

Protecting Broadcast Facilities From Lightning

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Abstract

Lightning strikes cause more damage to broadcast site equipment than any other natural phenomenon. With radio towers taller than surrounding terrain, lightning tends to be attracted to these sites. This paper will describe some of the elementary physics of lightning, describe the characteristics of a "typical" lightning strike and detail specific steps that broadcast engineers can take at the tower, tuning units, transmitter building and studio to shunt lightning currents away from equipment. It will deal with treating power lines, transmission lines, control cables and telephone lines in addition to specific pieces of equipment, such as solid-state transmitters.

1.0 Introduction

Since the first antenna tower was erected in the early days of radio, lightning has been a hazard which radio engineers have had to deal with. Man has known throughout history that lightning is an arbitrary, random and unpredictable phenomenon. Despite our ever-improving technology, lightning remains beyond man's ability to control.

The insurance industry tells us that in the US alone, lightning causes more than 26,000 fires with damage to property in excess of \$2 billion. One damage claim results from every 57 lightning strikes. Worldwide, there are typically 2,000 thunderstorms in progress at any one time in which 100 lightning strikes occur each

second.

While we may not be able to accurately predict or control lightning, there are steps that can be taken that will mitigate the amount of damage that a lightning strike causes.

2.0 Strike Characteristics

The type of lightning that does damage to broadcast installations is the discharge of energy from an electrically charged cloud to the ground. Cloud-to-cloud discharges seldom cause damage on the ground.

When lightning strikes the earth or an object on the earth, a more-or-less usual sequence of events occurs. First, downward "leaders" from a highly-charged thunderstorm cloud pulse toward the earth, seeking out electrical ground targets. Objects on the ground, such as buildings, trees, power lines and radio towers, emit differing amounts of electrical activity during this event. Streamers are launched upward from some of these objects. Some of the downward-going leaders connect with some of the upward-reaching streamers. It is at this point that the circuit is completed and current flows. The arc is then visible, and the superheated air displaced by it creates the thunderclap.

There are ways to dissipate static charge from a tower structure that reduce the attractiveness of the structure for a strike. These treatments are worthwhile in many cases and may be cost-effective for some installations. Most broadcast facilities do not have static dissipator arrays, however, and

we must deal with the problem from another direction. If we cannot prevent a strike from occurring, the goal becomes to give its energy a place to go that bypasses sensitive equipment.

A “typical” lightning strike has a peak amplitude of 20,000 amps and lasts 40 microseconds to half amplitude. Some lightning pulses can reach 400,000 amps and reach temperatures of 50,000 degrees Fahrenheit. The rise time of a typical strike is about 5 microseconds to peak amplitude.

The current path in a lightning strike is from the cloud to what we call “ground”. A perfect ground connection, however, does not really exist, and any real ground connection will have both a finite DC resistance and AC impedance of from several ohms to several hundred ohms. Applying Ohm’s Law, you can see that a large potential can be developed from a ground connection to “real” ground. Several million peak volts or more can easily be developed in such a situation.

In a typical broadcast transmitter or tower site, there is a ground at the tower base and a number of other ground points. The current from a lightning strike will see several parallel paths to ground. For example, the ground rod(s) at the tower base will be one path, the outer jacket of the transmission lines through the equipment cabinets to the transmitter building ground will be another, and the AC safety ground wiring to the distribution panel ground on the tower light wiring still another path. If you can imagine an equivalent circuit of these several resistive paths in parallel, you will be able to grasp the idea that even with a solid ground at the base of the tower, large and damaging potentials can be developed across the other paths. In addition, the fast-

rise-time currents that will flow in all these paths will produce large magnetic fields that will induce significant unwanted currents in nearby conductors such as AC wiring, control cables, audio lines and the like. These are sometimes the most damaging by-products of a lightning strike.

3.0 Grounding Systems

3.1 Ground Rods

The most important principle of lightning protection, as most of already know, is to provide the best, lowest DC resistance and lowest AC impedance local ground connection possible as close to the tower base as possible. This is usually best achieved by using an array of at least four ground rods driven around the tower base pier and tied together with a large copper conductor. The rods should be separated by at least twice their length, and ideally they should penetrate below the deepest frost level into the water table. Exothermic (welded, not clamped) 1/0 or larger bare copper wire to the rods, making a ring connecting all the rods and then connecting each rod with a separate length of wire to the tower base. The tower connection should also be welded. A wire connected to the tower by way of a lug or using a bolt and washer will have a lot higher resistance than a welded joint.

In some areas where the soil is particularly dry and non-conductive (such as a mountaintop with no water table and little top soil), there are chemical ground rods available to lower the impedance of the ground connection. These rods contain a chemical paste that over the life of the rod seeps into the soil into which the rod is driven through weep holes in the rod. Once

the chemical paste has been exhausted, the rod must be replaced. The service time of the various chemical rods is listed in their specifications.

3.2 AM Ground Considerations

Those with AM towers should not be fooled into thinking that the ground screen and radial system provides a good lightning ground. In some areas with very conductive soil, this may be true, but in many locations it is not. A set of rods should be installed at the tower base and connected with 1/0 cable or larger to the ground side of all the arc gaps. Unless it is a certainty that the local soil is conductive enough to make the screen and radial system an adequate lightning ground, use an array of rods.

AM tower bases should also have their antenna tuning unit (ATU) chassis connected to the tower base ground rod array. Even with the best ground rod array, some portion of the current is going to flow in the parallel path presented by the tower feed tubing to the ATU. Once it hits the ATU chassis, it needs a low-impedance path to ground to prevent it from flowing through ATU components and into the transmission line. Most modern ATUs have a horn or ball arc gap right at the point where the tower feed tubing leaves the chassis. The ground side of this gap needs to be tied into the ground rod array. If your ATU does not have an arc gap at this point, you can purchase one inexpensively from Kintronic Laboratories, Phasetek and other manufacturers.

4.0 **Transmission Lines**

In most cases, the tower at a broadcast transmitter site is located some distance from the transmitter building.

Whether this is twenty feet or several hundred, the transmission line outer conductor needs to be firmly connected to the ground rod array at the point where the line leaves the tower in FM and grounded-base AM towers. Transmission line manufacturers offer grounding kits for their various lines that provide a secure, weatherproof ground connection to the outer conductor.

A component of the current from a lightning strike that hits the top of a tower with one or more transmission lines will flow down the tower structure and a portion will flow down the parallel path presented by the transmission line outer conductors. If the transmission line outer conductors are not properly bonded to the tower structure at the top and bottom (and at the manufacturer's recommended interval along the length of the lines for long runs), large potentials can develop between the lines and the tower structure. When the potential exceeds the breakdown voltage of the outer jackets, it will arc through. Such an arc can be sufficiently hot to actually create a pinhole in the outer conductors, making a way for pressure to leak out and water to get in.

This parallel current in the transmission line outer conductor needs a place to jump off to ground before it travels into the transmitter building and into your equipment. This is why the outer conductor of every line leaving the tower needs to be bonded to the ground rod array in addition to being bonded to the tower structure.

For long horizontal transmission line runs, it is a good idea to provide one additional grounding point for the outer conductor just outside the transmitter building. This ground should be the central

point of the ground array for the transmitter building. Shorter lines, where the tower is within ten or fifteen feet of the transmitter building, do not need the additional ground.

5.0 Tower RF Feeds

A piece of copper tubing is usually employed to carry the RF current from the AM antenna tuning unit to the tower itself. As already noted, this tubing presents yet another parallel current path for lightning currents.

While a path to ground for this current by way of an arc gap at the output of the ATU can and should be provided, what is in essence a “pi” low-pass filter can be created with the tower feed and the tower and ATU arc gaps, making this parallel current path very unattractive for lightning currents. This is done very simply by winding one or two turns into the tubing on a 12 or so inch diameter to form a series inductor. This series inductance will present a high impedance to the fast rise time lightning current while the arc gaps at either end present a very low impedance to ground. Adding a couple of turns to the feed tubing will often require a slight retuning of the output leg of the ATU network, but the payoff can be greatly reduced potential for ATU damage due to lightning strikes.

6.0 Arc Gaps

Arc gaps consist of two conductors spaced a certain distance apart with an air space between them. They give lightning current a path to ground on an insulated tower. When the potential between the two conductors exceeds the breakdown voltage of the dielectric (air), ionization occurs and

a very low-impedance path between the conductors develops.

Commonly seen in AM installations are ball gaps, which are common at tower bases, and horn gaps, which are more commonly seen in phasing/coupling equipment and transmitters. Many times, transmitters feature gas-discharge gaps with a specified voltage rating across the RF output terminals.

Proper spacing of air gaps makes the difference between a gap providing the proper level of protection and having little effect in terms of lightning protection. At sea level, the breakdown potential of air is about 5 peak kV per 0.1 inch, or 1 peak kV per .020 inches. As altitude increases, the breakdown voltage decreases. A good rule of thumb is to reduce the breakdown voltage by 20% for every 5,000 feet AMSL.

The peak modulated RF voltage across the base of an AM tower can be calculated by the following formula:

$$V_{PEAK} = 3.182 \times Z_A \times I_A$$

Where: Z_A = antenna impedance in ohms
 I_A = antenna current in RMS amps

Once the peak modulated RF voltage is known, multiply the voltage in kV by 0.020 to determine the proper ball gap spacing. Horn gap spacing can be calculated using the same method, but the sharper points on a horn gap may require slightly wider spacing.

On a practical level, the optimum spacing for an arc gap is that which is just wider than the point which produces arcs during normal full-power modulated

operation. Remember that the wider the spacing, the greater the potential which must develop across the gap before the air ionizes and the gap conducts. This translates to higher voltages applied to ATU components, isocouplers and the like, which beyond a certain point will cause serious damage and result in down time.

7.0 Station Equipment Protection

7.1 Station Reference Ground

The heart of any effective lightning protection scheme is a central ground system. Such a system is shown in Figure 1.

Some call this a “star” grounding scheme because of the way all the ground conductors return to a central point or reference ground. If the transmitter building is located very near the tower, this ground can be the same as that for the tower itself. In most cases, however, there will be some distance between the tower and transmitter building, and in those instances, another array of ground rods should be provided.

All conductors operating at ground potential that enter or

leave the transmitter building, including transmission lines, control cable shields, and conduits, should be bonded to this ground array.

A single conductor from the ground rod array should be brought into the transmitter building via the shortest and straightest route possible. The point where it enters the building becomes the center of the “star”, or the point to which everything in the building is grounded. This is called the “station reference ground”. All grounds in the building, including the safety ground of the electrical system (service entrance ground) and the ground conductors from all

the equipment and outlets, then connect to this point. Figure 1 is a diagram of a properly-designed station grounding scheme.

Beware of having a separate ground rod connected to the electrical service entrance. Such separate rods are standard practice, but having a separate rod connected can spell trouble as a huge potential can develop between the station reference ground and a separate rod outside the system.

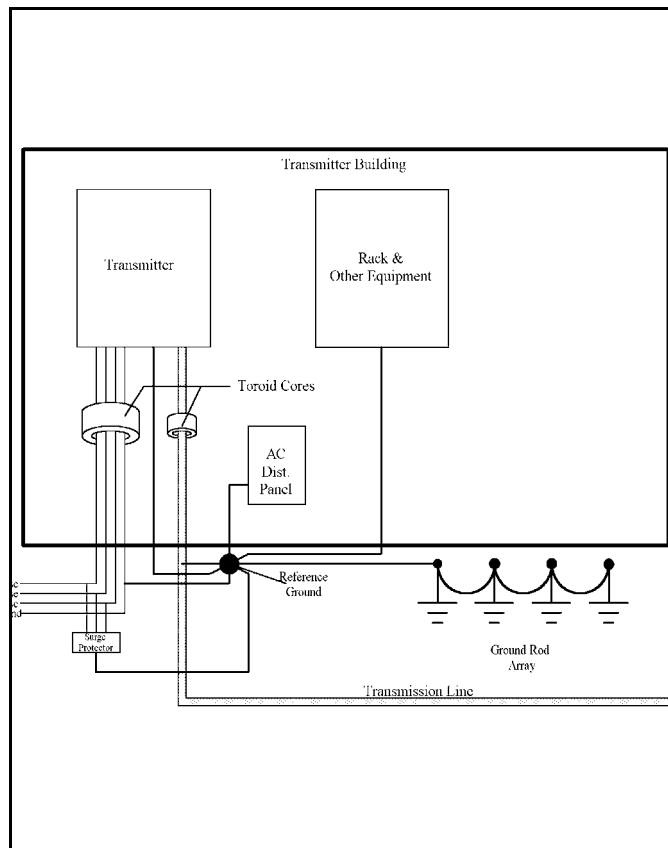


Figure 1

If you have a ground strap or

terminus of an AM radial ground system coming into the transmitter building from the tower(s), be sure to connect it to the station reference ground. If there is no such strap coming from the tower(s) you do not specifically need one, but an advantageous location for a transmitter building is often at the end of the ground system at the end of the transverse ground strap. If this is the case, that strap may have been extended to connect inside the building.

When connecting transmitters, racks and other equipment to the reference ground, it is important to do so in such a way that lightning currents will not flow through the equipment cabinets enroute to ground. On a transmitter, for example, make the ground connection as close to the RF output connection as possible. In that way, residual lightning currents coming in on the transmission line outer conductor can flow through the short copper path to the ground conductor and not through the metal of the cabinet. Such currents create a strong magnetic field that will induce currents into nearby unshielded conductors. By keeping surge currents out of the cabinet steel, this keeps them out of the transmitter's wiring harness as well.

7.2 Transformer Configuration

If the site has three-phase power, when it comes to lightning protection, a "wye" secondary on the utility power feed is preferable. This type of connection has several advantages, the most important of which are that every leg is referenced to ground (balanced with respect to ground) and the lower voltage (208) is easier to clamp in surge conditions.

Unless you specify a 208-volt wye, the utility company will probably provide a

delta. Worse, they will probably save themselves a transformer and provide an *open* delta, which is terrible from a lightning protection standpoint.

Most all broadcast transmitters will operate just fine on anything over 200 volts, so switching to 208 volts will pose no problems. A change of taps should be all that is required. Beware, however, of the increase in current. Service conductors and disconnects sized for 240 volt operation may be too small for use at 208 volts. If undersized conductors are not replaced with those of appropriate size, a fire hazard will exist.

7.3 Surge Suppression

A good surge suppressor is the only way to minimize lightning transients on the incoming utility power. These devices range from inexpensive "kamikaze" devices that work one time and have to be replaced, to very expensive series/shunt devices. Somewhere in between is an economical device that will adequately protect the equipment at most every broadcast facility without breaking the bank.

The metal-oxide varistor (MOV) is at the heart of most shunt-type surge suppressors. These devices conduct when the potential across them exceed a threshold voltage. The devices must be rated to carry most of the anticipated lightning current. This may seem like an impossible specification, but the device only has to carry the current for a very short period of time.

Modern surge suppressors are available with fused MOVs in many voltage ratings that will hold up well under typical lightning surge conditions, clamping the AC line to ground during the surge and thus

protecting equipment downstream. The fuses are designed to act slowly, holding their state for the short duration of the surge but blowing if the MOV becomes shorted as a result of excess current. The affected MOVs and fuses can then be replaced and the effectiveness of the surge suppressor restored.

Be sure to install the surge suppressor downstream of the main fused disconnect at the site. The ground connection from the surge suppressor must connect to the station reference ground. All the conductors to the surge suppressor must be relatively large, as the instantaneous currents that they will be called upon to carry can be substantial.

When it comes to surge suppression, the best policy is to buy all you can afford. If the budget can sustain a \$10,000 series-shunt type, this will provide a high degree of protection. If the little “kamikaze” cans are all that the budget will stand, buy and install them. Any working surge suppression is better than none. In practical terms, the insurance deductibles and premium increases you will save may well pay for one of the more expensive units in just a few years.

7.4 Cable Protection

The final step in creating an effective lightning protection scheme is to build a low-pass filter into all your power, control and monitor cables. This is easily done by placing a toroid core over the conductors. This effectively forms an RF choke that presents a very high impedance to fast rise-time lightning energy. Such cores are available from most mail-order electronic parts houses, and they come in a variety of

sizes.

One such core should be placed over each of the cables entering a transmitter cabinet or rack. Run all the AC power wires through a single toroid. Pass the remote control cable through a core, and do the same with any small coaxial feeds (RF drive, mod monitor sample, etc.). Finally, for transmission lines up to and including 1 $\frac{5}{8}$ ”, install one or more cores on the cable just above the connector.

Larger, rigid transmission lines should be installed so that they form a “trombone” section, making at least three 90-degree turns before connecting to the transmitter. The 90-degree bends also present a high impedance to lightning energy.

8.0 Conclusion

Although the focus of this paper has been on transmitter site lightning protection, the same principles can be applied at studio and other locations as well. There is no substitute for good surge suppression on the incoming studio AC power feed, and provide good grounds and install toroids on transmission lines coming in from the STL tower. The studio is a place where multiple grounds can easily exist, especially if the building has been expanded over the years, so close attention should be paid to this.

There is no way to completely lightning-proof a site, but by taking some effective steps, the probability of sustaining significant damage and down time can be greatly reduced.. Money spent on shunting lightning away from a site and equipment will pay dividends many times over during the life of the site.