

Installation Methods for Protecting Solid State Broadcast Transmitters Against Damage from Lightning and AC Power Surges

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Introduction

Broadcast transmitters have historically been manufactured using high power vacuum tube technology. In the past two decades, however, the broadcast industry has been progressively converting to all solid state transmitter designs, because of their greater reliability and efficiency compared with vacuum tube transmitters. The power vacuum tube has the disadvantage that it slowly fails with use, and it consumes much more power for a given output than its solid state counterparts. However, it has a major advantage over solid state – it can withstand a great deal of abuse and keep on working. Tube transmitters can operate into substantial load mismatches and have been known to absorb a large number of power line and antenna surges and transients with little or no damage. Transistors and other solid state devices, on the other hand, will operate almost indefinitely without degradation if their maximum operating values are never exceeded, but can be destroyed in just a few milliseconds of over-voltage or over-current conditions.

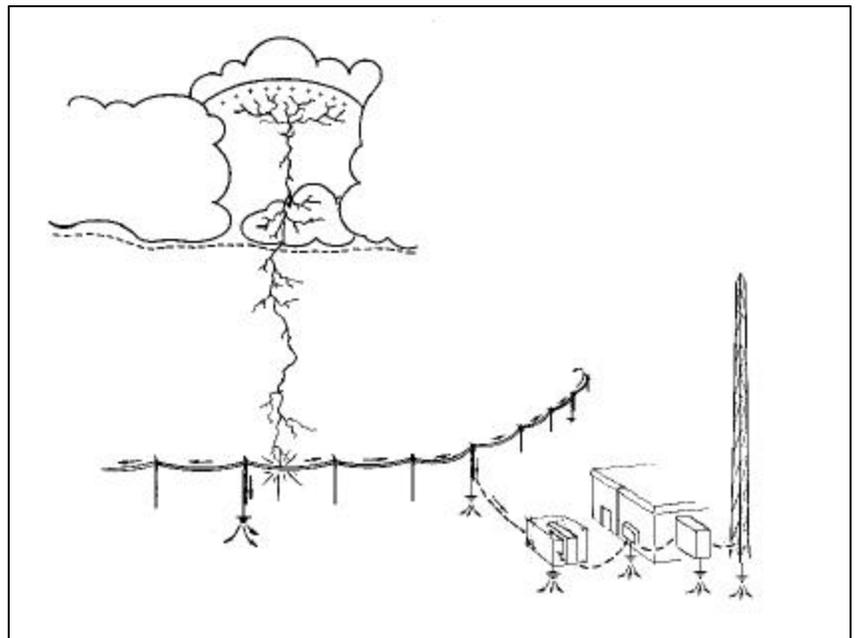
All solid-state products shares these risks, but broadcast transmitters face much greater risk because of their class of service. The typical transmitter is installed at a rural, remote location, often at the end of a long power line, where it receives all of the voltage instabilities and transients caused by users farther up the line. Further, it is often installed at high altitude locations and directly connected to a tall tower, which performs as an excellent lightning rod. At the same time, unlike many other types of commercial and consumer electronics, high reliability and continuous operation is required for its class of service – a failure can mean great economic loss and possible loss of a critical public service in time of emergency.

It stands to reason, then, that much greater care and planning of the installation is required when replacing a tube transmitter with a new solid state model. It is incumbent upon the broadcast engineer to understand methods of surge protection and grounding necessary for a proper installation. If he follows these procedures correctly, the solid state transmitter he installs will perform with a reliability unheard of only a few decades ago.

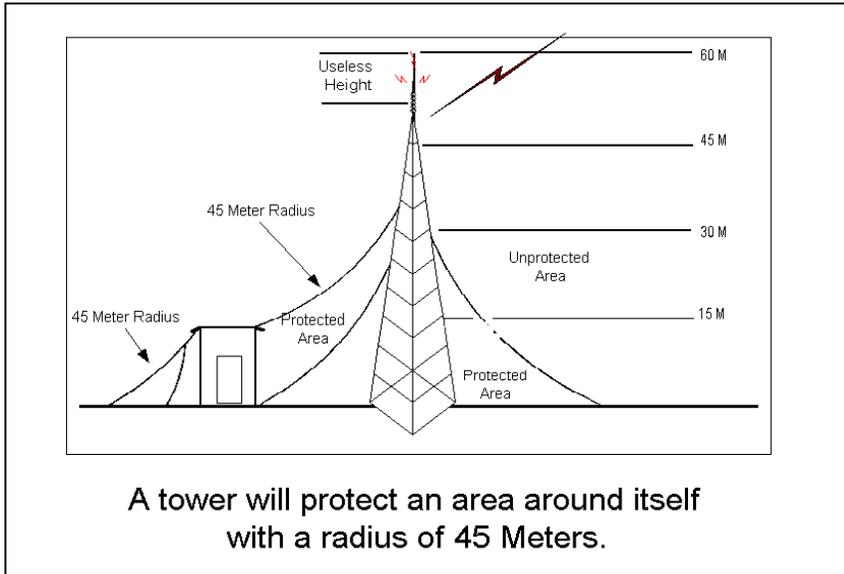
Lightning

Lightning can cause the greatest damage to broadcast equipment of any externally generated event. Lightning will strike the highest object and will take the path of least resistance on its way to ground, and a broadcast tower becomes an attractive target, by nature of the fact that it is an excellent electrical conductor and offers many connections to earth ground. Because of the great risk that lightning represents, it is important to comprehend its nature, which is key to understanding the methods of protecting yourself from lightning-induced damage.

Lightning is created by weather conditions, most prevalent in the spring and summer and in tropical climates. When a warm air mass meets a cold air mass, tremendous upsurging



convection air currents are created. Friction between these air masses creates static electricity in the cloud formations. A negatively charged cloud layer will positively charge the ground beneath it, resulting in a condition much like the two opposing plates of a capacitor. When this charge overcomes the dielectric resistance of air, a current will flow between them to neutralize the charge, in the form of lightning. These discharge currents can pass either from cloud-to-ground or cloud-to-cloud. The latter can be just as destructive as a direct ground strike, because they create sympathetic currents in the ground beneath the discharge.

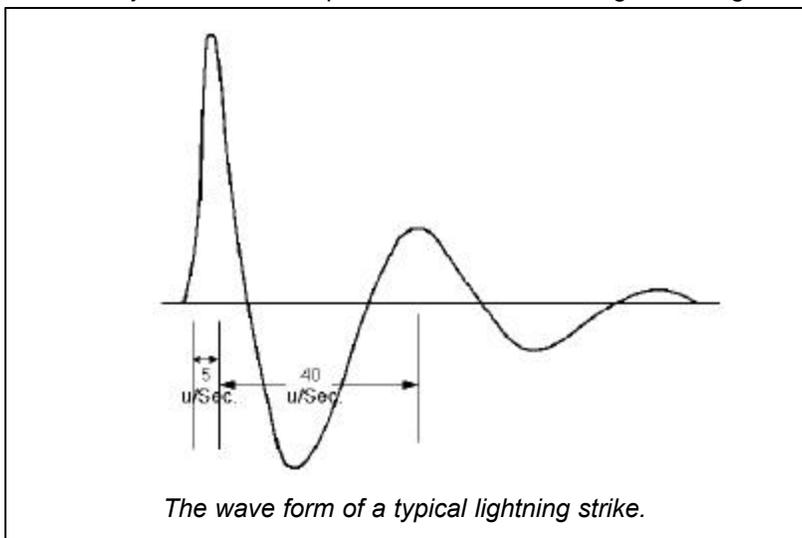


Lightning will strike the tallest conducting object in the vicinity. Thus a tall tower will shield the area surrounding the tower, and this area has the shape of a cone with the tower at its apex. The taller the tower, the larger the area that it shields.

There are many ways to deal with the possibility of lightning strikes on a radio tower. One is to take steps to prevent lightning from striking the tower. The most effective means of doing this is to install an ionization dissipator at the top of the tower. This is an array of multiple sharp steel points, connected to ground by a substantial conducting cable. It has long been known that a sharp point in the air will attract the ionized air particles, drawing the charge out of the air in the area surrounding the point. There is a limit to how

much current each point can draw, and so to make it more effective, many points are installed. These take varied forms, from the relatively inexpensive "bottle brush" style to large, umbrella-like dissipation arrays which can be expensive and add considerable weight and wind-load to a tower structure. The use of all but the largest ionization dissipaters can be a double edged sword: there are limits to how much charge each point can attract, so the current drain is limited by the number of points. When the charge buildup exceeds the ability of the device to drain it, the device can act as a lightning rod and becomes a lightning COLLECTOR, actually attracting the largest lightning strikes. Also, its effectiveness is only as good as its ground connection.

There is another, simpler approach to lightning damage mitigation: to simply accept the fact that lightning will strike the tower from time to time, and to take steps to minimize the damage by providing an attractive and direct path to ground. Concurrently, any paths that pass to ground through the station equipment are made as unattractive as possible. To successfully achieve this requires some understanding of how lightning currents behave in a conductor.



The average lightning strike has maximum current of 20,000 Amps, and there are occasional strikes that exceed 100 thousand amps! The typical lightning surge has a rise time of 5 microseconds, and then takes another 40 microseconds to decay to half amplitude. Because the earth has a measurable resistance, it will be impossible to attract all of this current into the ground. A typical radio tower site will have a ground resistance of from 5 to a few hundred ohms, consisting of the resistance of the soil itself plus the resistance of the electrode's connection with the soil. Additionally, there are many paths to ground at a typical site, each having its own impedance. Thus, the path to ground will resemble a parallel resistor network,

with different levels of current flowing in each leg. Some of these paths to ground will be direct, but others will invariably pass through the station equipment. The installation objective should be to improve the effectiveness of the direct earth connections, and reduce the currents in those paths through station equipment to the extent possible. More on this later.

If we presume a ground resistance of 50 ohms, then Ohm's law tells us that with a current of 20,000 Amperes there would be one million Volts peak voltage drop between the tower ground system and true earth. This voltage will appear between the shield of the coaxial cable and ground, and some if it will try to find a path to ground through the transmitter's cabinet. Further, any current flowing in the coax shield will be inductively coupled to the center conductor, which will appear at the transmitter's output network. This is a frequent cause of lightning-induced arcing inside a transmitter.

Power Line Surges

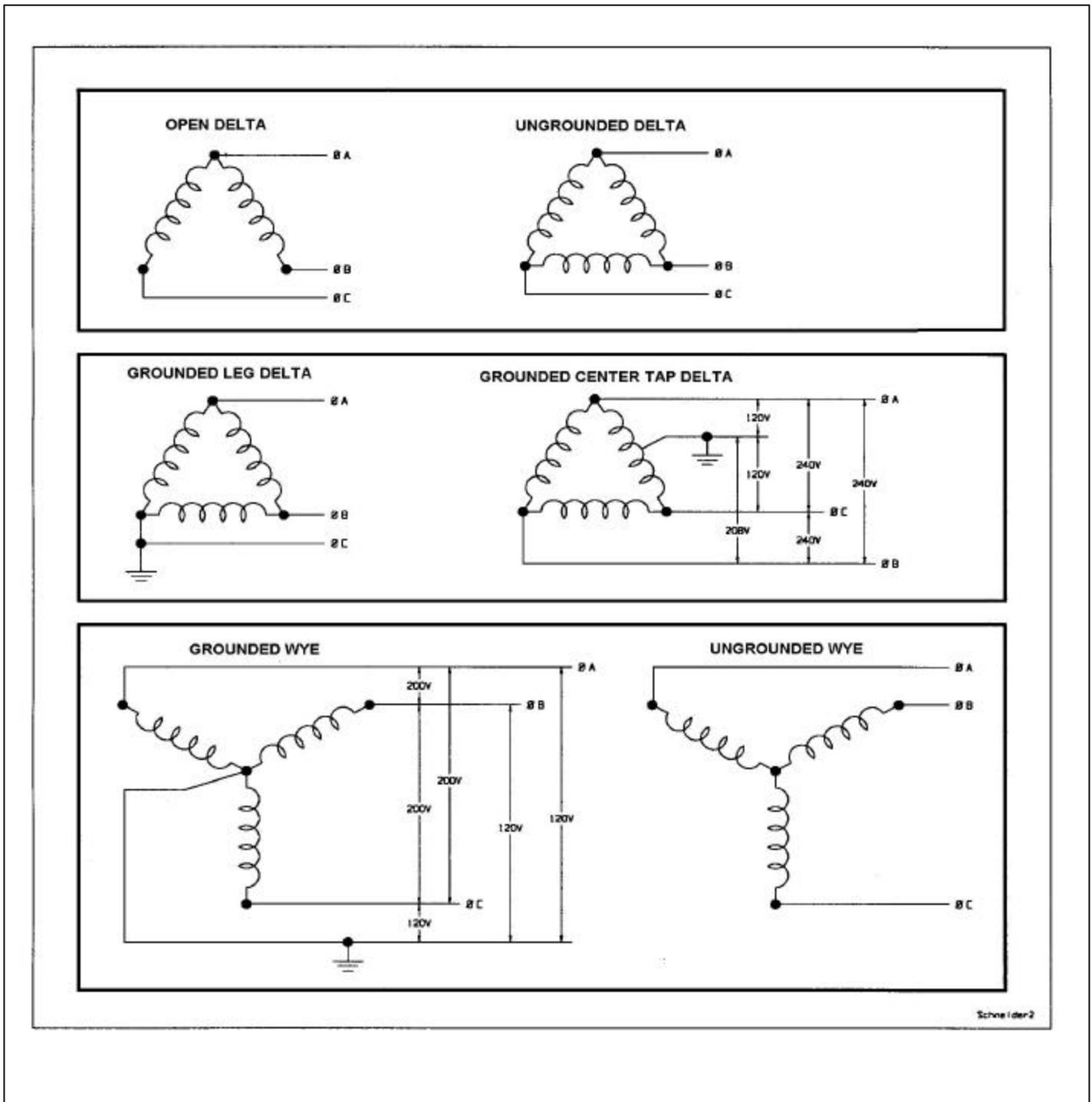
Another major source of damage to solid state transmitting equipment is power line voltage instability. It's a difficult job for a power company to provide reliable, stable power – even more so in rural electrical service. Power providers have little actual control over their users. Voltages rise and fall with varying load demand, and inductive loads such as electric motors operated by other users on the same line cause voltage transients and surges to be fed back into the line. After a wide area power outage, line voltages can be extremely unstable when power is restored until the load is stabilized. Large voltage surges can also be induced into power lines by lightning strikes to other users or AC transmission lines, often many miles distant. It has been shown that the average urban power system in the United States experiences some form of line voltage anomaly more than four times per day, and this occurrence can be even more frequent in some other countries.

These voltage surges and transients can cause damage to power supply components of broadcast transmitters, and can also damage other circuitry beyond the power supply. In short, the broadcast user cannot rely on his power service provider to maintain stable voltages at all times, and must take reasonable precautions to protect his sensitive equipment from the vagaries of the power grid. Fortunately, a wide variety of AC transient protection devices are available on the market today, which, when properly installed, can greatly reduce the incidence of power-caused transmitter damage.

The stability of three-phase AC service is greatly dependent upon the type of service connection provided. Here are the main types of three phase transformer hookups, and their relative merits:

- a. OPEN DELTA: This is the worst possible choice. The open delta provides no inherent transient suppression, plus can experience wide voltage fluctuations on the phantom or "wild" leg. The open delta connection should be always be avoided for broadcast transmitters.
- b. UNGROUNDED OR FLOATING DELTA: While better than the open delta connection, this service can still be problematic because no ground reference is provided. Thus, while voltages between legs can be relatively stable, the voltages can vary widely with respect to ground.
- c. CLOSED DELTA with a grounded center tapped winding or grounded leg. This is better than the floating delta because it provides a ground reference, but each leg is still not equally referenced to ground. It can still suffer from differential mode surges (leg to leg).
- d. WYE: This is the best option, because each leg is balanced and equally referenced to ground.

The type of AC power connection will determine the nature of any line surge protection equipment installed to protect it. If the power source is unbalanced, surge arrestors must not only provide leg-to-ground suppression, but also leg to leg.

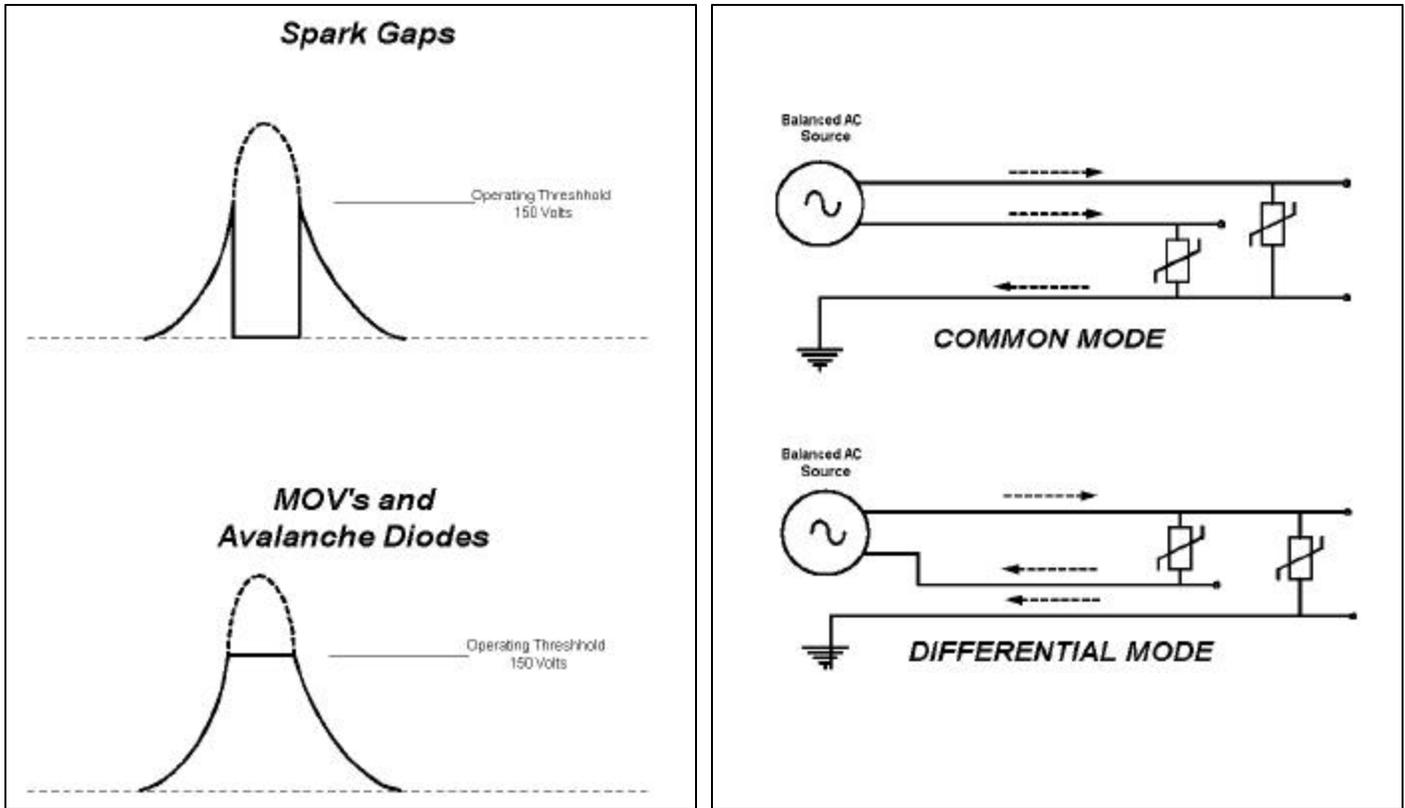


Basic Tools

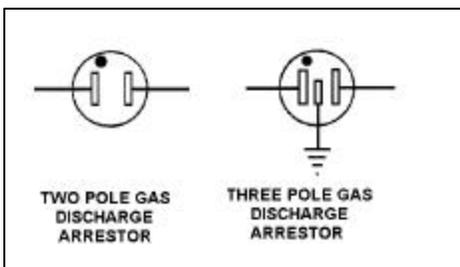
A. Surge Protectors

There are a number of different surge protection technologies, which vary in robustness and effectiveness. They are all based upon the basic premise of a voltage-clamping device in shunt with the main power line. The voltage threshold of this device is chosen so that it has no effect at normal line voltages. However, when the line voltage exceeds the threshold, the device conducts current, either clamping at the threshold voltage (as in as a zener or avalanche diode), or

else shorting the line completely (as in an ionized gas discharge tube). These devices may be connected between each conductor and ground (for common mode surges) as well as between conductors (for differential mode surges), and are selected for both their attack time and current handling capacity. Some systems also provide an inductance in series with the load that is transparent at AC line frequencies but provides substantial reactance to high frequency transients.

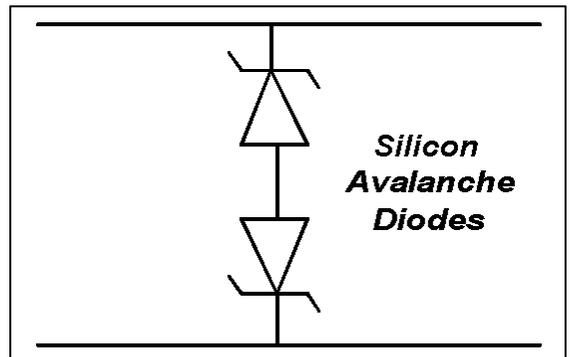


Some of the various kinds of transient shunting devices available include:



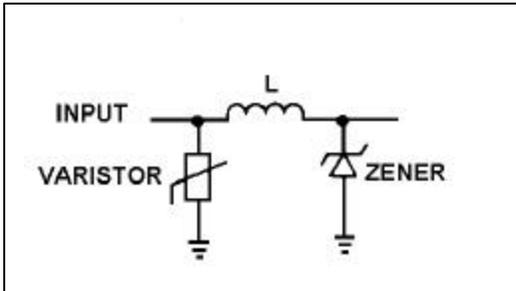
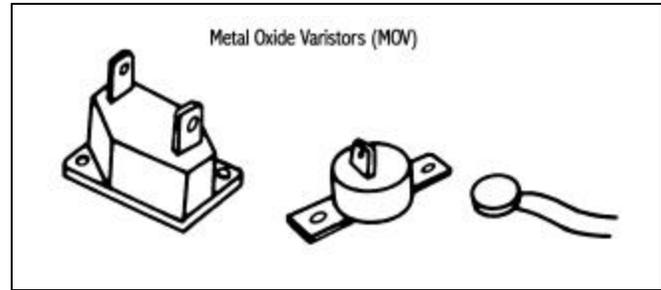
1. Air spark gap: Two terminals are spaced far enough to withstand normal voltages, but will arc and conduct during excessive voltages. These are very slow acting, as the air between the gaps must ionize before the gap will conduct, but their current carrying capacity is only limited by the physical size of the terminals. The most familiar example of the air gap is the ball gap found at the base of an insulated AM tower.

2. Gas discharge spark gaps: These consist of a spark gap sealed inside an inert gas chamber. The gas will ionize more quickly than air, but these are not as rugged as an air gap. They are also available in bipolar configuration, for protecting both sides of a balanced line: both poles conduct at same instant once the gas ionizes, thereby eliminating the possibility of differential mode surges.
3. A pair of back-to-back zener diodes is often used as a low current protection device across the output of each leg of a bipolar power supply.



4. More effective than the simple zener is the silicon avalanche diode, such as General Semiconductor's TRANZORB. It is similar to a zener, except for its much larger junction size and current capacity.

5. The most popular surge protection device presently is the MOV, or Metal Oxide Varistor. MOV's work much like an avalanche diode, clamping above a critical threshold voltage. They are slower to act than an avalanche diode, but can handle much greater currents. MOV's are available in a wide variety of power ratings and voltages, and vary from small packages resembling a disk capacitor, which can be installed at the circuit to be protected, to the large capacity blocks that are typically installed at the service entrance of a building. MOV's suffer from the drawback that they degrade in performance over time as the metal oxide substrate is eaten away by repetitive conducting cycles, until the device finally fails to conduct entirely. Two rules of thumb apply to the use of MOV's: First, they should be rated to clamp at approximately 1.5 times the normal peak circuit voltage. Secondly, they can fail in either a shorted or open condition, and so should be installed in series with a fused disconnect or circuit breaker. This allows the protected equipment to continue in operation in the event of a shorted MOV, and prevents the possibility of fire damage from an exploding MOV. Also, be aware that while effective at AC power line frequencies, an MOV can add some capacitance to a circuit, and this can create signal leakage at higher frequencies, such as in an audio circuit.
6. The Thyrite surge arrestor is a voltage dependent resistor installed in shunt across an AC line. Their advantage is that they are always conducting, so there is no turn-on time. The normal dissipation is about 40 watts, so the device will feel warm to touch if working properly. Thyrite surge arrestors are typically available in the \$1,000 to \$1,500 price range. The thyrite surge arrestor is less popular today than a few years ago, as its reaction time is not fast enough to protect modern digital electronics. However, its large current-handling capacity makes it well suited as a second-level protector.



7. Most commercially manufactured systems today are hybrids, using several of the above devices in a single package. An example of a simple hybrid device is an MOV in shunt, followed by an inductor series element, and then by avalanche diodes in shunt. In this circuit, the diodes clamp more rapidly, but the MOV absorbs the majority of the surge. The purpose of the inductor is to drop the voltage enough to force MOV to conduct. Hybrid arrestors can run from less than \$1,000 to more than \$20,000, depending on current-carrying capacity and effectiveness.

B. Single Point Grounding

The majority of surge arrestor devices are installed in shunt between the line and ground, which can be either an earth ground or the power line neutral, which is in turn connected to ground. Thus, the quality of the ground connection is as important as the surge arrestor itself, which can only operate if it has someplace to send the surge. Equally as important as the quality of the ground connection is the topology of the connection itself.

Most system installations have many pieces of interconnected equipment, all of which require grounding. If each device has a different path to earth ground, voltage differentials will develop between these grounds, and currents will flow between them. In the event of a high rise-time surge, such as a lightning strike, the currents tend to act in a conductor more like AC than DC. Lightning currents will oscillate inside a conductor as damped wave at a frequency in the VHF region. This means that the inductive reactance of a conductor becomes more important than its DC resistance, and it doesn't take much inductance to create an inductive reactance at that frequency. Consider a copper conductor 6 Meters in length of #6 AWG wire. It has a DC resistance of 0.013 Ohms and an inductance of 10 uH. For a 1000 Amp surge with a one-microsecond rise time, the resistive voltage drop is only 13 Volts, but the reactive voltage drop is 10,000 Volts! This higher instantaneous voltage will build up at the source end until the current can overcome the inductance and flow through it. Further, any bends in the conductor will greatly increase the inductance -- a 90 degree bend in the path can be thought of as a quarter-turn coil, and the sharper the bend, the greater the inductance. An additional problem is created by the "skin effect" at that frequency, where the current will only flow on the surface of the conductor, which makes the surface area more important than the cross-sectional dimension in the conductor's ability to pass current.

Six Meters of #6 AWG Wire:

$$R = 0.013 \Omega$$
$$L = 10 \mu\text{H}$$
$$I = 1,000 \text{ A.}$$
$$f = 1 \text{ MHz (1 } \mu\text{Sec./cycle)}$$

$$E = I R$$
$$E = 1,000 \text{ A} \times 0.013 \Omega$$
$$E = 13 \text{ V.}$$

$$X_L = 2\pi f L$$
$$X_L = 1 \text{ MHz} \times 10 \mu\text{H}$$
$$X_L = 6.28 \times 10^6 \times 10^{-5}$$
$$X_L = 63 \Omega$$
$$E = I X$$
$$E = 1,000 \text{ A} \times 63 \Omega$$
$$E = 63,000 \text{ V.}$$

There are three methods generally accepted to reduce the inductance and equalize ground voltages in a system installation:

1. Make all connections to ground as short and straight as possible, to reduce the inductance to a minimum.
2. Use large cross-section conductors to maximize the current carrying capacity in consideration of the skin effect, such as copper strap or large cross-section multiple-strand cables.
3. Use a single point grounding system to avoid circulating currents caused by multiple ground connections.

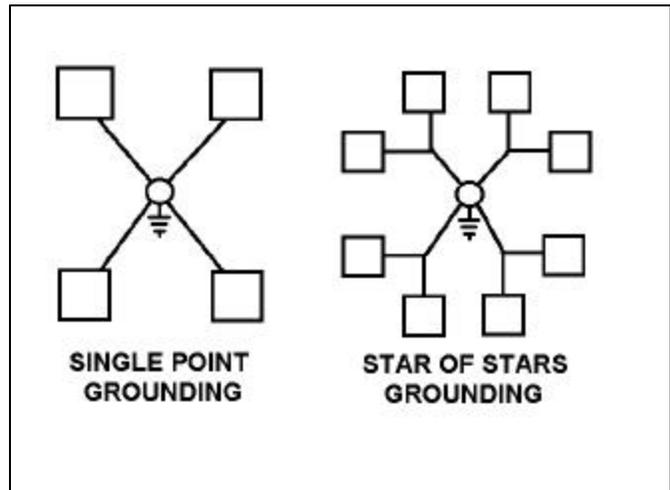
Conductor:	Inductance for 100 ft. in uH:
#6 AWG Wire	50 uH
#14 AWG Wire	60 uH
1/2 inch coaxial cable	51 uH
7/8 inch coaxial cable	48 uH
1-5/8 inch coaxial cable	44.2 uH
3 inch coaxial cable	40.4 uH

Approximate inductance per 100 ft. for some common conductors.

This last point requires more explanation.

If a piece of equipment is grounded at more than one location, utilizing different paths that eventually connect to earth ground, differences in potential may develop between the two connections for the reasons just discussed. These grounds will attempt to equalize themselves, resulting in a current passing through the equipment itself. Further, standing waves can be established in the loop formed between the two pieces of equipment, their connections and the ground itself, resulting in circulating currents which can damage the equipment or impede its proper operation (similar to the well-known ground loop buzz experienced in audio connections). One common example of this occurs when several pieces of equipment are mounted in a grounded cabinet, where the input and output cable shields and the power line neutral connection provide additional paths to ground.

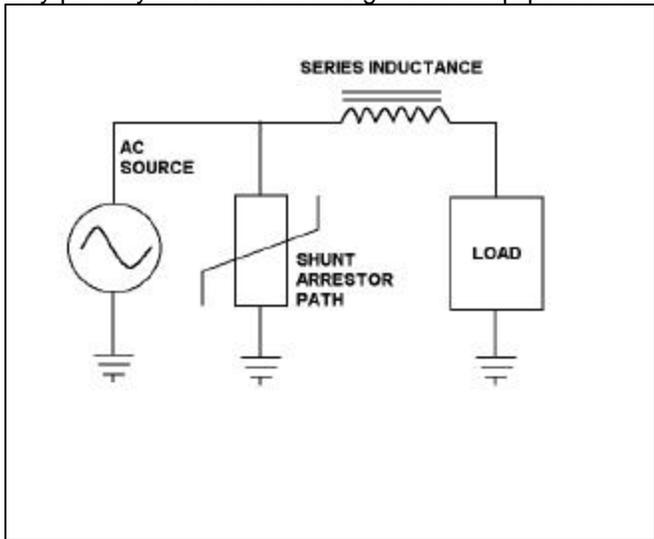
In a single point ground system, only one ground reference is established in a system, which is well bonded to an earth ground. All ground connections branch out from here so that there is only one ground path for each piece of equipment. This method eliminates the possibility of ground loops and equalizes the ground voltage differentials within the system. The single point ground system is also sometimes referred to as a "star" grounding system. Larger systems can be connected using what is called a "star of stars" system.



C. Shunt Path Plus Series Inductance

Even if a piece of equipment has been protected by a surge arrester connected to a proper earth ground, the problem is only partially solved. Presuming that the equipment the arrester is protecting is also grounded, not all the surge current

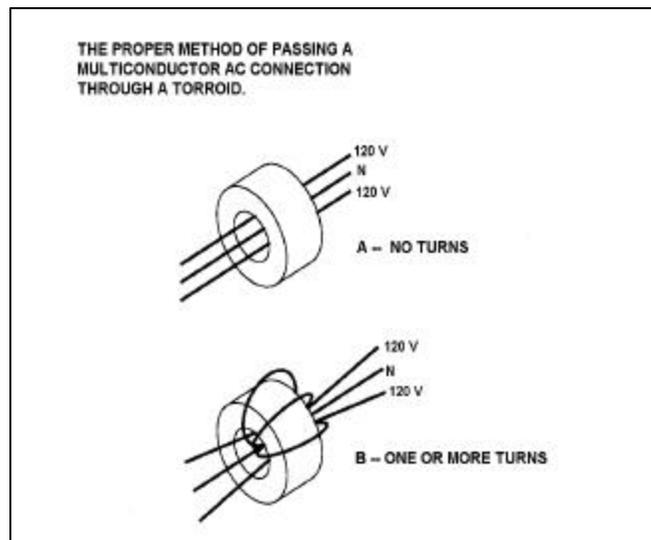
will flow through the arrester – some of the current will still pass to ground by means of the other path going through the equipment. An analogy can be made to a resistor voltage divider circuit, wherein some current flows through each of two parallel resistors, the current dividing in proportion to the ratio of the two resistor values. If we want to maximize the current flow through the surge arrester and minimize the current through the equipment, we do this by lowering the inductance of the path through the arrester as much as possible, but we also try to maximize the inductance of the path through the equipment. An inductive element can be added in series with the load after the arrester. This inductance should have little or no reactance at low frequencies, such as a 60 Hz AC connection, but should present substantial reactance to a fast rise-time surge such as a lightning strike or power surge.



This series inductance can be accomplished in several ways.

A long conductor with numerous bends or turns, such as a long run of conduit between a service entrance and the equipment, provides some inductance. For more, this conductor can be formed into an air core inductor by adding several coiled turns. Still more effective is to pass the conductor through a ferrite torroid, or wrap one or more turns around a ferrite torroid or bar. Be certain to use a ferrite core with the proper formula “mix” that will provide a low inductance at the desired frequency (in this case 60 Hz), and the highest inductance at the surge frequency.

When applying a series inductance to a multi-conductor path, such as an AC power line, it is important to have all conductors follow the same path. When installing a torroid core, this means all conductors must pass through the same core, and if turns are taken, they must all be the same number of turns and in the same direction. This causes the inductive fields to cancel each other in a standard (differential mode) AC circuit, but they will resist a ground-referenced (common mode) current.

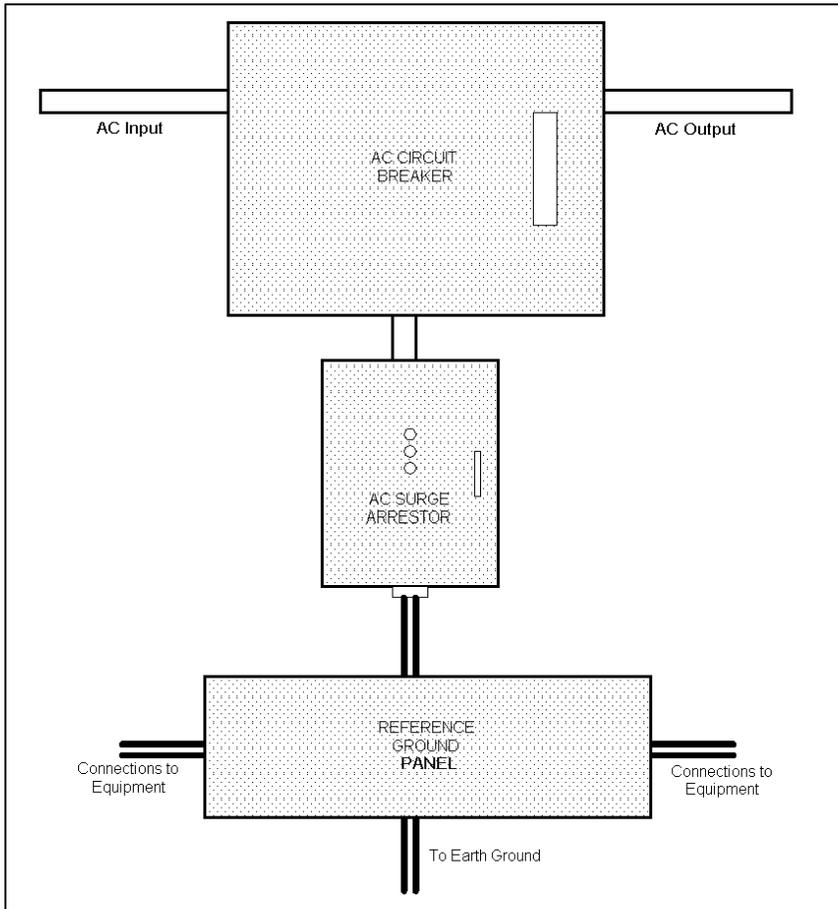


Inside the Transmitter Building

The above protection concepts can be applied to the transmitter building by treating the entire building as a system.

Establish a single reference ground in the building, preferably close to the main service entrance of the building. This reference can be a large conductor, such as a wide copper strap or plate.

All inside ground connections are attached to this point with no more than one conductor per grounded device. The AC service entrance ground should be connected to the reference ground. (If local building codes do not allow a direct connection, then consider bonding through an appropriate surge arrester such as a gas discharge tube to allow it to conduct only during a surge.) Bring all coaxial cables that enter the building directly to the reference ground location, and securely ground them to the reference point with the cable manufacturer’s grounding kits (or coaxial cable surge arrestors) before routing them over to the equipment. As surges will tend to enter the building via either the coaxial cable or the power lines, these two steps will provide a direct path to ground which should not flow through any equipment inside the building.

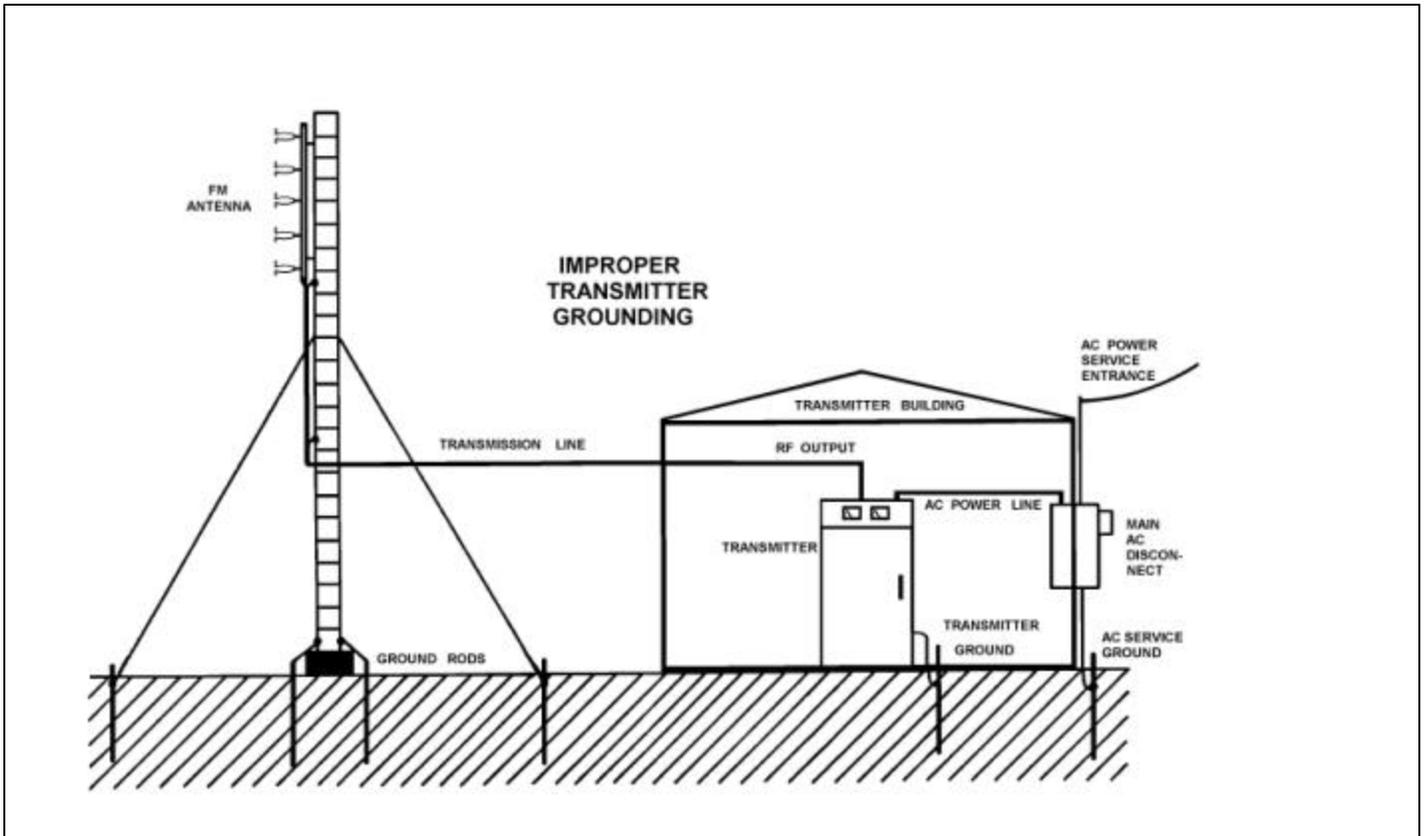


AC line surge arrestors should be installed between the AC service entrance and the reference ground. The arrester should be located as close as possible to the primary service entrance. This bypasses any surges originating on the power lines to the AC neutral, and keeps it as far away from the transmitter as possible. The AC neutral presents a low impedance path to ground for a lightning strike on the tower, due to its large conductor size and distribution to many ground connections upstream from the service entrance.

Many of the better surge arrestors include a series inductance element in addition to the shunt element. If this kind of arrester is not being used, an inductance can be added externally by passing all AC conductors through a single ferrite core or torroid located between the arrester and the transmitter. This is also effective with coaxial cables. Pass the entire cable through the center of the torroid and fasten it to the core with tie wraps or electrical tape. It is possible to find torroids of

sufficient size to accommodate up to 1-5/8 inch transmission line. (NOTE: This method may not be effective in AM installations where the transmitter building is located physically within the tower's ground plane. The transmitter's cabinet ground connection can act as a return path for part of the RF current, so that not all current returns on the cable shield. In this event, the current on the center conductor of the cable is then greater than the return current on the outer conductor. The two fields do not completely cancel, causing the ferrite core to saturate. If the torroid becomes hot to the touch under normal operation, it should be removed and not used, as it will be ineffective in the event of a surge.)

The same methods described above can be applied to any other connections to the outside world, such as incoming telephone or audio control cables. On phone lines, connect an MOV of the appropriate voltage rating between each conductor to ground, as well as leg-to-leg for balanced lines. (On a dial-up line, be sure to allow for the ring voltage.) These can be disk-type MOV's, and they are easily installed on a punch block type of service panel, with the ground bus connected to the station reference ground. After the telephone circuits leave the service panel, wrap the conductors through a torroid several times before they are connected to station equipment.



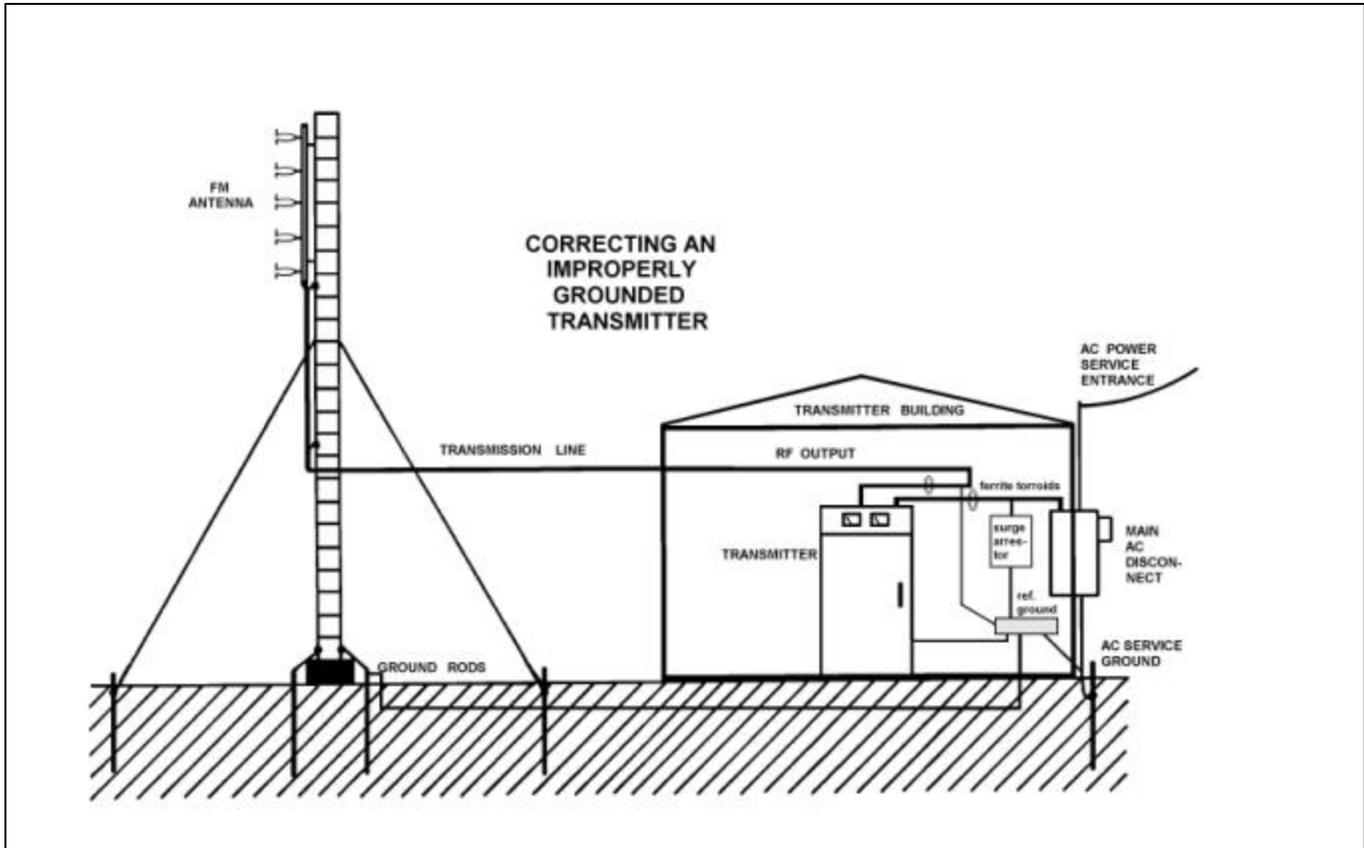
Correcting an Improperly Installed Transmitter Installation:

The drawing above represents a typical installation such as can be found at transmitter sites around the world. It is also represents a poorly-grounded facility that will be very susceptible to lightning or AC transient damage. Here is what’s wrong with this installation:

- a. No AC surge arrester has been installed to protect the transmitter.
- b. There are three separate ground circuits: the AC service ground, the transmitter ground and the tower ground. When a surge occurs that raises one of these grounds above the level of the others, current will flow through station’s equipment to equalize them.
- c. The transmitter is in the center of ground connection. Currents from a lightning strike on the antenna will flow down the coaxial cable and make their way to ground through the transmitter; AC power line surges will pass to ground through the transmitter; and, lightning currents passing to the AC neutral will also pass through the transmitter.

Refer to the drawing below to see how this installation has been modified to protect the equipment:

- a. A single reference ground panel has been established inside the transmitter building, and all equipment is grounded to it with straight, branching connections.
- b. An AC surge arrester has been installed in shunt with the power connection to the transmitter, and grounded to the reference ground panel.
- c. The AC service ground has been connected to the reference ground.
- d. The coaxial cable has been re-routed to first pass by the reference ground panel, where the shield is grounded with a short, straight conductor, before it changes direction and connects to the transmitter.
- e. Ferrite torroids have been installed over the coaxial cable and AC conductors between the reference ground panel and the transmitter.
- f. The tower ground has been connected to the reference ground panel with a buried copper strap.



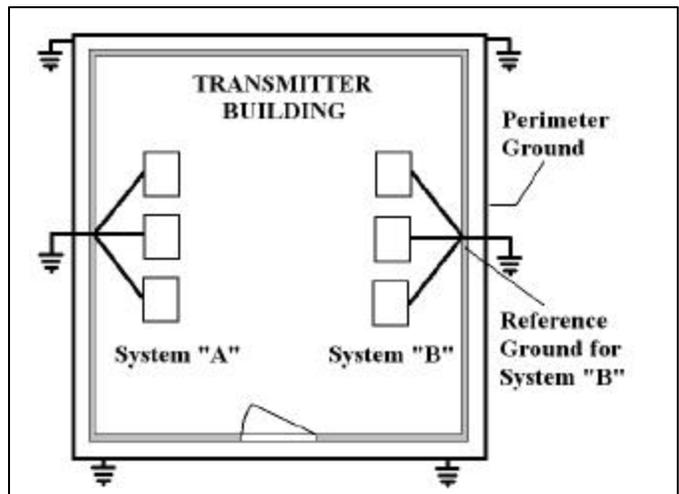
Rack Cabinet Grounding

The single point grounding technique can also be effective to protect multiple pieces of equipment installed inside an equipment rack cabinet. Treat the rack the same as you would a building, and mount a panel on the cabinet to act as both an entrance panel and reference ground for all conductors entering and leaving the rack. Install AC surge protectors at this point in shunt to ground, and install a series impedance between the panel and the equipment. Don't count on the metal cabinet itself to serve as a ground conductor – paint and oxidation may conspire to prevent a good connection. A copper strap should be run along the inside of the cabinet, bonded to the cabinet along its length, and also bonded to the access panel. The chassis of each piece of equipment is then bonded to this buss bar with a single copper braid or strap. Redundant ground connections by means of the AC cable and the shields of audio cables should be avoided when possible. Finally, connect the rack's access panel to the building reference ground.

An Effective Earth Ground

Once all connections have been made to the master ground point in the building, it must be bonded to an effective earth ground system outside the building. Four-inch or larger copper strap or #2 AWG multi-strand wire is recommended, with short, straight connections. Corrosion will dramatically increase the resistance of a connection, so use silver soldering or cadwelding for all connections exposed to the weather. A network of four or more 10-ft. ground rods driven at least 20 feet apart makes the best earth-ground interface.

A commonly used earth grounding method for transmitter buildings is the perimeter ground, where a conductor is



run around the base of a building and bonded to ground rods spaced at even intervals around the building. In a large building containing several independent systems inside, each system can have its own reference ground established, which is in turn connected to the perimeter ground at the closest point. This is preferable because it avoids long runs of ground strap inside the building. It's important that any ground connections between these separate systems be avoided, and torroids or surge arrestors be installed on the interconnections that cannot be avoided.

In the case of an AM transmitter plant, be aware that there are two separate types of grounds, the RF ground and the earth ground. While some conductors may serve both functions, the facility should be analyzed separately with regard to its effectiveness for both functions. For instance, it should not be assumed that a tower is adequately grounded for lightning protection because it is connected to a radial ground system. The RF ground radials are usually ineffective as an earth ground because they lie just below the surface and do not make contact with the water table. If possible, ground rods should be driven into the soil to at least the depth of the water table and bonded to the radial system.

In cases where there may not be an accessible ground water table, such as a mountaintop, desert or permafrost site, chemical ground rods have proven effective. These are hollow copper rods filled with earth salts, which slowly leach conductive salt water into the soil, dramatically improving its contact with the soil. However, they are more complicated to install, as a well drilling rig is often required.

At mountaintop installations where it may be impossible to install driven or buried ground rods of any kind into solid rock, it has been shown effective to place long lengths of copper strap on the surface, run along the ground in several directions from the transmitter building or tower. This has the effect of capacitively coupling the ground connection to the rock below.

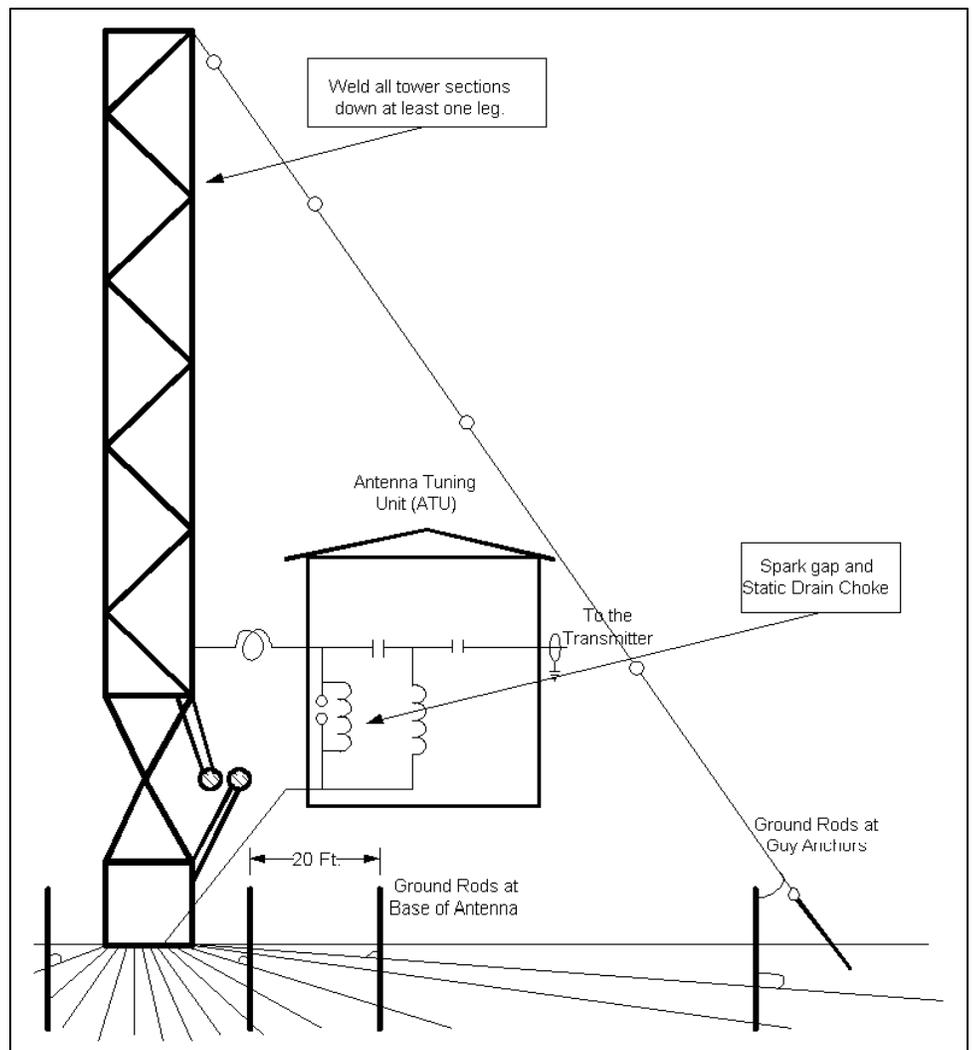
At the Tower

The following are some of the important steps to be taken at the base of a tower to maximize protection against a lightning strike:

1. Tack weld all tower sections together running down at least at one leg, to provide corrosion-free electrical continuity to ground.
2. Drive four or more ground rods at ten-foot intervals around the base of the tower, and ground these to the tower.
3. Install a ground rod at each guy wire anchor and connect them to the guy wires with a short jumper cable.

The following additional steps apply to base-insulated AM towers:

4. Adjust the ball gap at the base of the tower, located across the base insulator. Make certain the contacts are close enough to be effective – just beyond the point of flashover at modulation peaks. Typically, they should be set for .02 inch (1.25 mm)



- per 1,000 volts peak. Orient the terminals horizontally to keep rainwater out of the gap, and to assure that the gap is self-quenching. Periodically clean any corrosion from the spark balls, which would otherwise increase the resistance of the gap.
5. There should be an inductive loop in the connection from the antenna tuning unit (ATU) to the tower, usually fabricated from hollow copper tubing. This creates an inductive reactance to the path, causing the voltage to momentarily build up behind the inductor and encouraging the spark gap to ionize and conduct. Run tower lighting conductors, if any, through the center of the tubing to give equal inductive reactance to all paths.
 6. Install an air spark gap between the RF conductor and ground at the tower side of the tuning unit. There should also be a static drain choke in parallel across this same path to bleed off atmospheric-generated static from the tower. A 100K ohm non-inductive resistor can also be used, rated at about 200 watts. It should be noted that these devices are made to carry only small currents caused by static electricity, and will frequently be destroyed in the event of a direct lightning strike.
 7. Bond the RF radial system to the earth ground rods that have been driven at the base of the tower and at each guy anchor point.
 8. If an isocoupler is used for auxiliary antennas mounted on the tower (FM, STL, cellular, etc.), their coaxial cable shields should be bonded to the tower at several locations, plus grounded at the tower base below the isocoupler. There are several companies marketing in-line coaxial surge arrestors, and these can be connected in series with the coaxial cable at this point, or at the building entrance.
 9. If a tower lighting system is in use, bond the lighting conduit to the tower at several points as well.
 10. If a side mounted FM antenna is installed on the tower, are the elements at DC ground potential? Some models of antennas, such as the ERI "Rototiller" series, require the installation of an optional quarter wave stub to place the bays at DC ground.
 11. Another problem area to consider is arcing across the guy insulators. With an electrical storm in vicinity, insulators can develop several hundred volts across themselves. This can be enough to cause arcing across the insulators which can damage the insulators. This problem can be tolerated in most cases, but in extreme conditions a viable solution is a static dissipation resistor made by Racal-Decca. It consists of a Voltage Dependent Resistor in series with a fixed resistor, designed to be connected across the insulator. As a voltage builds up, its resistance lowers and drains off the static charge, preventing arcing. This is not an inexpensive solution, and they can be subject to damage during direct lightning strikes.

Conclusion

The protection methods just described are not difficult to implement at a new facility. However, adding them to an existing installation can sometimes be difficult. Often, facilities have grown so complex and interconnected over time that reworking them becomes a monumental task. This raises the question, "How much protection is enough?"

To answer the question, apply the reasonable risk concept: Given the statistical occurrence of lightning in the area, and the relative susceptibility of the equipment to damage from surges, one should expend enough time and money as is required to reduce the risk of damage to tolerable levels. Some of the methods described in this article are inexpensive and easily implemented. They are the most important steps to take when reworking an existing operation. And for those who find themselves in the position of planning a new facility, they are in the fortunate position of being able to "do it right" the first time.

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