

White Paper

Tower Strikes & Solutions

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Most sites in use today separate the coax cables from the tower and route them toward the building entrance panel at a relatively high point on the tower, typically 8 to 15 feet above the tower base. This practice is the single most damaging source of lightning energy directed toward the equipment.

Chapter 1 discussed the best way to reduce coax cable shield currents directed toward the equipment: Take the coax cables to the base of the tower and ground the shields there, routing them at ground level or below to an entrance panel at ground level.

Tying It All Together

One grounding system must be formed interconnecting all other site grounds. A lightning strike possesses a given amount of current and by installing a radial ground system around the tower and a perimeter ground loop around the equipment building, the division of current will send most of the lightning strike energy to be dispersed by the radials. A below-grade perimeter loop around the building will also reduce the amount of step voltage inside the loop. This is due to the repelling effect of like charge emanating from all points on the loop, reducing current flow through concrete floors, protecting both equipment and personnel.

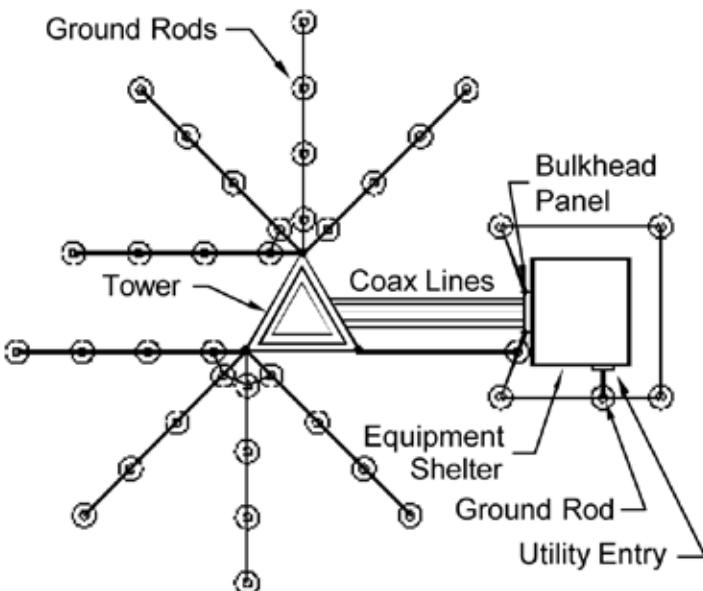
The lightning pulse series is a “fast rise time” event requiring a ground system capable of dispersing large amounts of electrons into the soil very quickly with minimum ground potential rise. This requires multiple paralleled inductances shunted by conductive earth. Multiple tower radials with ground rods (parallel inductances reduce overall inductance, improving the transient response) have been proven to be the most effective method of grounding towers.

Tower To Ground Connection

Most self-supporting or guyed tower legs are individually bolted to plates or brackets imbedded in a concrete pad. If the plates, brackets, or steel mesh in the concrete are interconnected (bonded together), a “Ufer” ground is established. Radials with ground rods must be attached to the Ufer to further lower the impedance and improve the ground system’s transient response.

Conductors from the tower legs to the radial system must have low inductance (large circumference) to direct lightning’s fast rise time peak current towards ground with minimum voltage drop.

The method of attachment to the legs and ground system should be very low resistance and not subject to corrosion. Accepted practice is to lug a large round conductor to a flange bolt, or exothermic weld it to the flange or bracket. The conductor is routed, on top of the concrete pad, to where it goes below grade to the ground system. Emphasis has been placed on 8-inch minimum radius bends for lightning current carrying conductors, suspended in air, to minimize inductance. Higher inductive right angle bends or



Connecting all ground rods together forming a “single point” ground system.

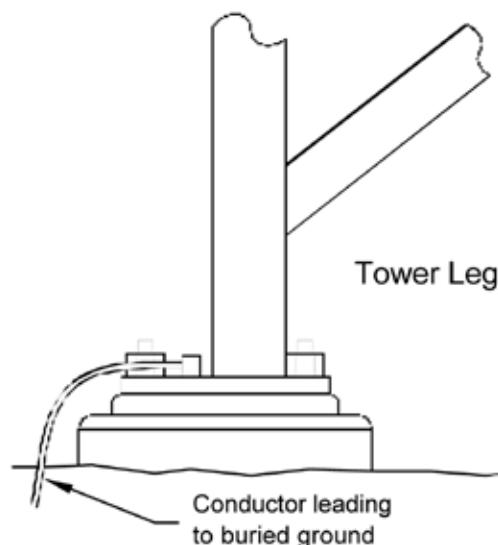
connections should be avoided if possible, but the alternative trade off may be worse.

If tighter bends are required to get an overall lower inductance ground conductor, we recommend solid bond copper strap.

Some guyed towers use a tapered base with a ball joint on a concrete pier. For example, the nearest ground rod is some 24 inches (vertical + horizontal) from the top of the concrete pier. If we want to utilize the Ufer effect, connect three or four large conductors (one per leg) from the bolts on the plate above the ball joint to the bolts on the plate below the ball joint. Continue the same conductor (if possible) down the sides of the pier to the ground rod/radials using optimum routing as determined below.

Assuming the wire gauge is #2/0, the inductance is approximately $0.32\mu\text{H}/\text{ft}$. Knowing the distance, the inductance for each route can be calculated. Each 90-degree bend develops about 0.1mH of additional inductance. Each sharp angle has about $0.15\mu\text{H}$ inductance.

Solid bond copper strap is once again the better choice for a low inductance conductor, however the interconnections to the tower base can be troublesome. Some engineers have solved the strap interconnect problem by brazing steel tabs to leg pads (in contact with the concrete), then turnin exothermically welding the copper strap to the steel tab. The tab/strap interface is coated with a weather-proof sealer to eliminate corrosion problems. This is a good idea but, contact the tower manufacturer before drilling or welding to the tower!



Equipment Stress

Even with a “perfect” ground system, voltage stress during a lightning strike may still be experienced by the equipment if the coaxial cables are not brought to the base of the tower before the outside shield is grounded, or if a proper bulkhead panel/ground bar connection is not utilized.

In Chapter One we examined the tower’s inductance and the associated voltage drops during a strike. A tower connection at 15 feet above the earth may appear to be a good grounding point. An ohm meter might show it to be a “good dc ground”. But it is really a poor, possibly dangerous grounding location due to the high peak voltages present during the strike.

For a 1-5/8” coax cable, it is virtually impossible to make as sharp a bend as is necessary to ground the shield at the tower base. Yet in the absence of other grounding methods, it is essential to ground the shield at this point to keep the shield voltage near zero.

If the coax slopes downward from an elevated point on the tower so it enters the equipment building at or very near ground level, another shield grounding kit should be incorporated at the wall penetration.

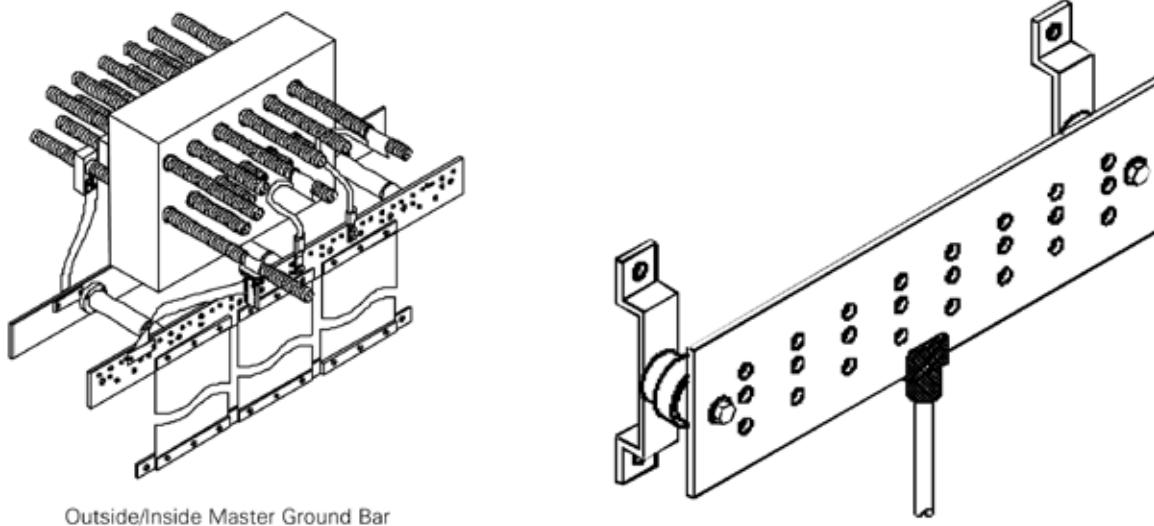
If either method is not practical and the coax must enter the building elevated above the earth, then a large surface area bulkhead panel should be used to ensure a low inductance route to earth ground.

Bulkhead Panel

Bulkhead panels have been used for many years. The initial reason was to provide the equipment building with a structurally strong entry point for one or more cables. The bulkhead panel was a rigid metal plate that covered a penetrating hole in the building's wall.

In installations where the coax lines must exit high on the tower, it is best to terminate the feeder coax at a bulkhead plate/coax center pin protector and run a smaller more flexible coax jumper from the protector to the equipment.

Grounding the entry bulkhead panel usually consisted of connecting a ground wire to it. In most installations a master ground bar (MGB) is used with coax cable ground kits connected and a ground wire routed from the MGB down the wall to the site ground system. A wire like this is ineffective for fast rise time pulses because of its inductance.



Outside/Inside Master Ground Bar
(PolyPhaser - GSIE)

If a larger bulkhead plate were continuously extended from the entrance opening down the building exterior and beneath the soil to the ground system, a low inductance interconnection to the ground system could be made. (Because of its large surface area - skin effect - and large W/H ratio, it should be less inductive than an equal height on the tower.) If the coax cable were grounded with a short low inductance connection to such a bulkhead plate, lightning surge current would be stripped from the cable shield. A copper "grounding finger" should be used and weather protected by a boot. However the ease of installation (weight) and cost of such a full length copper extension plate may be prohibitive. A cost effective variation is to substitute copper strap material for the thicker full length panel material going to ground, making it lighter, easier to install, and less expensive. The strap would be affixed to the building with silicone and then covered or painted for camouflage and wind resistance.

Flat strap is the best conductor for a grounding system. It has maximum surface area, for skin effect and low inductance. Strap actually has less inductance than wire for a given angle bend and can be bent to a tighter radius. Mutual inductance the cross coupling of the magnetic fields at the bend, is the reason for the added inductance of a bend. The distance from one side of the strap, when bent, is further away from the opposite side of the strap by the angle it makes, plus the width of the strap. The distance is greater so the mutual coupling is less. Also, the magnetic field susceptibility is maximum at its edges and it is similar to a dipole antenna. Therefore, it is less likely to intercept tower magnetic fields if its flat side is oriented

toward the tower.

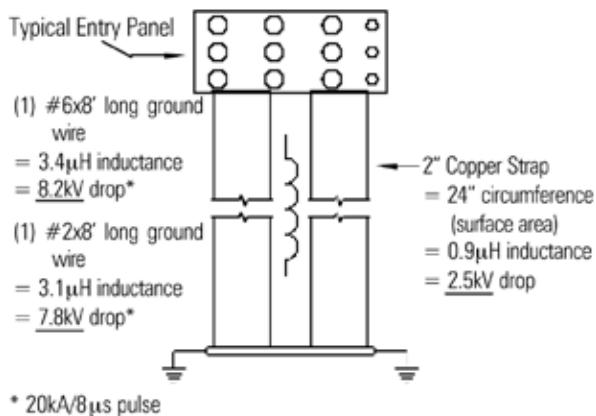
One can calculate expected peak current and voltage drops for ground conductors and, if done properly, will get accurate inductance value requirements. The inductance requirements can then be translated to physical conductor dimensions. The goal is to reduce the voltage drop to a minimum. This is a valid exercise and good engineering "practice".

Master Ground Bar (MGB)

An easier way to determine minimum ground down-conductor sizes would be to compare the total of all circumferences of incoming surge bearing conductors from the tower (coax cables, conduits), to the total circumferences of all grounding down-conductors.

If the length of the grounding down-conductor(s) from the MGB to where it goes below grade does not exceed the length of the coax(s) horizontal run from

$$\begin{aligned} (9) \text{ 7/8 coax} &= 24.75" \text{ circumference} \\ (3) \text{ 1/2 coax} &= 4.75" \text{ circumference} \\ \text{Total Circumference} &= 29.50" \end{aligned}$$

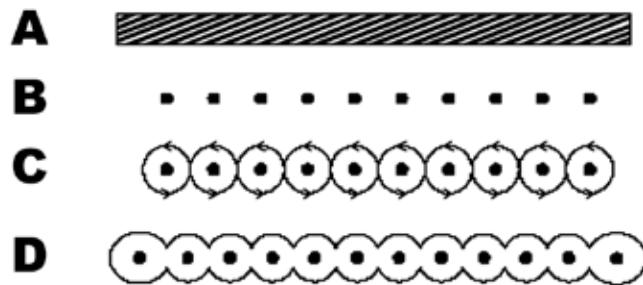


Ground conductor circumferences should equal the combined circumferences of all coaxial cables.

blocked type lightning protector (see Chapter 6) can prevent the center conductor's surge energy from reaching the equipment if it is mounted (grounded) to the bulkhead panel. The use of a dc blocked center pin protector will prevent the sharing of differential surge energy present on the coax center conductor due to high frequency roll off and velocity of propagation differences between coax cable shield and center conductor.

Subpanel

To further protect and restrict access to the coax-to-center pin protector connection, a "U" shaped subpanel (see page 16) could be mounted/ grounded to the bulkhead front plate. The subpanel is attached so it protrudes from the main panel through the penetrating hole inside the building and creates a secondary surface on which the protectors are mounted and grounded. All connectors are accessible from inside



A) Copper strap may be looked at as if made from an infinite number of infinitely small wires spaced infinitely close together. B) The mag field of each wire C) is shown and they will add vectorially D) toward the edges.

the tower, the total down conductor circumferences should be at least the total of all incoming coax cable and conduit circumferences. Wide copper strap will give the largest circumference ("skin effect") with the least amount of copper.

External cable trays or ice bridges should not be in contact with both the tower and the building ground system. Isolate and support the cable tray at the building end. Only the coaxial cables should complete the circuit.

Center Conductor

Shield currents can almost be eliminated with proper grounding techniques. However, the center conductor surge current should also be eliminated before the current damages the equipment. A dc

the building for tests and changes. If waveguide is used, it would extend straight through, since a center pin protector is not needed. The grounding finger under the weather boot (see bulkhead drawing), accomplishes proper grounding of the waveguide and coax cables. The subpanel would be deep enough for concrete block construction. The added depth allows for external coax feeder entry angle correction and jumper support in the absence of internal cable trays.

The bulkhead panel is made of 1/8" half hard C110 (solid copper). Only this hardness of copper can be properly tapped for screw threads. The C110 copper weighs 5.81 pounds per square foot. Mounting hardware used to join the subpanel to the bulkhead is 18-8 stainless steel.

For small to medium size sites, the bulkhead panel should be the central grounding point inside the building for single point grounding procedures. Holes can be drilled into the U panel for bonding straps and grounding cables from inside racks of equipment. The bulkhead panel then serves as the master ground window or ground bus (MGB).

Other types of bulkhead entry panels are open on the equipment side with no "U" panel for restricted space locations. An outside/inside ground bar assembly can be retrofitted to existing sites for single point use. Attachment points are provided for 6" strap external ground conductors and 1-1/2" strap internal connections for grounding coaxial protectors.

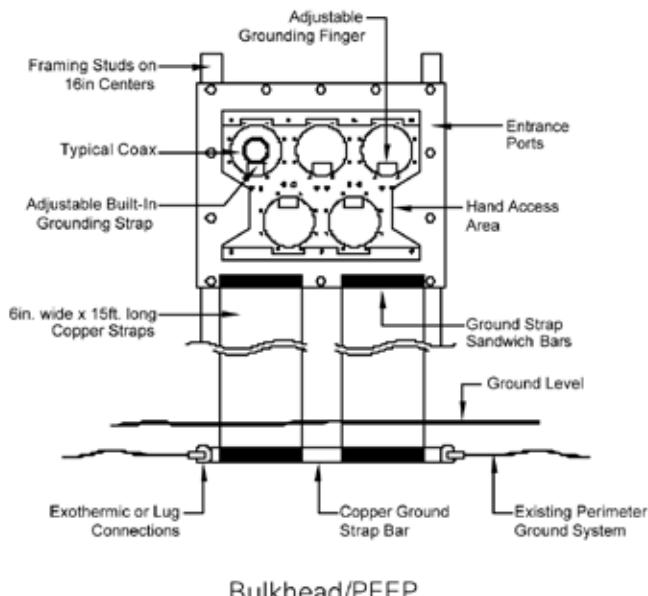
Single Point Grounding

Surely everyone has heard of the safety procedure that says to keep one hand in your pocket while working around high voltages. If the body does not complete a circuit, there is no current flow and danger is averted.

For small- to medium-size equipment rooms, it is best to have the equipment's input/output (I/O) protector grounds and equipment chassis tied together. The telephone line protectors, coax protectors, and power line protectors are then grounded either on a bulkhead panel or mounted together on a single point ground plate and tied to system ground. Equipment chassis ground would then be connected by a low inductance strap to this ground point. An exterior ground system should consist of the tower leg grounds (radials and rods), power company ground rod(s), and a below-grade copper strap sandwich bar connecting the bulkhead strap down-conductors to the below-grade building perimeter ground loop.

To keep equipment safe in the event of a lightning strike, the same one-connection concept applies. Single point grounding is a grounding technique that ties all the equipment in a building together and grounds it at one common point. Implementing this technique is quite easy.

The single point ground must be implemented properly so the coaxial protector can do its job. As Chapter One's example illustrates, the outside coax ground plate could rise to 7.3kV above the earth ground system, emphasizing the importance of a single point grounding concept. The bulkhead or "PEEP"



Bulkhead/PEEP

(PolyPhaser Earthed Entry Panel), with proper coaxial cable protectors installed, would be the primary "firewall" protecting equipment. If the equipment has a separate path to earth ground in addition to the bulkhead or PEEP, the added parallel path could allow strike current to flow through the equipment.

I/O Ports

For repeater installations with a single telephone interconnect, there would be three Input/Output (I/O) ports: the coax cables, power lines, and telephone lines. These I/O's can be either a lightning source or sink. Lightning surge energy may originate from one I/O and exit another I/O causing circuit damage in equipment connected to one, or perhaps all of the I/O's. Since it is impossible to ground an I/O, a surge protector must be provided for each.

The surge protector's purpose is to divert and isolate the equipment from the surge. Whenever a surge exceeds a preset voltage, the surge protector diverts the surge to a ground sink. By installing a surge protector at each I/O, it is possible to configure a grounding scheme that allows the equipment to survive a lightning strike.

A single point ground system would be created, if all the I/O surge protectors were grounded/ mounted onto a bulkhead panel or MGB. The equipment racks are also bonded to the MGB. Surge energy stripped from the lines by the coax cable ground kits and each of the surge protectors is diverted to ground via a single path.

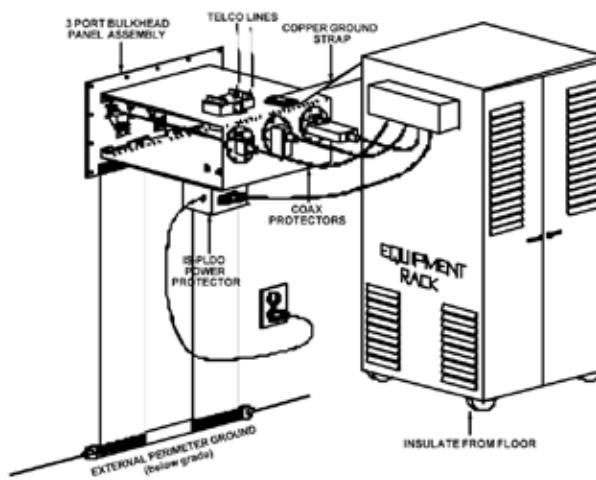
Imagine each I/O port to be a hand or a foot. If a hand or a foot touched a high-voltage dc source at a single point, no current would flow through the body and no injury would occur. (The surge current necessary to elevate the body up to this higher voltage might be felt.) The body must therefore be insulated from everything else; no other path for current flow can exist.

As in the above example, the equipment must be properly isolated from conductive flooring. By mounting the surge protectors on the same bulkhead or metal plate connected to a common ground, no surge current flows between the I/O's and no voltage drop is created (no ground loop). Damage does not occur since the equipment chassis is also grounded to this same point. The surge protectors have low impedance between them, so no voltage drop can develop.

Personnel Safety & The Single Point Ground

Why protect the equipment but risk the technician? The first and most obvious answer is he should not be there working on equipment during a thunderstorm!

A low resistance single point ground, with insulated racks, could still allow the potential on the racks to rise to dangerous levels. During a "normal" 18kA strike with 2 or 3 return strokes of 9kA each, the event would probably be over before the rack's capacitance would be charged to dangerous levels. If the event were a 140 kA strike with 10 or 11 return strokes of 70 kA each, the whole site would be a dangerous



Bulkhead Single Point Ground

Preferred method of grounding I/O protectors for coax, telephone line and power line. The bulkhead plate in turn connects to the perimeter ground outside the equipment hut.

place. It is a difficult and unpopular decision to compromise safety no matter what the statistics are. A technician working on equipment during a thunderstorm is at risk no matter what kind of grounding scheme is used. There are some compromises to the single point ground that can be implemented to increase safety (at some sacrifice of system effectiveness).

- Install an overhead insulated bus bar connected only to the single point ground and extending out and around the inside walls of the equipment room in a "U" shape. Do not connect any additional ground conductors downward to the outside below grade perimeter ground.
- Connect all metallic objects within the technician's reach (while touching the equipment rack) to the bus bar. The bus bar ground should be the only ground connection for the object. Even after considering propagation caused peak differentials, the voltage should nearly equal the rack potential.
- Place high voltage insulating rubber mats on the conductive floor where technicians would stand.

If a bus bar connected object is also connected to a different ground point, there could be additional magnetic field in the building as a consequence of current flow through the bus bar and connected object to ground. If outside low inductance conductors (multiple copper straps) are installed at the bulkhead or MGB, the peak voltage drop will be minimal, reducing current flow in the building.

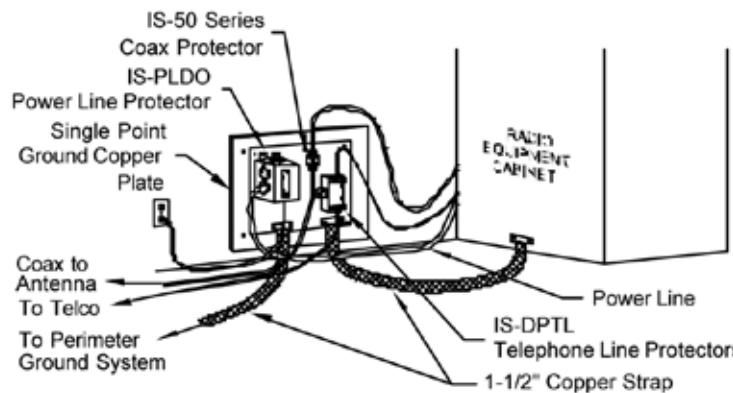
The only satisfactory approach to lightning protection and safety is an integrated set of grounding techniques, protectors, and safety procedures all working together (You can't engineer common sense).

Protector Mounting

Current that is diverted by the protectors should go to ground by a path whose inductance is as low as possible. If a grounded bulkhead panel with its large surface area, low inductance ground straps is not used, the next best place for mounting the surge protectors would be on an inside, floor-level, wall-mounted plate. A low inductance interconnection to the perimeter ground is essential.

No matter how low the protector path inductance may be, it still has some inductance. Since the surge protectors send current through this inductance, a voltage drop ($L \frac{di}{dt}$) is created. This voltage drop may cause problems for sensitive equipment.

Control lines or balanced lines, for example, may become elevated above chassis ground. To ensure the equipment chassis is held to the same potential as the surge protectors, a low inductance connection between the equipment chassis and the bulkhead panel or protector panel is required. This conductor should have a lower inductance than the coaxial shield.



Example of Single Point Ground without Bulkhead

Shield Current Flow

If radials, rods, and a single point ground for site protectors and equipment are installed, have all the possible problems been eliminated? Very low surge current could still flow on the coax shield within the equipment building toward the rack even though it is insulated from conductive flooring.

The equipment chassis or rack, like your body, has the ability to accept a charge (capacitance). The rack is elevated in potential to the $L \frac{di}{dt}$ (inductive voltage drop) of the interconnection to the exterior ground via the MGB. Current must flow along the coax jumper shield and other ground conductors to bring the rack to this higher potential. A magnetic field is created inside the room by the lightning pulse current surge charging the rack's capacitance through the coax shield and ground conductors. The path(s) from the protector panel or MGB to the equipment radiate the field.

PolyPhaser manufactures a coax protector that dc blocks the center conductor and the shield (to 2kV). There is no dc continuity between the antenna coax shield and the equipment side shield.

Lightning Electromagnetic Pulse

The fast rise time to peak current creates an electromagnetic field (electrostatic and magnetic fields) that radiates out from the stroke discharge path to earth. The amplitude/frequency spectra of the radiated component would depend on the current density/rise time of the stroke and the distance from it. Frequencies in the pulse extend well into the communications bands and can couple damaging energy to equipment

Magnetic Shielding

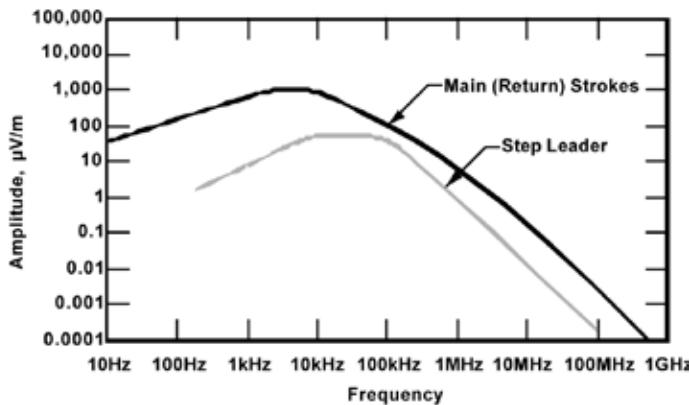
Lightning's high current means that the associated magnetic fields from the tower will radiate and cross couple to cable runs inside the equipment building. Sites are usually designed to have a 5 ohm ground system, but the building is placed close to the tower with little or no magnetic shielding. The distance, between the tower and the building, is usually kept small so the transmission lines are short. This places a heavier burden on your ground system to absorb and quickly conduct the strike energy away from the tower base. Magnetic fields from the close spaced tower will cut through the equipment building causing induced damage to interconnected equipment.

Aluminum buildings, like aluminum chassis, do little to attenuate low frequency magnetic fields. Concrete with steel mesh or rebar, which is ferrous, will show some attenuation.

Steel shipping containers used as an equipment building, with either single or double walls will act as a faraday shield for both radiated (plane wave) RF energy and magnetic (H) fields. The containers also provide a uniform ground for the equipment from anywhere inside the container. Inside the container you may not need Electro Metal Conduit (EMT) for shielding, however, for other non-ferrous enclosures you should run all electrical and sensitive lines in separate EMT conduits.

Distance Vs. Shielding

The only alternative to a ferrous container is to use distance. Magnetic fields drop off at a rate of one over the distance (from the source) squared. To attenuate the strike's powerful magnetic field from entering the equipment and causing upset or damage, space the tower a practical distance from the building. Distance will also add length to transmission lines which gives additional series inductance (voltage drop), forcing more surge current down to the tower ground. More transmission line will not pick up more



Amplitude spectra of the radiation component of lightning discharges.

magnetic field. The straight run from the tower to the building is orthogonal to the magnetic field from the tower and will not pick up any additional surge.

Bulkhead panel strap orientation is at minimum for H field coupling. The most coupling for both E and H fields is off the strap's sharp edges. Therefore, the strap(s) will couple less energy than a round conductor.

Latent Damage

Stress to electronic components can cause failure at a later date. The US military has spent large sums of money to study what has been termed "latent damage". Latent damage leads to reduced MTBF (Mean Time Before Failure) of equipment. Lightning stress from coupled magnetic fields to high speed, small junction semiconductors, can lead to unexplainable failures. Since the user does not have design control over the PC board layout, trace length, proper I/O protection, or the equipment enclosure, EMP and RFI environmental considerations need to be considered.

Large Site Grounding And Shielding

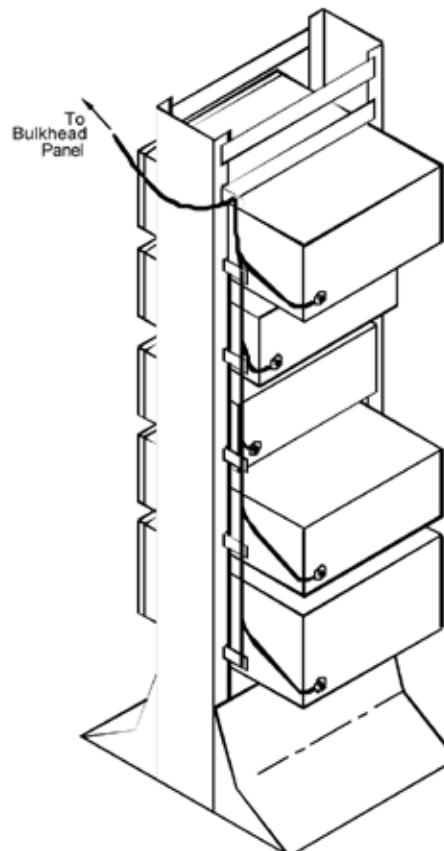
At very large sites (over 30 x 50 feet) where lightning shielding is important but steel sheets cannot be used to make a shielded room, an internal ground halo (with multiple downconductors connected to non-electronic fixtures) may be provided around the room as an inexpensive alternative. It serves to intercept the low frequencies of lightning, although it is not very effective. It is often used for (multi-point) grounding of equipment racks. However, if also connected to the Bulkhead or MGB, large currents would flow through the multiple ground conductors creating an intense magnetic field instead of absorbing it.

Grounding Equipment Chassis

Racks are commonly used to mount larger base station equipment and repeaters. Rack panels may be painted or the rails where they are mounted may become oxidized. The paint and oxidation may have enough resistance to prevent the rails from being an adequate interconnecting grounding conductor.

Under non-screen room conditions and within high RF environments, such as those found at broadcast transmitter sites, the contact between the dissimilar metals of the bolts, rack rails, and equipment panels can form "diodes". These "diodes" have been known to cause intermodulation interference and audio rectification.

One way to tie the equipment together is shown. Insulators support the vertical ground bus. Each piece of equipment is connected to the bus by a short strap. Any "noise" created by poor joints and dissimilar metal contact within the rack is "shorted out" by the short strap. The short strap may be a resonant antenna near the frequency of the strong RF field from a nearby or co-located high-power



Each equipment chassis in a rack is connected by short strap to a vertical grounding bus suspended by insulators.

broadcast. It may be resonant near your operating frequency, or some other intermediate frequency used by your equipment. A grid dip meter may be used to determine whether the loop is resonant at a frequency that could cause a problem.

The loop's resonant frequency can be found with other methods. A spectrum analyzer may be linkcoupled to the loop and observed to see where the noise floor rises when the loop is opened and closed. The same technique could be used with a service monitor tuned in the AM mode to a quiet channel. (Note: Front-end overloading could give false readings.)

A possible alternative uses corrosion resistant conductive plating or metal treatment on the rack rails and chassis mounted rack brackets.

Grounded Screen Rooms

Screen rooms work best for shielding equipment from high RF and electromagnetic pulse (EMP) fields associated with high-power transmitters, lightning strikes, and high-altitude nuclear detonations. However, proper grounding of the screen room is required to meet specifications.

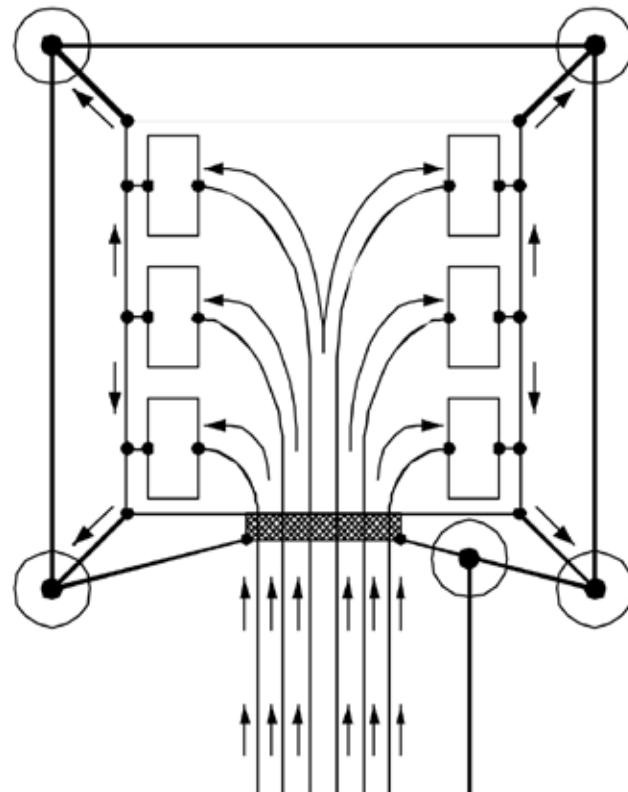
The screen room manufacturer should be able to detail the techniques that ensure maximum screen room effectiveness. All I/O's to the screen room should be filtered and protected. All protectors should be mounted to the outside wall of a double screened enclosure. Each equipment chassis in a rack is connected by short strap to a vertical grounding bus suspended by insulators.

Multi-Point Grounding

Some microprocessor controlled equipment makers have attempted to reduce noise and RF on the logic bus (when connected to RF equipment) by using multi-point grounding techniques.

When the site is a large installation, it is not always practical to install a low inductance interconnection back to the single point ground panel (unless a screen room or container wall is used). Connections to an installed "halo loop" (an isolated conductor run high on the inner walls connected back to the single point ground with additional spaced, downward ground leads to the below grade perimeter ground loop) are attempted to equalize potential and reduce noise. The propagation differentials during a lightning "event" between the coax jumpers connected directly to the rack from the entry panel (MGB or Bulkhead) and the entire inductive path from the upward connected equipment "halo grounds" and their downward ground conductors, will cause current flow and an L di/dt potential through the halo until it is also equalized. Additional magnetic field will be radiated from this current flow.

Therefore, independent rack interconnects from the



While single-point grounding is in most cases preferred, large installations may make use of multi-point grounding to overcome the inductance of a ground interconnect conductor suspended in the air within the equipment hut. Careful design is required.

top to the below grade perimeter ground loop would seem to be the answer. The problems that can arise from not having a single point ground (lightning damage) can be worse than the possible noise from the RF equipment. Each site design would need evaluation and compromise.

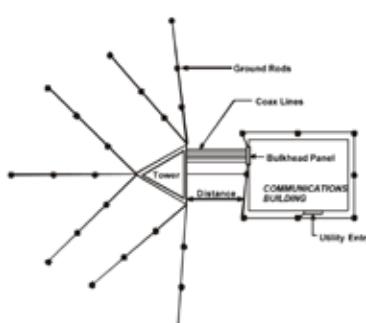
Electrons take time to travel from one position to another (propagation time). For this reason, care must be taken in designing the perimeter ground system and spacing the connecting points for a multi-point system.

For large equipment rooms, using many connections to the perimeter ground is a viable method. As a result, some surge current will enter the equipment room. However, with multiple paths to ground, the total number of paths divides the current. In this way the current could be reduced to a harmless amount (each $L \frac{di}{dt}$ is small enough so no breakdown occurs in the equipment). Ideally, each path from each piece of equipment to the perimeter ground should be of equal length. This means that for a typical site, the downward paths to the perimeter ground system should be interconnected to the inside halo about every two feet! This is rarely done and is why the halo has problems! It is easier (and safer) to do a single point ground system than it is to install multiple halo to perimeter ground connections.

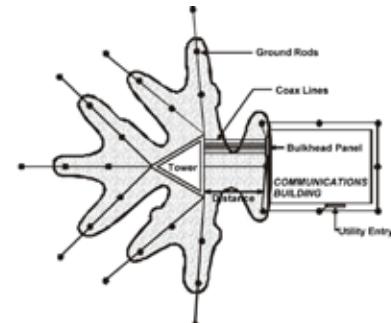
Fast Propagation Time

The multi-point ground design concept places more emphasis on the perimeter ground connections. Since the I/O's are the only means by which current may enter the room, the lower the interconnect inductance to the perimeter ground by the numerous parallel paths, the smaller the $L \frac{di}{dt}$ voltage present. The propagation time of the ground system and the timing of the current in the earth around the hut can cause problems with a multi-point ground that is not present with a single point ground.

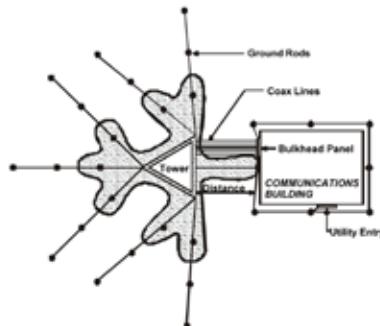
Look at how the surge propagates in the following series of drawings. Note that the majority of the surge is diverted out and away from the building. Also note the time it takes to progress around the building. This is why some currents traverse the parallel multi-point paths through the building in order to get to unsaturated perimeter ground locations. The race is between the speed of the perimeter ground loop versus the speed through the building. Normally if the ground system is good, it will be faster than the slightly more inductive path through the building. You can wind up fighting yourself by adding more paths, making the voltage drop less, which then makes the propagation time faster through the building. This means more current will traverse through the building with undesirable



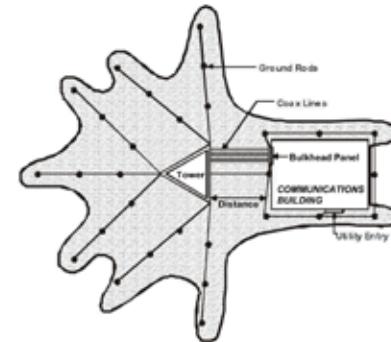
Recommended site grounding system about to be hit by lightning.



On a well-designed ground system, the strike energy spreads out initially from the building.



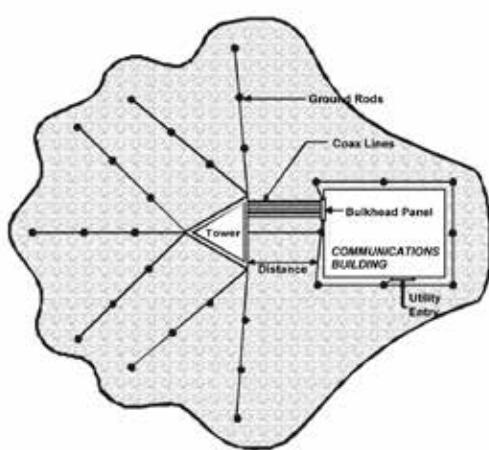
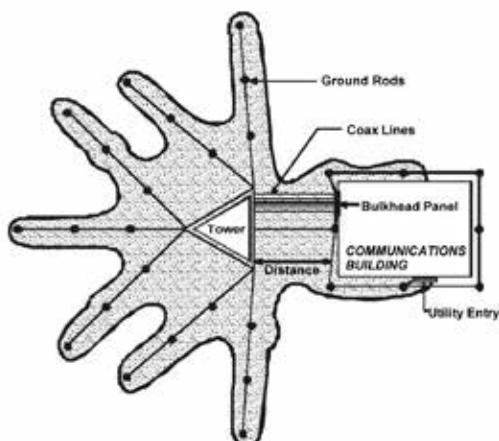
Neglecting the coax currents, the strike energy moves outward from the tower base along the radial line.



As it reaches and saturates the radial system, it will traverse the building perimeter.

$L \frac{di}{dt}$ drops and current caused magnetic fields.

With a tower strike, and the perimeter ground loop propagation that follows, there could be a period of time when the bulkhead panel or MGB would be elevated in potential but the utility entry ground rod might be at a lower potential. During this period, current could flow through the ac power safety ground towards the neutral/ground bond at the main breaker panel. However, unless the strike current and number of return strokes were high, the small safety wire conductor would "choke off" most current flow and not be a cause for concern.



through the electrical ground connection back to the below grade perimeter ground loop. Coaxial jumper cables and ground conductors should be spaced from sensitive, low level signal lines. Ideally, signal lines should be run in EMT conduit.

Insulated Support Structures

Wood or fiberglass support structures are not a good idea. They are an insulator. The cabinet earth ground, coaxial cables, and conduits on the insulated support would be the only conductive path for lightning energy. If a wood or fiberglass support must be used, the first step is to provide an alternate

Equipment Room "Ufer" Grounds

A Ufer ground on new building construction should not be overlooked. Wire mesh encapsulated inside the building floor can be used as a low impedance grid. If the aesthetics of wires emanating from various locations on the building floor are not acceptable, the wire mesh may be bonded to an inside bus ground just above floor level for easier distribution. Two feet should be the maximum separation between vertical interconnections bonding the ceiling halo and the mesh floor bus. The mesh should likewise be connected to the outside perimeter ground at the same 2-foot intervals.

Cable Trays

Large installations may make use of cable trays to support overhead runs of coax lines and other interconnecting wires. Ground the cable tray to the single point MGB or bulkhead. Connect the cable tray to the top of each rack. This prevents any arc-over from coax lines and reduces current flow through the coax cable jumper connector.

There should be jumpers to make the cable tray one conductive piece. The tray is an excellent way of grounding equipment racks together, since it has a very large surface area (low inductance).

If PolyPhaser isolated shield coax protectors (IS-IE series) are used, isolate the tray and racks from the bulkhead panel. The tray and racks will be grounded

conductive path down the pole to earth. A lightning diverter (lightning rod) on top of the pole (above the antenna) with a separate 6- inch copper strap as an earth ground conductor, would provide a low inductance/large surface area conductive path to an earth ground system. The 6-inch copper strap earth ground conductor should be routed on the opposite side of the pole from the cables.

When large currents flow through any conductor, a strong magnetic field is developed around the conductor and can couple energy to other nearby conductors. A circular conductor will usually be surrounded with a cylindrical magnetic field varying in intensity as the current flow propagates down the conductor. The circular conductor's cylindrical field is indicative of its magnetic field susceptibility.

A copper strap will also develop a magnetic field closely aligned with its physical shape. As current propagates down the strap, a magnetic field develops close in to the flat portion and extends out from the edges. The strap's field pattern is also indicative of its magnetic field susceptibility.

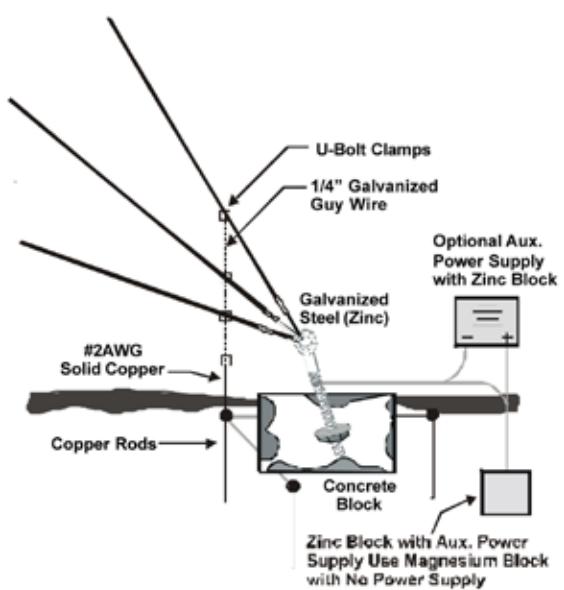
If downward circular cables were arranged perpendicular to the flat side of the copper strap (opposite sides of wood pole), the magnetic field overlap would be reduced and mutual coupling would be minimized. The strap would conduct most of the current to earth ground with little reverse EMF developed on the cables.

Outdoor weather-proof cabinet grounding with an insulated support structure should be considered as follows:

- If using a pad mounted outdoor cabinet, all the energy on the large surface area conduits and/ or coaxial cables would be directed towards the cabinet (entering from the top or side) with resultant large currents through the cabinet to local earth ground. Below grade cabinet bottom entry with a low ground connection on the coax would reduce current flow through the cabinet (recommended). Entering conduits and/or coaxial cable shields should be connected to a low resistance, fast transient response ground system through the cabinet's internal low inductance earth ground conductor. The usual center pin/shield propagation differential voltage would occur and could be blocked by an appropriate center pin protector.
- If the Cabinet is pole mounted, current flow from the coaxial cables shields (to the top of the cabinet) and conduit (going downward from the cabinet) would pass through the cabinet, duplexer housings, and connector panel PCB ground plane. Duplexer internal ground connections could sustain cumulative damage and PCB ground plane traces could be destroyed. If antenna coaxial cables were brought down the outside of the cabinet, looped up, and entering through a bottom connector (preferred), the lowest inductance path would be through the bottom panel of the cabinet to downward going conductors. However, large shield currents would flow through the connector shell of the surge bearing cable, traverse the cabinet's bottom plate, and continue out the connector shell of the downward cable. An interconnecting cable or shield ground kit(s) at the bottom of the cabinet, between cables ahead of the connectors, is recommended. Current flow through equipment would be minimized. A bulkhead type coaxial protector could be used as a bottom feed through connector.

Guy Wire Grounding

Guyed towers are better at handling lightning surge currents than self-supporting towers. This is only true



if the anchors are grounded properly. Some of the strike current traverses the guy wires (instead of the tower) and may be safely conducted into the guy anchor ground(s). With some of the current conducted by the guy wires, less is available to saturate the ground at the tower base.

Turnbuckles should not be a path for lightning current. If the turnbuckles are provided with a safety loop of guy cable (as they should be), the loops may be damaged due to arcing where they come into contact with the guy wires and turnbuckles.

The following diagram shows the preferred method of grounding the guy wires - tying them together above the loops and turnbuckles.

These connections should not be made with copper wire. When it rains, natural rain water has a pH of 5.5 to 6.0 which is acidic. Copper is only attacked by acids. Dripping water from the top copper wire will carry ions that react with the lower galvanized (zinc) guy wires. The reaction washes off the zinc coating, allowing rust to destroy the steel guy wire. The best way to make the connection is with all galvanized materials. This includes the grounding wire, cable and clamps. The galvanized wire is bonded to a copper conductor (just above the earth's surface) that penetrates below grade to a radial system spreading the strike energy into the earth.

How high this bonded connection should be placed above the soil, depends upon local snowfall or flood levels. Snow's electrical conductivity, although low, can still cause battery action from the copper through the surface water to the zinc by the solar heating of the wires. The joint should be positioned above the usual snow or flood level.

The lead is dressed straight down from the highest to the lowest guy or with a slight tilt toward the tower at the top. After bonding to a guy wire, it should be dressed downward from the lower side to the next guy wire. Wire brush the members, removing all oxides, and then apply a joint compound if a pressure clamp is to be used.

To ensure no arcing will occur through the turnbuckle, a connection from the anchor plate to the ground rod is recommended. Interconnect leads that are suspended in the air, must be dressed so the bending radius is not sharper than eight inches.

For guy anchors in typical soil conditions, use two radials with ground rods. The radials need not be much longer than 20 feet each since there are lower currents due to the higher guy wire inductances. A chain link fence post can be used as part of the system. Bond to the fence post and continue the radial to 20 feet.

Please contact us for questions or further information on this topic.

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