welded, mechanically lugged or crimped.

11) There is no such thing as *copper ground rods*. Copper is soft and cannot be driven into the earth. Copper-clad steel is standard.

12) The roof warranty is of substantial importance to the Owner. On new construction, the lightning protection installer must coordinate with the roofing installer in order to keep the roof warranty in place. For retrofits, the lightning protection installer must get a signed, dated statement that the installation will not void the roof warranty.

Bad Sample Lightning Protection Specification #2

Specification – Lightning Protection Systems

The contractor shall furnish all labor, materials, equipment and services to provide a complete lightning protection system for the structure(s) included in this contract. The system(s) shall include strike termination devices, interconnecting conductors, a proper grounding system, interconnection with other building grounded systems, and surge suppression at service entrances. The system design shall comply with the National Fire Protection Association (NFPA) Standard # 780, the Lightning Protection Institute (LPI) Standard # 175, and Underwriters' Laboratories, Inc. (UL) Standard # 96A. The manufacturer of the material components shall be a manufacturer member of the Lightning Protection Institute, and all materials shall be listed and labeled in accordance with the requirements of a nationally recognized testing laboratory. The system installation shall be made under the supervision of an LPI Certified Master Installer. Upon completion the contractor will deliver to the owner an as-built drawing and the appropriate system Certification documents under the LPI inspection program.

Course Comments

1) This is one, dense paragraph. CSI format uses numbered sections and numbered paragraphs and a fairly rigid form, so that the specifier, reviewer, construction manager and installer know where to find specific requirements. It is also obvious which standard paragraphs have been omitted. A dense paragraph like this suggests marketing more than specifying.

2) No reference to NFPA-70, the National Electrical Code (NEC). This is critical. Specialty installers, as lightning protection, photovoltaics, wind turbines, data and communications, do not normally follow the rules for fire-stopping and grounding. Referencing the NEC doesn't make them any more knowledgeable, but it gives you a reference for demanding good work.

3) Does not mention *UL Master Label Certification*.

4) Does mention *Lightning Protection Institute*, a marketing organization.

5) Be very, very careful with *nationally recognized testing laboratory*. UL is UL. Others are not-UL.

6) Does not mention materials of construction - copper, bronze and copper-clad steel. You will get aluminum.

7) Does not mention downcomer scheme required, external cables, concealed cables, building column or steel handrails.

8) The roof warranty is of substantial importance to the Owner. On new construction, the lightning protection installer must coordinate with the roofing installer in order to keep the roof warranty in place. For retrofits, the lightning protection installer must get a signed, dated statement that the installation will not void the roof warranty.

Bad Sample Lightning Protection Specification #3

Lightning Protection Specification

Lightning Protection System

1.1 General:

A. The Contractor shall provide and install a complete Lightning Protection System for all of the building(s) included in this project. This specification addresses the requirements of Lightning Protection Systems for buildings only.

B. Compliance Requirements
1. System Design: NFPA 780, latest edition.
2. Component Design: UL 96 Standard, latest edition, L.P.I. 175.
3. Certification: Lightning Protection Institute Certified System and Underwriters' Laboratories 96A Master Label, Lightning Protection Institute certification.

C. Submittals
1.Complete Shop Drawings
a) Layout
b) Details

2. Catalog Data with complete description of material components.

1.2 Product:

A. Manufacturer: ERITECH Lightning Protection/Grounding a division of ERICO Inc. phone:(800) 248-9353. E-mail: application_eng@erico.com

B. Prior approved manufacturer, who is a Lightning Protection Institute Member in good standing.

C. Materials are to be listed and labeled in accordance with Underwriters' Laboratories 96A requirements.

1.3 System Design:

A. System to be designed and installed by a L.P.I. Certified Master Installer/Designer in good standing with the Lightning Protection Institute.

B. System to consist of groundings, down conductors, air terminals, interconnecting conductors and bonding, designed to appear as a part of the building.

C. Design to be complete per current NFPA 780 requirements.

1. Class II Aluminum materials required.
2. Class II Copper materials required.
3. Aluminum Lightning Protection materials not to be embedded in concrete or masonry or installed on or below copper surfaces.
4. Copper Lightning Protection materials not to be installed on aluminum surfaces.
5. Grounding shall be suitable for the soil conditions per NFPA 780, this may include:
   a) Ground loop only (full size cable) 2/0 buried 18 in. deep.
   b) Ground loop combined with ¾ x 10 ft. rods buried 18 in. deep.

more, ….

Course Comments

1) This is an installer's specification. I have an aversion to purported specifications that do not identify what is to be provided in a form that can be verified.

2) No reference to NFPA-70, the National Electrical Code.

3) Prominent reference to Lightning Protection Institute, a marketing organization.

4) No requirement for UL Master System Label.

5) Sole-sourcing to Erico. There are many problems with this. First, when a specification lists a provider, it must list three acceptable providers. Second, I really like Erico products. They consistently do an excellent job on design, fabrication and quality control. Unfortunately, Erico has adopted a business model of aggressively selling non-NFPA, non-UL lightning protection systems. It is hard to find NFPA-compliant system components on their website.

6) I do not consider aluminum to be acceptable.

7) Class II materials are called for. NFPA only requires Class II materials for structures over 75-ft high. I am not aware of benefits of oversizing the downcomers.

8) The grounding system to be provided is not well described. If you don't like it when you get the shop drawings for review, it is almost certain there will be a cost adder.

9) There is considerably more wording in the specification, not repeated here. I get the feeling this is an honest, diligent installer who is under pressure to be price-competitive with shady bidders.

10) The roof warranty is of substantial importance to the Owner. On new construction, the lightning protection installer must coordinate with the roofing installer in order to keep the roof warranty in place. For retrofits, the lightning protection installer must get a signed, dated statement that the installation will not void the roof warranty.

The final topic in this course is an outline of NFPA-780-2011, to help you find answers to specific questions.

DISCLAIMERS

PREFACE
History and changes in the current edition

TECHNICAL COMMITTEE MEMBERSHIP
Paid, voting lobbyists

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Note that the Index is copyrighted separately and may not be reproduced in whole or part.

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This concludes the content portion of the PDHonline course on Designing to the Lightning Standard, NFPA 780-2011.