PDH Course E250

Design to Lightning Standard, NFPA-780-08

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2007

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Course Content

GRAPHIC OVERVIEW

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

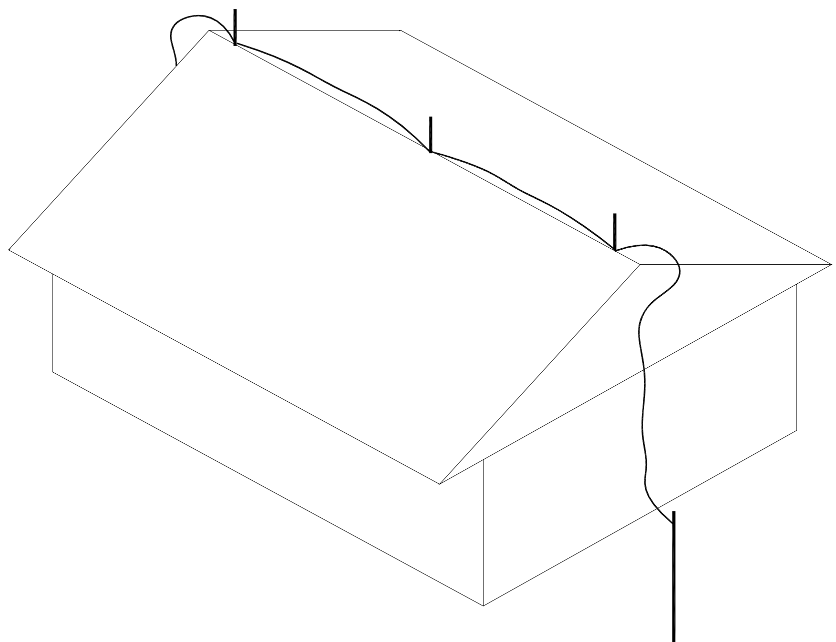


Fig 1 - Ridge Protection, Class I Small Building Face Downcomer

NTS, 8Nov07, follows NFPA-780-08, Fig 4.8.2

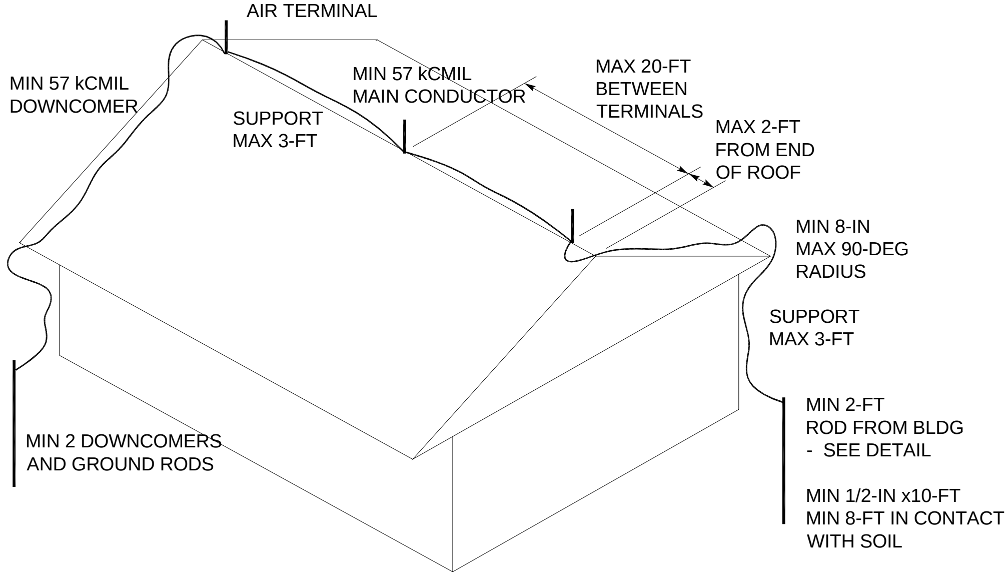


Fig 2 - Ridge Protection, Class I Small Building, Corner Downcomers

NTS, 8Nov07, follows NFPA-780-08, Fig 4.8.2

NOTE: CLASS II IF OVER 75-FT, REQUIRES 1/2-IN AIR TERMINAL AND 115 kCMIL DOWNCOMER

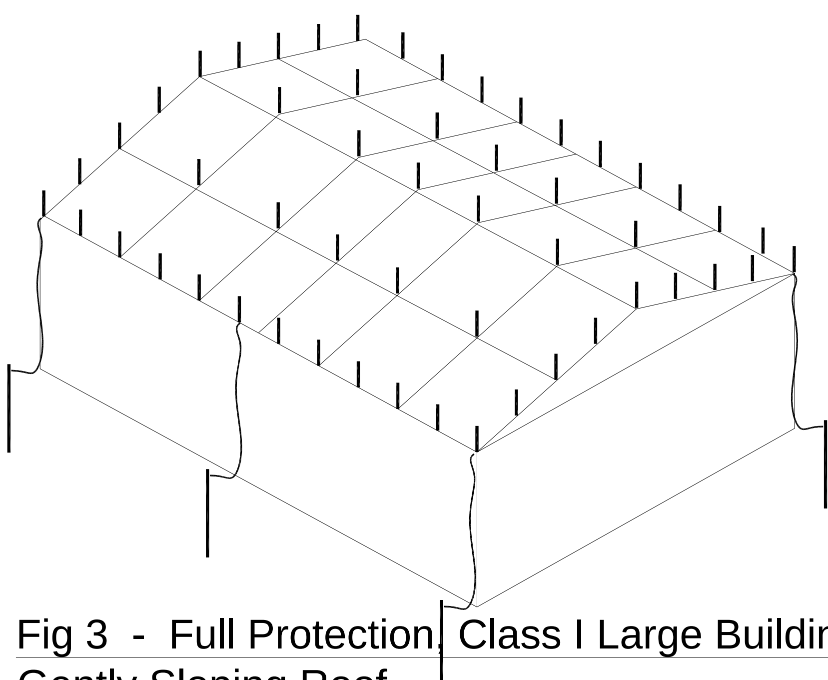


Fig 3 - Full Protection, Class I Large Building, Gently Sloping Roof

NTS, 8Nov07, follows NFPA-780-08, Fig 4.8.2.4(b)

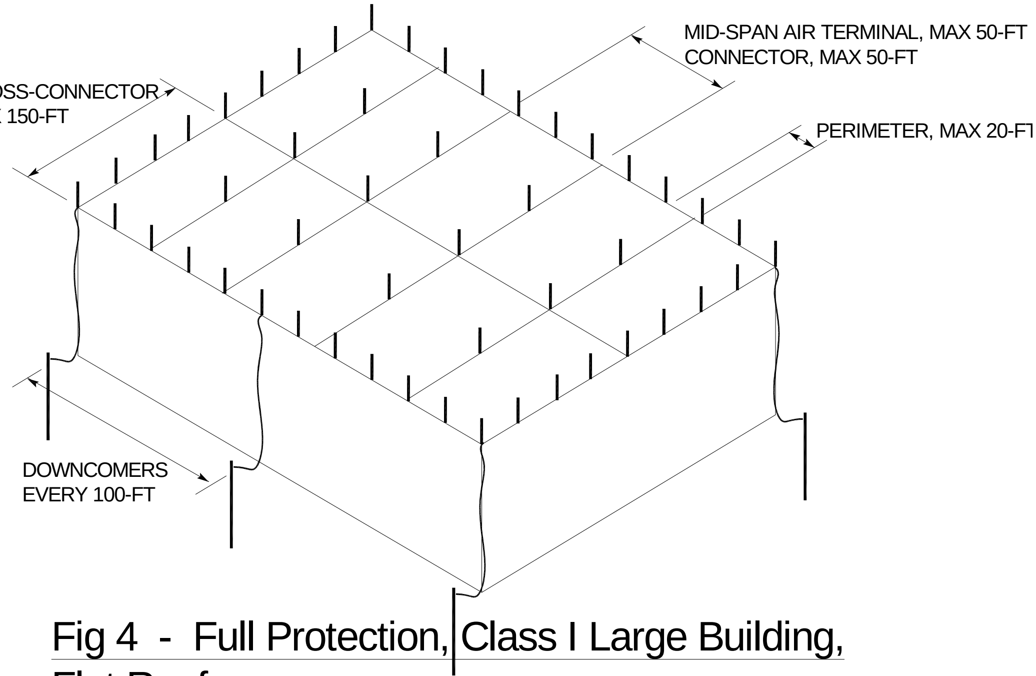


Fig 4 - Full Protection, Class I Large Building, Flat Roof

NTS, 8Nov07, follows NFPA-780-08, Fig 4.8.2.4(b)

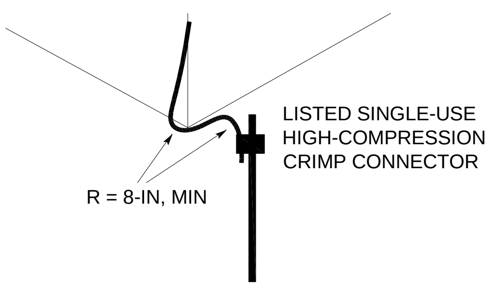


Fig 5 - Ground Rod Detail

NTS, 8Nov07, follows NFPA-780-08, Fig 4.13.2.3(B)

where, Class I = ordinary structures, less than 75-ft high, use 57 kcmil (#2 AWG) main conductor, downcomer and ground loop

Class II = ordinary structures, over 75-ft high, use 115 kcmil (#2/0 AWG) main conductor, downcomer and ground loop

Downcomer = Base, copper; Alternates, not recommended, aluminum, building steel, stair tower handrails and concealed downcomers

Aluminum = aluminum devices and conductors are considerably less expensive than copper. Sufficient care will produce an initially acceptable lightning protection system. There are two drawbacks. Aluminum has a higher thermal expansion coefficient than copper so it grows and shrinks more with temperature changes. This causes mechanical connections to loosen. Aluminum also has poorer conductivity than copper. Lightning doesn't travel over aluminum as well as it does copper.

Building Steel = building steel is an accepted lightning downcomer and poses no incremental cost to the project. Bond the top connection loop in several places and bond to the ground loop in several places. A lightning strike will drive 200,000 A thru the building steel, leaving char mark at visible and inaccessible locations. It will cause substantial shift of local ground references for data and communications equipment. It is very, very expensive to change your mind later and install copper.

Handrails = NFPA-780-08 specifically permits use of continuous steel handrails in stairwells to act as main lightning downcomers. Bond the top connection loop in several places and bond to the ground loop in several places.

Concealed downcomers = NFPA-780-08 specifically permits downcomers to be concealed within the building façade. There are two problems. First, it is difficult to inspect concealed connections during construction and later. The National Electric Code section 250.68(A) requires accessibility to ground electrode or bonding jumpers for this reason. Second, lightning demonstrates a nasty habit of jumping into the downcomer from the side of the building and sometimes jumping out of the downcomer to something nearby then jumping back in. All standard requirements apply to concealed downcomers, min 8-in bend radius, protection (usually a chase with 2-layers of gypsum) and bonding of nearby metal objects.

Air Terminal = UL-96 listed device to intentionally receive the lightning discharge. 1/2-in diameter copper preferred. Note that recent laboratory tests indicate a 1/2-in tip radius is most effective. Permitted lengths are 10-24-in or more than 24-in with intermediate supports.

Air Terminal Spacing = Prescriptive method: per sample sketches; Performance method: Rolling ball, 30-deg, 45-deg, 63-deg cone of protection. See later discussion.

Strike Termination Device = obfuscation; (sorry about this/that). If you put it up to get hit, it is an air terminal. If it is already there, and likely to get hit, it is a strike termination device and must be bonded. Examples are HVAC equipment, cell towers and elevator penthouses.

Bonding = run a connection cable to the roof perimeter loop or the nearest connection cable to provide an intentional ground path for a strike.

Main Conductor = When it is coming down it is a downcomer. When it is running around the roof, it is a roof loop conductor. When it is connecting terminals it is a connection conductor. When it is running around below grade, at least 2-ft beyond the foundation, it is a ground loop conductor. All must be sized for a hit. Class I (less than 75-ft high building) = 57 kcmil. Class II (more than 75-ft high building) = 115 kcmil.

Main Conductor Support = every 3-ft. Remember it is going to jerk hard and get hot. Use UL-96 listed components and try to avoid corrosion.

Ridge Space between Terminals = 20-ft (small buildings), 50-ft large buildings.

Terminal from end of Roof = max 2-ft. More than this and the lightning will hit the soffit or parapet instead. There is research on the behavior of the "leaders" which initiate a strike, but results are not consistent enough to be reported here.

Bend Radius = minimum 8-in.

Downcomer Support = every 3-ft. Remember it is going to jerk hard and get hot. Use UL-96 listed components and try to avoid corrosion.

Downcomer Protection = required from grade to 6-ft above grade.

Bonding of Downcomer Protection = if conductive conduit is used to protect the downcomer, it must be bonded at each end to the downcomer. If PVC conduit is used, then nearby metallic objects must be bonded to the downcomer. (4.9.14) Note that this applies to concealed downcomers as well.

Ground Rod = typically copper-clad steel 10-ft long with 8-ft in contact with soil. Conductive salts vastly improve the operation of ground rods but leach away within 10-years. The first hit dries out the earth around a ground rod, requiring alternate grounds to handle expected re-strikes (typically 3, total).

Spacing from Building = minimum 2-ft.

Ground Rod Spacing = minimum 10-ft.

Ground Loop = recommended for Class II systems for several reasons. First, a high-rise typically has a relatively small footprint, making the loop economical. Second, the high-rise is more likely to get hit, hit repeatedly and need back-up to the first dried-out rod.

Bonding = the ground loop or a #6AWG conductor from the lightning protection grounds must be connected the electric service ground.

Foreign Bonding = the National Electric Code, Section 250.94, requires that all services to the building, telephone, data, CATV, etc must be bonded to the electric service ground. If this has not been done before the lightning protection system is installed it must be done now. Voltage potentials between systems are deadly. Bonding forces them all to the same zero.

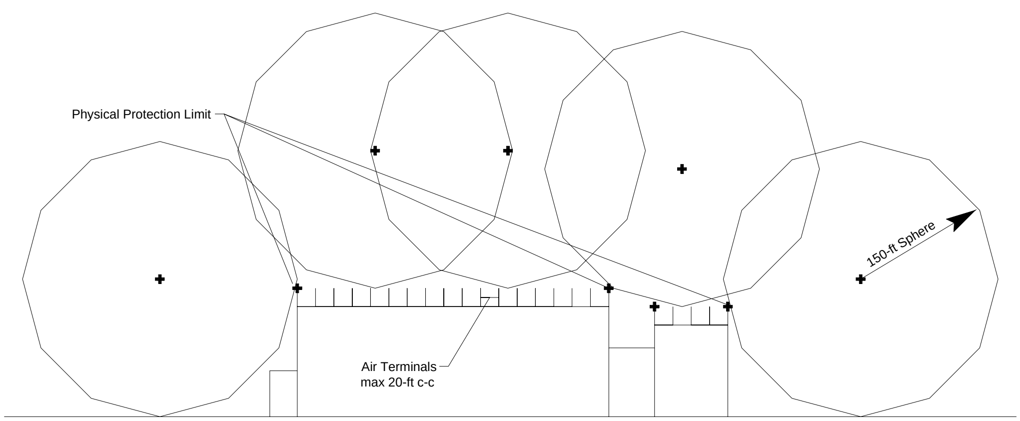
Surge Protection Device = (SPD), a box connected between incoming signal lines and a good ground. It is not supposed to normally affect the power, or telephone, or CATV or data, but when a high-magnitude pulse comes down the line, it shunts it to ground. Required by NEC Section 800-90 for all services.

It is possible to save money by carefully reading the details of the Standard. You may be forced to repeat this detailed examination to a Judge. Please consider this possibility before utilizing the absolute minimums of the Standard.

PERFORMANCE METHOD: 150-FT ROLLING BALL, 30-DEG, 45-DEG, 63-DEG CONE OF PROTECTION

The sketches and explanatory material present the prescriptive method of designing a lightning protection system. Put the terminals at the required intervals; connect them with the right size wire and ground it.

An alternate method involves analyzing each of the surfaces and projections of the building to be protected and carefully select locations for each air terminal. Note that terminals must not be spaced further than the intervals of the prescriptive method, but areas protected by higher terminals may be omitted.



Zone of Protection, 150-ft Rolling Sphere Model

The recommended method of identifying terminal locations by the performance method is by use of the 150-ft rolling ball. A sphere with 150-ft radius is envisioned rolling across the site and up to the building. Where the ball hits the building, lightning strikes are a hazard. In the space between the ball and ground, lightning is considered unlikely and no terminals are required.

As the ball rolls up the side of the building and across the HVAC units, any antennas and the elevator penthouse, again, where the ball touches an air terminal is needed. In the space where it cannot touch the roof or projections, no terminals are needed.

The older method of determining where individual air terminals are needed and where they can be omitted is called the "Cone of Protection". Early insurance companies noted that lightning rods reduced the number of fires and insurance claims. They promoted the installation of air terminals. Early rules-of-thumb, from observation of actual strikes and "safe" zones suggested the cone of protection. Unfortunately, different values for the protected angle were mandated in different decades. It's like Shark says on TV, "There are many truths; choose one". NFPA doesn't choose. They like the rolling ball a little better, but recognize all three cones.

Figs. 15 and 16 are diagrammatic representations of the 150-ft rolling ball and the 30-deg, 45-deg and 63-deg zones of protection associated with 100-ft and 50-ft conductive masts.

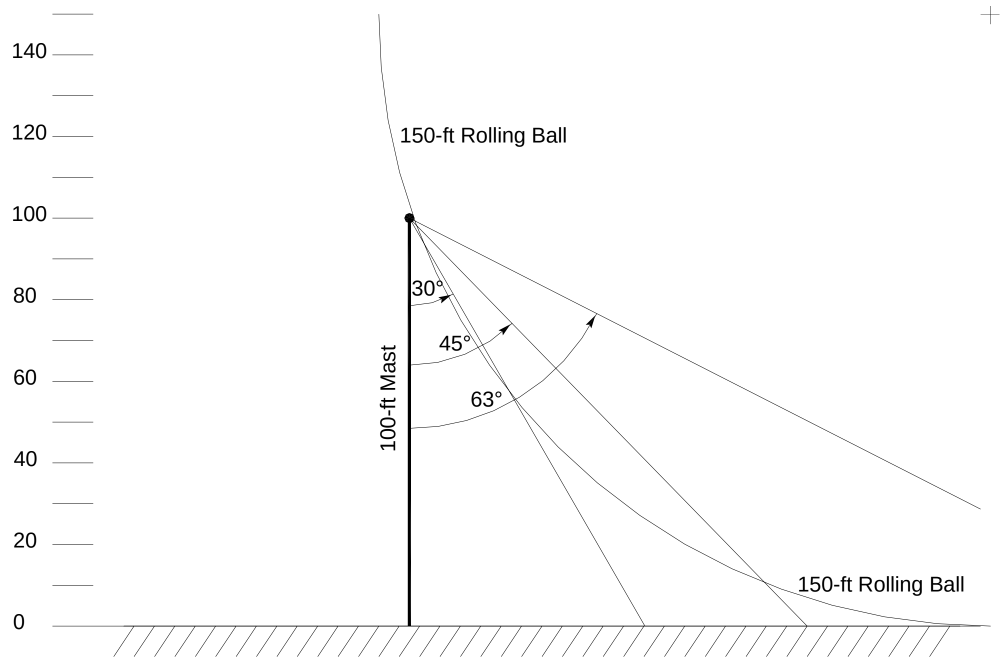


Fig 15 - 100-ft Mast
150-ft Rolling Ball;
30°, 45°, 63° Cone of Protection
NTS, 20Nov07

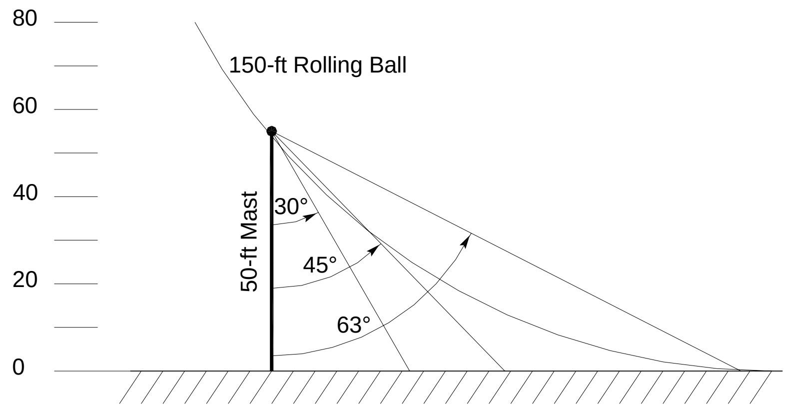


Fig 16 - 50-ft Mast
150-ft Rolling Ball;
30°, 45°, 63° Cone of Protection
NTS, 20Nov07

Fig. 15 applies the rolling ball and three cones to a 100-ft mast. The drawing is internally to scale, so, the 30-deg cone predicts a 57-ft safe zone below, the 45-deg cone predicts a 100-ft safe zone below and the 63.5-deg cone predicts almost 200-ft of safety. The 150-ft rolling ball predicts something like 120-ft, but it is hard to interpret. (Safe region is measured from mast to intersection of the geometry with a 6-ft person standing on the ground).

Fig. 16 applies the rolling ball and three cones to a 150-ft mast. The drawing is internally to scale, so, the 30-deg cone predicts a 28-ft safe zone below, the 45-deg cone predicts a 50-ft safe zone below and the 63.5-deg cone predicts almost 100-ft of safety. The 150-ft rolling ball predicts something like 72-ft, but it is hard to interpret. (Safe region is measured from mast to intersection of the geometry with a 6-ft person standing on the ground).

Again, air terminals installed must be at the intervals indicated by the prescriptive method. Apparently, terminals within the safe zone(s) may be omitted.

Real-world observations suggest that the methods and underlying concepts are largely ignored. At waste water treatment plants, with methane normally present, each structure has a full lightning protection installation, whether adjacent to the incinerator stacks or out among the lagoons.

GUIDEFORM SPECIFICATION

Students of this course are advised to hire a well-insured contractor to install their lightning protection system. There are a range of powerful reasons that can be accessed by calling lightning protection specialists listed in the Yellow Pages or on the internet. Ask for the story about “how they almost got killed installing a system.” Every installer has one.

This course will help by offering a guideform specification, from a State school funding agency, as follows:

SECTION 13100

LIGHTNING PROTECTION

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Air terminals and interconnecting conductors.
B. Grounding and bonding for lightning protection.

1.02 REFERENCES

A. NFPA 780 - Standard for the Installation of Lightning Protection Systems; 64p., National Fire Protection Association; 2008; $36.50; read free online at http://www.nfpa.org/freecodes/free_access_document.asp.
B. UL 96 - Standard for Lightning Protection Components; 22 p., Underwriters Laboratories; 2005, hardcopy, $974; pdf, $779.
C. US 96A – Standard for Installation Requirements for Lightning Protection Systems; 60 p., Underwriters Laboratories; 2007, hardcopy, $875; pdf, $699.

1.03 SYSTEM DESCRIPTION

A. Lightning Protection System: Conductor system protecting _____________, consisting of air terminals on roofs; bonding of structure and other metal objects; grounding electrodes and interconnecting conductors.

1.04 SUBMITTALS

A. See Section 01300 – Administrative Requirements, for submittal procedures.
B. Shop Drawings: Indicate layout of air terminals, grounding electrodes, and bonding connections to structure and other objects. Include terminal, electrode and conductor sizes and connection and termination details.
C. Product Data: Provide dimensions and materials of each component and include indication of testing agency listing.
D. Project Record Documents: Record actual locations of air terminals, grounding electrodes, bonding connections, and routing of system conductors in project record documents.

1.05 QUALITY ASSURANCE

A. Perform Work in accordance with NFPA 780 and UL 96A and provide UL Master Label.
B. Maintain one copy of each document on site.
C. Products: Furnish products listed and classified by testing agency acceptable to authority having jurisdiction as complying with UL 96.

D. Manufacturer Qualifications: Company specializing in lightning protection equipment with minimum three years documented experience.
E. Installer Qualifications: Authorized installer of manufacturer with minimum three years documented experience.

PART 2 PRODUCTS

2.01 MANUFACTURERS - not used

2.02 COMPONENTS
A. Air Terminals: Copper, solid, with adhesive bases for single-ply roof installations.
B. Air Terminal for Chimney: Lead-coated copper.
C. Conductors: Copper cable.
D. Connections and Splicers: Bronze.

PART 3 EXECUTION

3.01 EXAMINATION
A. Verify that field measurements are as indicated on shop drawings.
B. Coordinate work with roofing and exterior and interior finish installations.

3.02 INSTALLATION
A. Submit written approval by the carrier of the current roof warranty that the proposed lightning protection installation will not void the warranty.
B. Install in accordance with NFPA 780 and UL 96A.
C. Connect above ground conductors using mechanical connectors. Protect adjacent construction elements and finishes from damage. Connect below ground conductors using listed single-use high-compression crimp connectors.
D. Bond exterior metal bodies on building to lightning protection system and provide intermediate level interconnection loops 60-ft (18-m) on center.
E. Verify existing or install intersystem boding per NEC 250.94.

3.03 FIELD QUALITY CONTROL
A. Perform field inspection in accordance with Section 01400.
B. Obtain the services oF Underwriters Laboratories, Inc., to provide inspection and master system labeling of the lightning protection system.

[eof]

A guideform specification is not intended to be used as-is for bidding but as an indicator of proper form and necessary items. The designer here has had bad experience with exothermic welds, due to expired powder charges and poor workmanship. Typically, exothermic welding is preferred for underground connections.

PROPRIETARY SPECIFICATION AT http://lightning.org/documents/Long_Form_spec.pdf

A proprietary specification is one written for the benefit of the seller, not the buyer. For every project there are foreseeable unfavorable outcomes. In a Buyer's Spec, the burden is shifted to the seller to "make it right". In a Seller's Spec, the problems are not mentioned, declared unavoidable or listed as reasons for additional payment. The referenced spec is actually worth reading. Be aware, however, that the list of "acceptable manufacturers" is an exact replica of the "Board of Directors" of the Lightning Protection Institute, lightning.org.

The Lightning Protection Institute is a trade organization of manufacturers and installers. They have worthy goals and appear to be honest and straightforward within their objectives. They are not a standards body; though they publish something they call LP-175, for $36.

Another non-standards body is the National Lightning Safety Institute, NLSI, lightningsafety.com. NLSI is a retired self-educated fellow named Richard Kithil, Jr., who lives near Denver, CO. He has a very nice website and does consulting to the media.

DISCUSSION

What is lightning? It is observed that rubbing insulating materials against each other sometimes causes an electric charge to build up on each. There are tables showing which materials work best together. Another observation is that the charge can be transferred by conductive materials, such as metal or impure water. When the charges are transferred, some very interesting characteristics are seen.

For our purposes, the insulating materials are air and air. They rub against each other in wind currents. This is often observed in association with thunderstorms, but is not limited to thunderstorms. The charges build up in a volume of like-moving air. An opposite charge builds up in the fixed or differently-moving air. When water is present, usually partially precipitated on air pollution, the built-up charges are able to move easily and build up to very high magnitudes.

One of the interesting characteristics alluded to previously is that very high opposite charges sometimes breakdown the insulating property of intervening air. This changes it to conductive ions. A spark occurs, in one or both directions, often repeatedly, until the charge magnitude drops below that necessary to keep the air ionized.

We have just described cloud-to-cloud, or C-C lightning discharges. Over 90% of the discharges recorded by the National Lightning Detection Network are C-C. We will pursue cloud-to-ground, or C-G discharges.

Exactly the same phenomenon occurs when wind drives air along the ground, then into an updraft. Charge is created on the ground and in the cloud. Again, very high charge magnitude can ionize the air and a spark occurs, in one or both directions, often repeatedly. It is equalized by the strike and further equalized by restrikes along the same ionized path.

Science enthusiasts and teachers love to discuss plus and minus charges and electrons. We won't. Both polarities are created on clouds and both exist, locally, on the surface where we walk and live. We will address electricity in the characteristics of the lightning protection system later and in measuring the magnitude of hazard to the human body.

An observed characteristic of the charges is that opposite charges attract and collect, resulting in an increase in magnitude, if fed by conductive materials. Thus a charged cloud passing over a college campus will "drag along" an opposite charge on the grass. When it comes to a tree, the charge equalizes from the grass to the tree, with portions of the tree being closer to the cloud, making a lightning strike to the tree more likely than a lightning strike to the grass.

Supportive observations are that lightning strikes trees; lightning strikes grass and college campuses burn out data communications driver integrated circuits because of the voltage potential between buildings. The telephone people figured this out a long time ago, but the data people may have skipped that step and gone directly to fiber-optic cables.

Note that lightning more often strikes the side branches than the top branches. It strikes the sides of buildings also.

SHOULD YOU INSTALL LIGHTNING PROTECTION ON YOUR BUILDING ?

We are not going to answer the question, "Should you install lightning protection on your building?" Later, we will share the information contained in NFPA-780, but the only hard recommendation comes from Annex (formerly Appendix) A.4.18.2.5, saying that Surge Protective Devices (discussed later) should be installed when the likelihood is that more than one C-G flash per sq-km per year exists. Figures 8 and 9, below, have a PASS / FAIL perimeter drawn on the map of the United States separating the more-than from the less-than one C-G flash per sq-km per year areas.

Present understanding of lightning and the operation of lightning protection systems indicates that having well-grounded does not increase or decrease you chance of a hit. Having the system does not guarantee that the hit will not be to masonry adjacent to the air terminal. The protection system does radically reduce the damage from a hit and the likelihood of fire.

The discussion above mentioned thunderstorms. The presence of thunderstorms and the presence of C-G lightning are not identical. Rather than discussing meteorology, let us look at the national maps for thunderstorms (isokeraunic) and lightning (flash density)

The 2000 edition of NFPA-78 contained an isokeraunic map to help define the lightning hazard of a locality. But, no one can spell isokeraunic today. The reason is that in 1995, the National Aeronautics and Space Administration created the National Lightning Detection

Network (NLDN). The NLDN operates something over 100 sensor sites and offers real-time C-G flash data and archives since 1995. The sensor sites are shown in Fig. 6.

Recent evolution of NLDN involves Global Atmospherics Inc., GAI and Vaisala. Global Atmospherics got the contract from NASA to build and operate the NLDN. As they and the network grew, they became GAI. The newest name is Vaisala and they have trademarked the acronym NLDN (though nobody has picked up on the ® requirement).

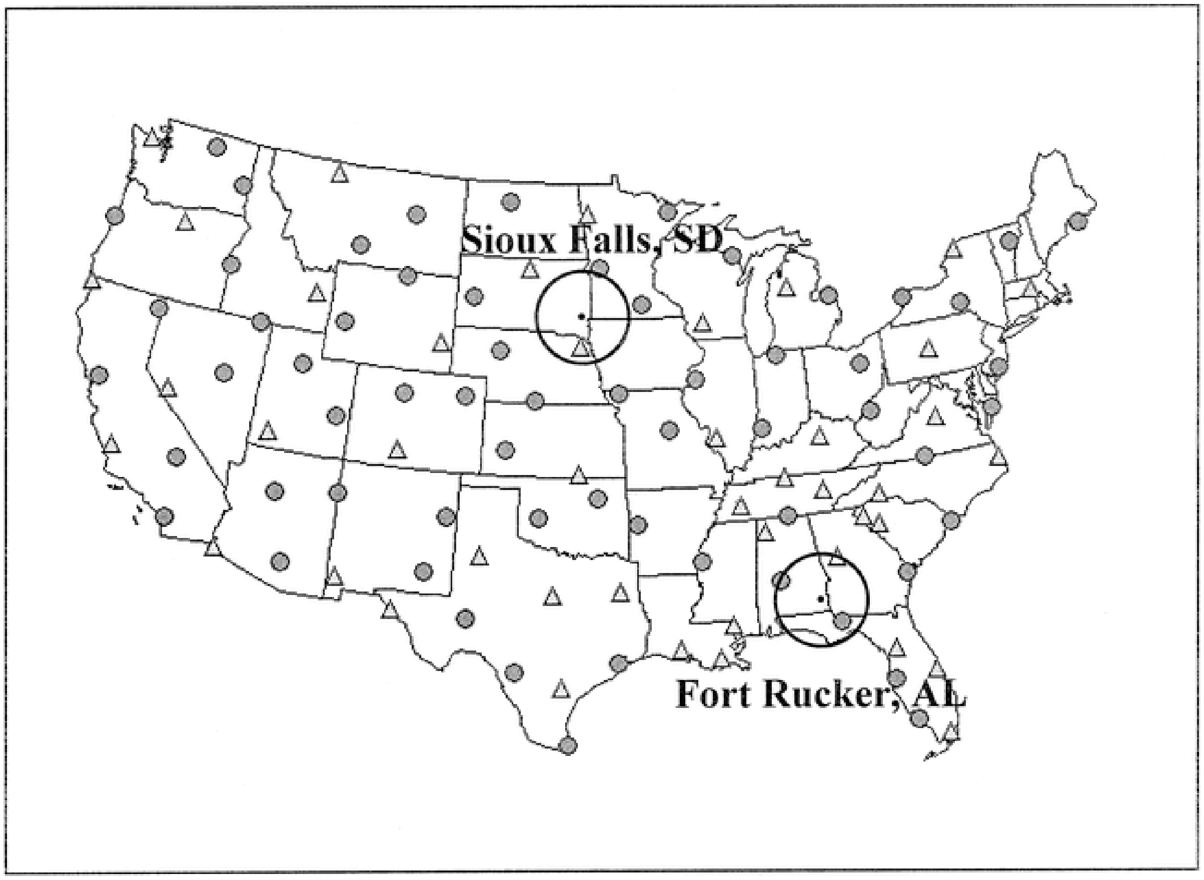


Fig. 6 National Lightning Detection Network Sensor Sites, currently nearly 200

For reference purposes, please compare the isokeraunic map, Fig. 7 with the flash density map, Fig. 8. Note especially Montana, Wyoming, Idaho, Nevada and the west coast.

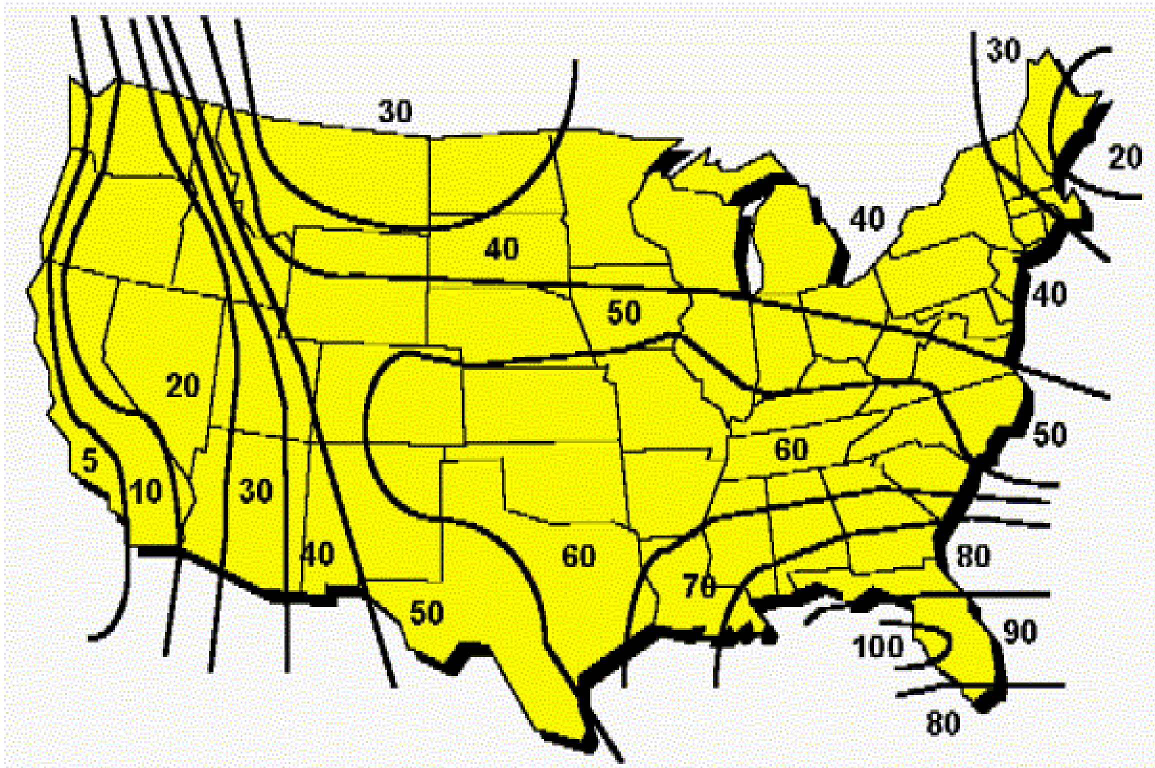


Fig. 7, Isokeraunic Map, http://www.laruscorp.com/isokera.htm

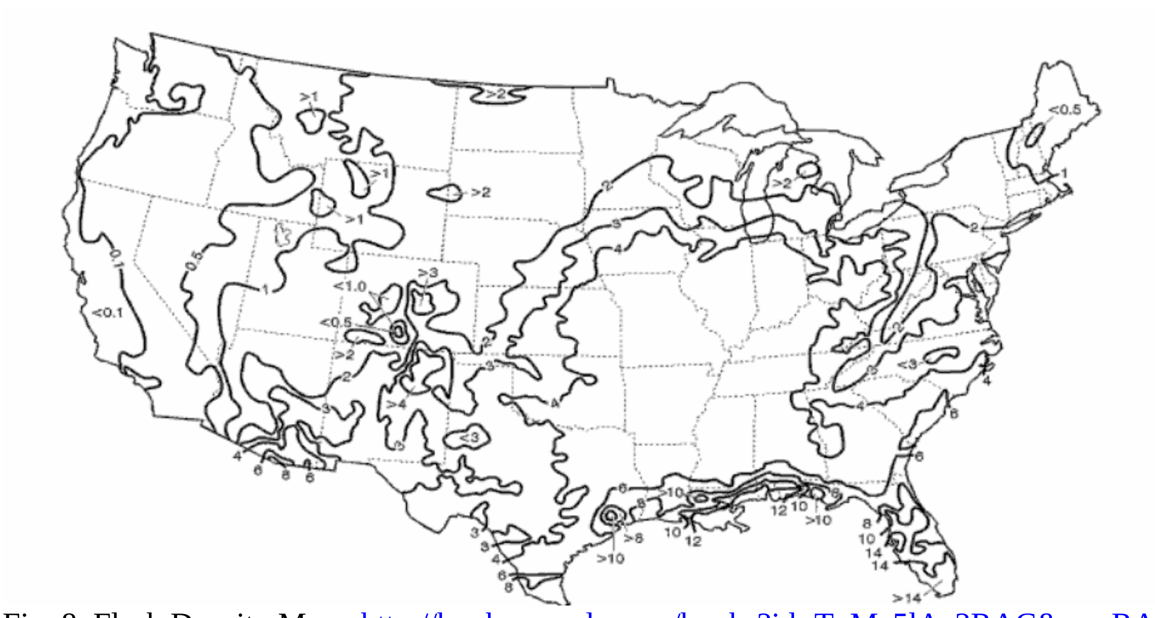


Fig. 8, Flash Density Map, http://books.google.com/books?id=TuMa5lAa3RAC&pg=RA1-PA41&lpg=RA1-PA41&dq=flash+density+map&source=web&ots=qt1zaD8bmD&sig=DNasDrRy30lfMPyfbItD-Hrddaw

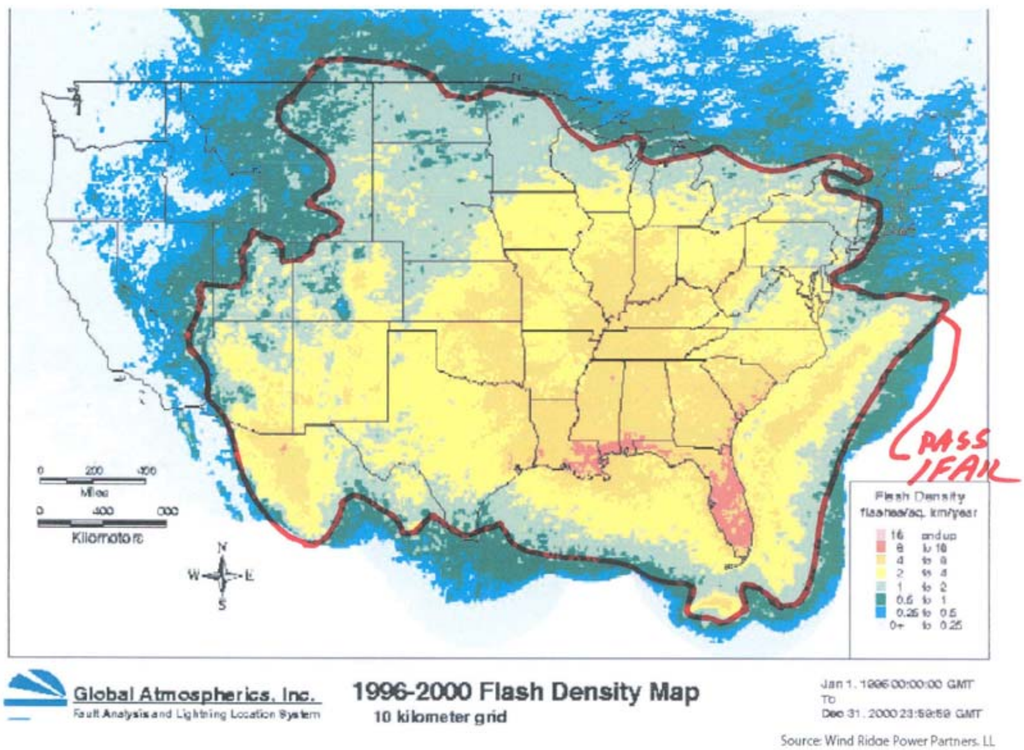


Fig. 9, NFPA-780 SPD-Required Localities, from
http://www.efsec.wa.gov/wildhorse/deis/figures/44%20Fig%203.15-1%20Lightning.pdf

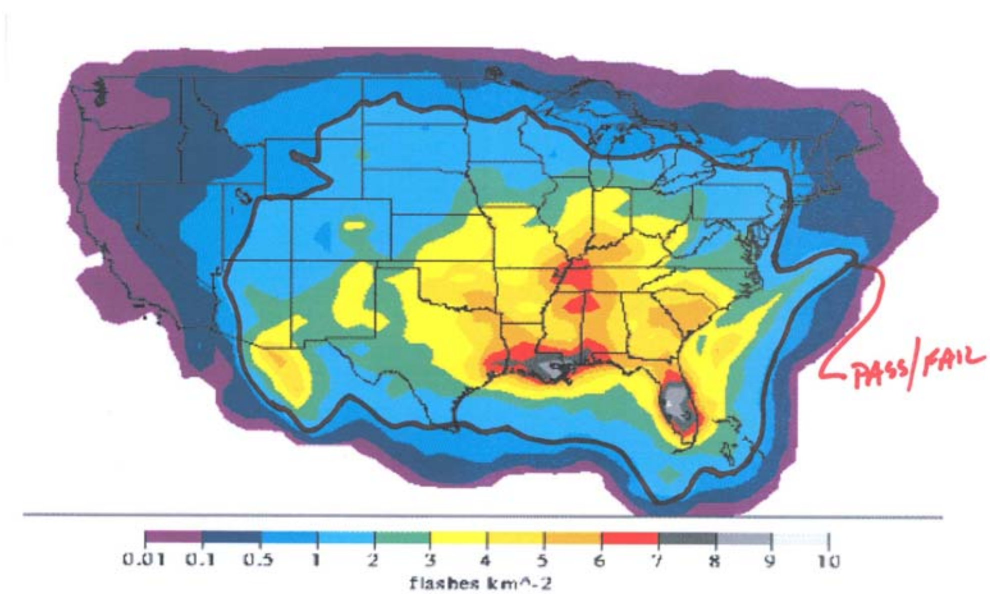


Fig. 10, NFPA-780 SPD-Required Localities, from
http://rammb.cira.colostate.edu/visit/lightning/afdmapsli.asp

NFPA COMPUTATIONS TO RECOMMEND A LIGHTNING PROTECTION SYSTEM

Lightning Risk Assessment

NFPA-780 says it is a no-brainer to install lightning protection for the following situations:

- Large crowds
- Service continuity
- Very high lightning flash frequency
- Tall isolated structure
- Building containing explosive or flammable materials
- Building containing irreplaceable cultural heritage

The only one that intuitively resonates with your author is the high-hazard building containing explosive or flammable materials - which has been excluded from the scope of this course.

Most lightning protection systems are installed following an expensive catastrophe. If someone is killed by lightning in a large crowd public gathering, there is an incentive to installing lightning protection before the next similar gathering. Other gatherings aren't going to get the attention.

Similarly, if electric service is interrupted by lightning, then an incentive exists to install a counterpoise over the transmission line or a catenary over the substation. Other transmission lines and substation aren't going to get the investment.

South Florida has the highest flash density of the US. Google reports 26,000 hits for lightning protection for Miami. However, Google reports 19,000 hits for lightning protection for Cleveland, OH, a moderate hazard area by the national flash density maps and 32,000 hits for Los Angeles, CA, a no-hazard area per the flash density maps.

Regarding very tall structures, my experience has been that after a strike, lightning protection is installed. A survey of a prominent moderate hazard rust-belt industrial area reports lightning protection devices on fewer than 30% of the very tall chimneys.

Many irreplaceable cultural heritage structures do not have lightning protection. A survey will be performed to see if the percentage is persuasive to the NFPA reasoning.

Annex L.1.3 states that the likelihood of a structure being hit is the product of the equivalent collection area times the flash density for the area times and environmental coefficient. The equivalent collection area is derived from the geometry of the building. The environmental coefficient is a WAG selected from a table, with values of .25 for a building surrounded by similar size buildings or trees, .5 if surrounded by smaller buildings or trees, 1 if not buildings or trees and 2 if on a hilltop.

After the likelihood of a strike is thus computed, additional factors are applied to recognize the value of the structure, the value of the contents and whether we care about saving the lives of the people present. The method presented is much less rigorous than conventional Value Engineering.

We have qualitatively identified the hazard of C-G lightning strikes. For engineering design of a lightning protection system, we need numeric values. Measurements for the last 100 years report numbers like 100,000,000 Volts, 100,000 Amperes and 50,000 degrees Fahrenheit(http://www.strikealert.com/LightningFacts.htm; http://www.thecomputerwizard.biz/lightning.htm). These are not the maximum, rarely-occurring values, but the typical values.

We are familiar with voltage measurements. An auto runs on about 12 VDC with charging value of 13.8 VDC. The US Government has decided that 50 VDV separates safe low-voltage from hazardous high-voltage. Household receptacles are 120 VAC, and can be lethal. The utility line buried in your front yard is probably 2300 VAC and the local overhead lines are something between 4160 and 35,000 VAC. The transmission towers range from 175,000 VAC to 500,000 VDC.

To understand the characteristics of high voltage (steady state or static discharge), it is valuable to play with a neon sign transformer. Sign shops replace them when they become noisy and fully-functional units are available at no cost by claiming to be a high school science teacher.

A neon sign transformer typically produces 10,000 – 20,000 VAC, limited to something less than 50/1000 Ampere. The very low current available reduces the likelihood of stopping your heart or burning you, but will give you an interesting tingle if you make a mistake. All experiments must be done with one hand in a back pocket and the other hand operating the equipment. This way, there is no path through the body. It is especially important to avoid a current path from on hand to the opposite foot, though the heart or from one hand to the other, through the heart. See Fig. 11.

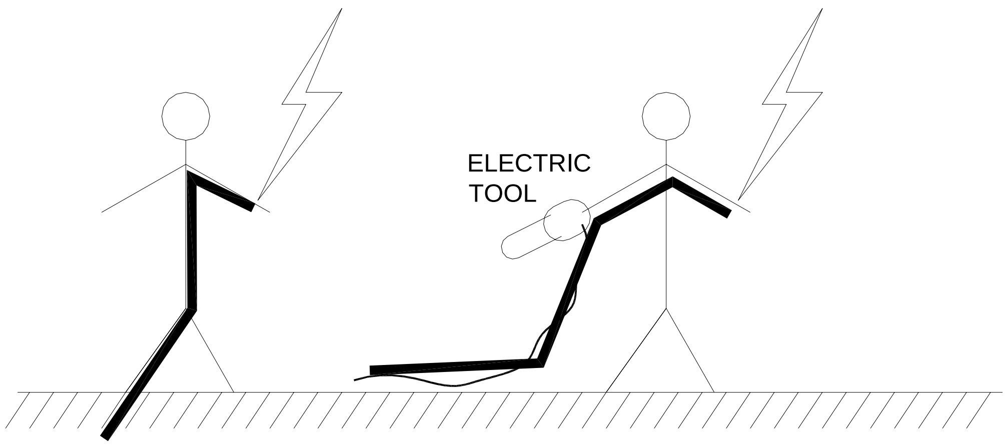


Fig 11 - Especially Hazardous Current Flows
NTS, 20Nov07

When these experiments were actually done for the high school science class an auto-transformer was used. This permits control of the 120VAC side of the transformer between 0-120VAC. This way, the effects of increasing the voltage can be seen. We used the dial on the autotransformer to say that 50% of 20,000 VAC means 10,000 VAC being observed. Measuring high voltage with a meter is not a good idea. See Fig. 12, below:

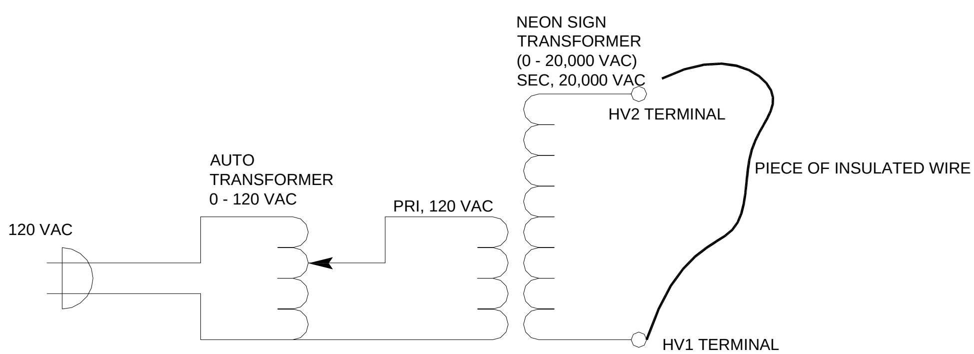


Fig 12 - High Voltage Test Circuit
(Don't do this at home - don't do it at all.)
NTS, 20Nov07

At (current-limited) low voltage, you brush one lead of the transformer against the other and a weak spark is created, as the strands of the conductor make and break contact. It looks like a spark and appears to be a small fraction of an inch in length (perhaps 1 mm).

As you turn up the voltage, you are able to pull a longer spark, reaching, perhaps 2-inches at the full 20,000 VAC. Some interesting things are observed, however. There is something random in initiating and maintaining the spark. It doesn't seem to start exactly the same way each time or from the same place on the fixed terminal or from the same place on the wire. Sometimes the spark extinguishes before you get the seemingly normal distance between the pieces. Ionized air is like this. I have a very nice video of a substation blowing up from a line-to-line high-voltage fault. The spark climbs in the air and dances around, then something explodes. (Anything containing water will explode when large current passes through it and creates steam.)

This experiment also produces interesting observations regarding wire insulation. If you use 50 V telephone wire, the high-voltage will burst through the insulation anywhere. It is like no insulation. If you use 600V house wiring, the 20,000 V will punch through any tiny damage in the insulation but will not punch through clean, new wire. As you move the wire along the fined terminal you can find the bad spots in the insulation. If you use 40,000 V tv high-voltage wire, the arc will burn the insulation at the end but will not punch through anywhere. 50V wire is intended to operate at 50V. 600 V wire is intended to operate at 120V or 240V or 480V or 575V in very old factories. 40,000 V wire is intended to operate at 40,000 V in old CRT televisions. 100,000,000 V will punch thru wire insulation unless we give a preferential path to ground. By the way, is it obvious why lightning protection conductors are not insulated ?

Our only discussion of current, or amps, so far, has been as part of the high-voltage experiment. Let us now address current directly.

An IPod run on 1/1000 ampere until its battery is discharged. The Federal Government, mentioned previously, had determined that 10/1000 Ampere (or 10 milliamperes or 10 mA) will kill you and sets the trip on ground fault interrupter (GFCI) receptacles at 5/1000 A. Most household appliances, TV, lamps, etc, operate on about 1 A. Your stove operates on about 30A, depending if you are on BAKE or BROIL and how many burners are glowing. Your car pulls about 100A from the battery to start. Things start to get dangerous above 100A.

A welder intentionally makes an arc, or continuing spark, with low voltage and high current. A maintenance welder has an open circuit voltage of about 30V and arc current of 200 – 400A. 30V is the absolute minimum to get an arc started by scratching the wires together.

A production welder may have 50 V open circuit and 800 – 1200 A current. For more, you use several welders and several electrodes. It is noted that production welder cables jerk suddenly when welding begins.

To understand the characteristics of high current (steady state or static discharge), it is valuable to play with a surplus filament transformer. Even today, vacuum tubes are used in some electronics applications (beyond vintage guitar preamps). A vacuum tube has a glowing filament. It glows because the equipment runs current through it. There is an industry which supplies replacement parts and junk parts for old electronics. The sales channel is termed, “Surplus”. You can easily purchase a 20A filament transformer for about $10 surplus. Shipping will cost more than you might expect. The filament transformer is designed to run continuously at 20A and will produce 500A for a short time. It fails by melting, not exploding. Such a setup was used for about 10-years without failure in a high school science class. The diagram, Fig. 13, follows:

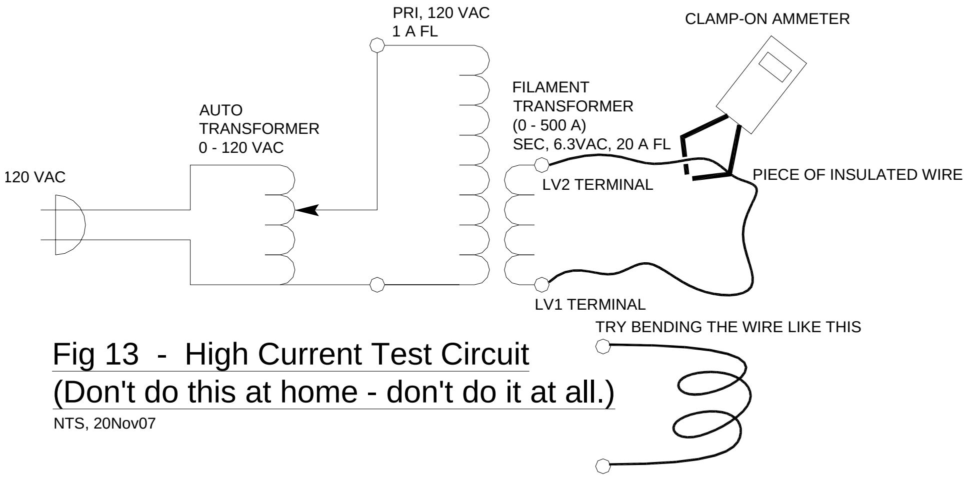


Fig 13 - High Current Test Circuit
(Don't do this at home - don't do it at all.)
NTS, 20Nov07

Fig. 14 shows the setup used by Colorado.edu for this demonstration

Fig. 14, from http://physicslearning.colorado.edu/website_new/Common/ViewDemonstration.asp?DemoCode=5H15.10

When these experiments were actually done for the high school science class and auto-transformer was again used. This permits control of the 120VAC side of the transformer between 0-120VAC. This way, the effects of increasing the current can be seen. A clamp-on ammeter is a non-intrusive instrument.

The wire is tightened down under the transformer terminals. If you try the "brushing" experiment, it tends to weld the wire to the terminal. That is because the current is not limited here, so we melt the wire and/or the terminal into each other. By the way, molten metal is a hazard, but this experiment is pretty safe, except for the 120VAC.

When we turn up the auto transformer to about 20% we see 20A on the ammeter. The filament transformer is operating at full load (FL). If the wire starts to get hot, we used too small a copper diameter. (This is OK, though, because the real test will last only 10-20 seconds.)

What can we see from 20A flowing through a wire, or if we turn it up to 200A for 10-sec ?

There should be a "twitch" of the wire if we turn it up suddenly. We may see a nearby screwdriver rattle while the large current is flowing. If we haven't cleaned up the bench well, we will see iron filings forming into patterns.

For the science class, we bought a small bottle of iron filings and sprinkled them around the wire. The photo from Colorado.edu shows a range of wires set up for display on an overhead projector. NFPA-780 is not concerned about the patterns formed is very interested in the "twitch" at 200A and the "jerk" expected at 100,000A.

The part about coiling the wire matches our understanding of electricity. In both sets of experiments we used transformers. These devices coil the wire intentionally to "group" the magnetism. That is what the second experiments were leading up to with the coils on the high-current side of the transformer. If we "group" the magnetism it magnifies the destructive forces. That is one of the reasons for the 8-in bend radius on lightning protection conductors. (The other reason is that a lightning discharge likes to go in a kinda straight line and if you try to turn it too sharply, it goes straight-ahead anyway.)

CONTENTS OF NFPA-780-08

This course has been devoted to the design application of the Standard for the Installation of Lightning Protection Systems, along with some extended diversions to deliver understanding of the underlying principles. The Standard is much more extensive in design details and includes additional information intended to save lives and property in special situations.

For this reason, the Table of Contents of NFPA-780-08 is paraphrased and annotated below:

Chapter 1 - Administration - thin, not intended as a Code

Chapter 2 - Referenced Publications - very, very thin

Chapter 3 - Definitions - Very, very good. Includes values for many of the variables discussed and references for values for the rest.

Chapter 4 - Protection for Ordinary Structures - This is the basis of most of this course.

Chapter 5 - Protection for Miscellaneous Structures - Things like masts, granaries, tipples, tanks, air inflated structures, silos. One page.

Chapter 6 - Protection for Heavy-Duty Stacks – Superb drawing and excellent discussion. Interestingly, almost all existing stacks have clear evidence of strikes at or near the lightning protection system. Take a good pair of binoculars and look at one sometime.

Chapter 7 - Protection for flammable vapors gasses and liquids. - The drawing on protection provided by a grounded mast, Fig 7.3.3.2 clearly demonstrates the rolling ball theory. The adjacent drawing demonstrates catenary protection of substations.

Chapter 8 - Protection for Watercraft - This is really, really interesting and especially meaningful if you participate in recreational boating.

Annex A - Explanations - These are notes keyed to the text sections of the Standard. In a Code, these explanations are non-enforceable.

Annex B - Principles of Lightning Protection - This is a good introductory explanation of lightning and Franklin lightning protection systems. It does not reflect latest research or innovative protection schemes. The field is advancing very rapidly. Check the copyright date on anything you read on the subject.

Annex C - Explanation of Bonding - thin

Annex D - Inspection and Maintenance - more bureaucratic than practical

Annex E - Ground Measurement - One method is demonstrated. The newer clamp-on ground testers are not mentioned. Reference to use of conductive salts belongs here, along with a warning about reduced conductivity on drying following the first strike.

Annex F - Protection for Trees - Check out how they address side-strokes.

Annex G - Protection for Public Open Places - This is much more extensive than you might imagine. Sideflash and touch potential hazards are addressed.

Annex H - Protection for Livestock in Fields - One good page.

Annex I - Protection for Parked Aircraft - The Standard recommends shutting down airports during thunderstorms.

Annex J - Not Used, this issue

Annex K - Protection of Explosives - There is considerable accumulated science in this area

Annex L - Lightning Risk Assessment - with formulas. This is a very quantitative method to perform a qualitative chore. The risk assessment may be valuable, but standard Value Engineering techniques yield better, and more justifiable recommendations.

Annex M - Personal Safety - Inside is better than outside, unless it is a shed or tent. Tractors, golf carts, bicycles, motorcycles, open boats and autos are rated especially hazardous.

Annex N - Wind Turbine Protection - This is an emerging area of study. Protection of the mast and blades is only now being invented. Conventional methods of protecting the controls appears adequate, but overlooked in most installations.

Annex O - References - Excellent bibliography of bureaucratic references. Nothing on established research programs, not even the National Lightning Detection Network

Index - The hyperlinked index, available online is especially valuable.

Note that the full Standard is available for reading, at no charge, at http://www.nfpa.org/freecodes/free_access_document.asp.