

Times *Protect*TM



Grounding & Lightning Protection for Wireless Networks

- *Overview of the Lightning Event*
- *Protection Techniques for Radio Equipment*
- *Why are Coaxial Cable Lightning Protectors Required*
- *Site Grounding Principles*



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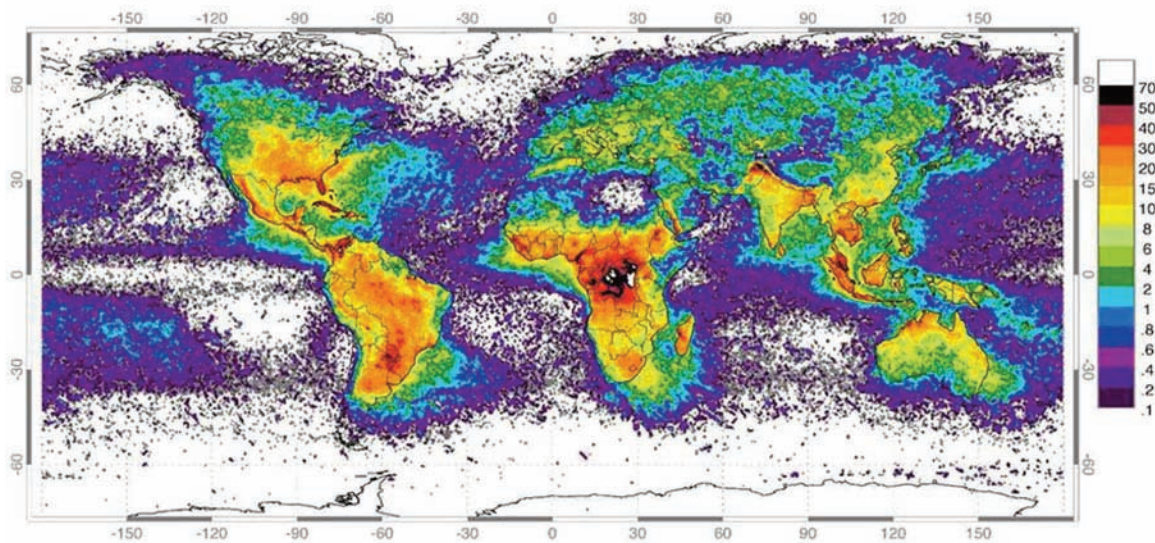
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Overview of Lightning Event

This paper will examine the characteristics of a cloud to earth strike, and the resulting probability of damage to existing wireless infrastructure. Most wireless networks rely on tall communication towers causing a statistically high lightning exposure probability. Typically, more than 2,000 thunderstorms are active throughout the world at any given moment producing on the order of 100 flashes per second. As our society becomes more dependent upon computers and communications networks, protection from system disruptions becomes essential.



High Resolution Full Climatology Annual Flash Rate

Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments

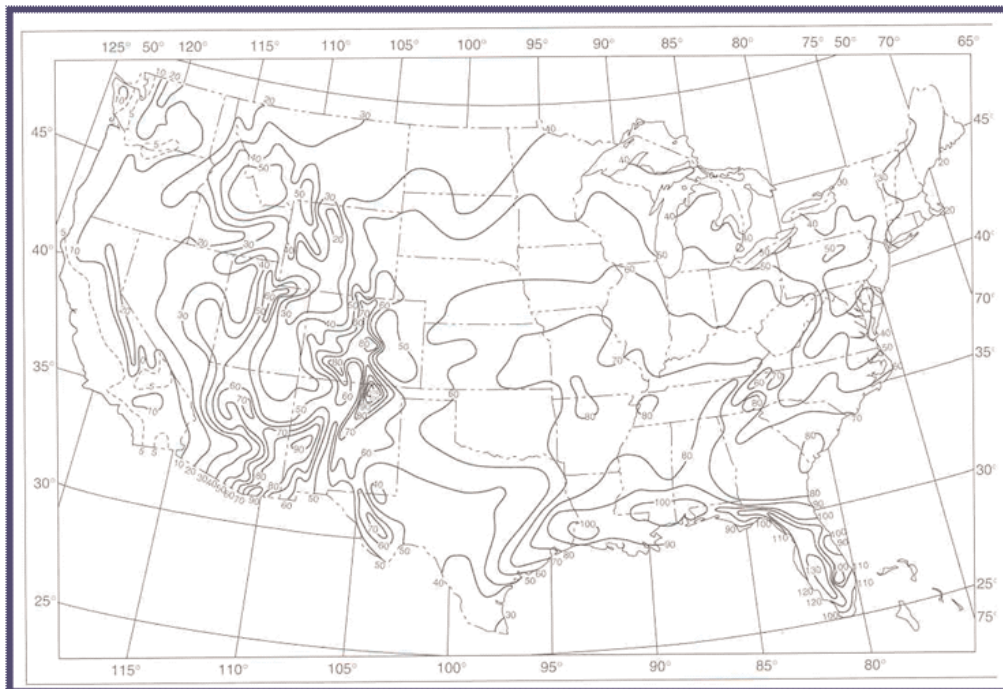
The conditions necessary for a thunderstorm are warm moist air from ground level to a few thousand feet, cooler air above with little to no wind, and full sun to heat the air mass near the ground. As the heated air near the ground rises to heights where the temperature is below freezing, a thundercloud is formed. Within the thundercloud, constant collisions among ice particles driven by rising and falling air columns causes static charge build up. Eventually the static charge becomes sufficiently large to cause the air to breakdown. An initial small charge called a "step leader" breaks out seeking an ideal cloud to cloud or cloud to earth path. Once this path is found the main series of strokes follow.

Lightning is a natural event with many unknown geographic, climatological, and electrical influences determining strike characteristics. Rf communication engineers, systems suppliers, and users, are accumulating data to understand what site configurations, lightning protectors, and grounding systems might be necessary to bypass sensitive electronics equipment and safely conduct lightning energy to earth. The following information is intended to help implement that goal.

Lightning as a Statistical Event

- Local thunderstorms determine the strike probability for any given tower
- A thunderstorm day is defined as a local calendar day where thunder is heard
- Prediction of a lightning strike to a specific object is not an exact science; however, thunderstorm day data is the only related parameter collected since the early 1900's
- Isokeraunic charts are developed from thunderstorm day statistics

The following information is extracted from recognized government and industrial standards, as indicated with references

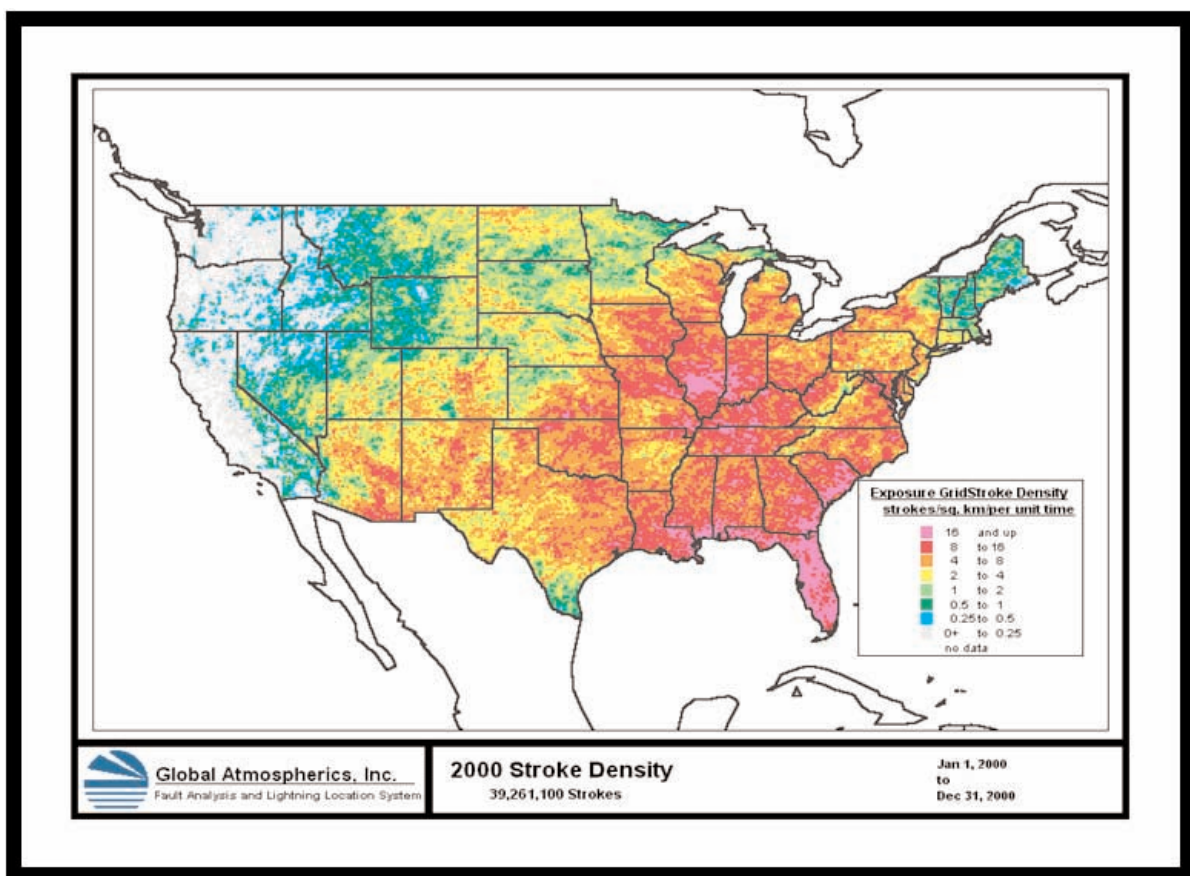


***Ref: Mean Annual Number of Days with Thunderstorms (1948-1972),
U.S. Department of Commerce, Environmental Science Administration***



Electrical breakdowns caused by over-voltages due to lightning are responsible for considerable property damage and business interruption. No section of the United States is immune, although in the Pacific Coast area lightning storms are infrequent. The Southeastern and South Central States experience the largest number of lightning storms each year.

The amount of lightning activity in any area can be determined by the Stroke Density, strokes / sq. km/unit time map.



Definitions of Lightning Voltage and Current Parameters

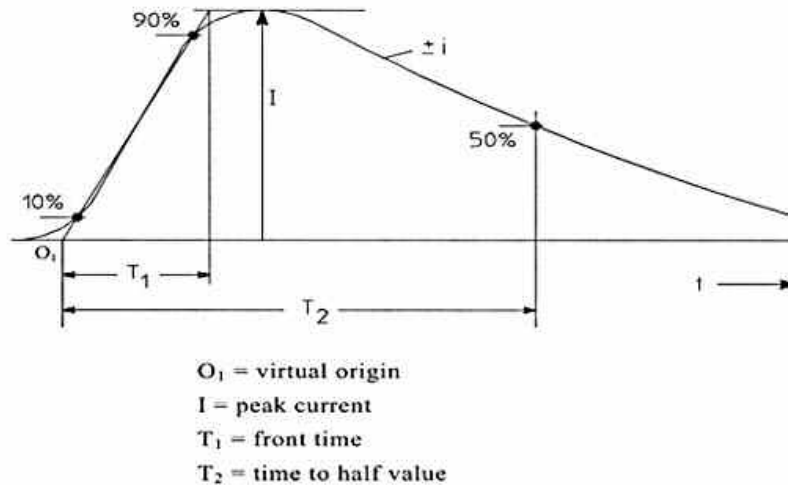


Figure A.1 - Definitions of short stroke parameters (Typically $T_2 < 2$ ms)

Lightning voltage can only be estimated since the cloud will produce whatever voltage is necessary to breakdown the atmosphere under varying weather and terrain. Peak voltages can be calculated from current flow, but only across the resistance (inductance) of a known conductor in the lightning path. Lightning researchers have performed peak current measurement of lightning strikes using the above method. In the next chart, current and statistical current likelihood is presented. With a 99.5% confidence level, the maximum current is determined to be 350 kiloamps, and with a 98% confidence level, at 300 kiloamps.

Since Lightning is a pulse waveform, researchers also measure lightning in terms of rise time to peak stroke current. Some researchers recorded the rise time from zero to peak and others recorded from 10% to 90%. When we analyze the chart, we can determine that the maximum current rise-time is about 10 microseconds and the minimum is 0.7 microseconds

Measured Peak Lightning Currents

350kA
Maximum with
99.5%
Confidence
Level

300kA
Maximum with
98%
Confidence
Level

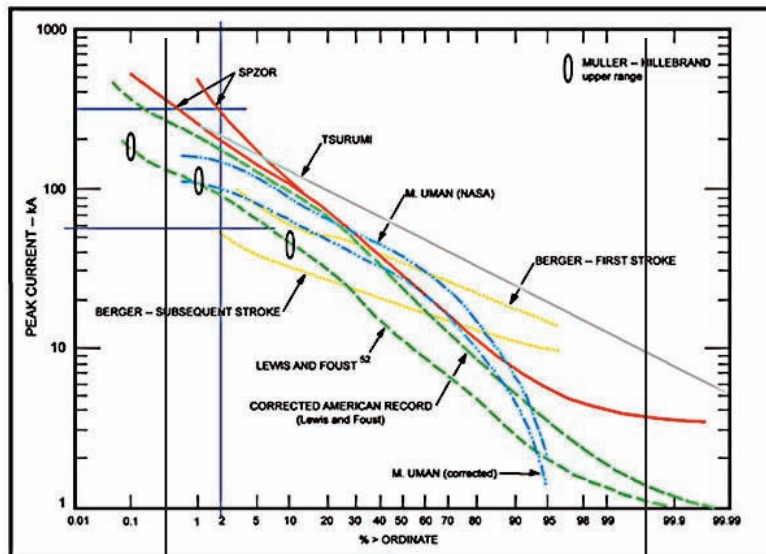


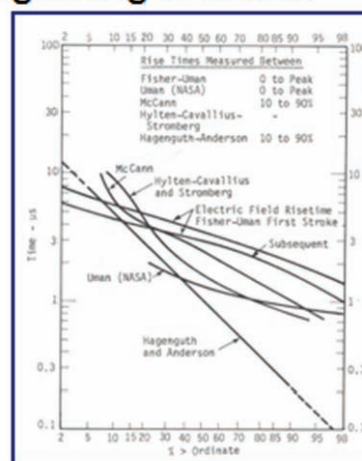
Figure 3.5 - Measured Peak Currents²

Six σ Distribution

Ref: W.C. Hart, E.W. Malone, *Lightning and Lightning protection*, EEE Press, 1979

Time to Peak Lightning Currents

Max. 10 μ -sec
Min. 0.7 μ -sec
0 to peak current with 95%
confidence level



Ref: W.C. Hart, E.W. Malone, *Lightning and Lightning Protection*, EEE Press, 1979

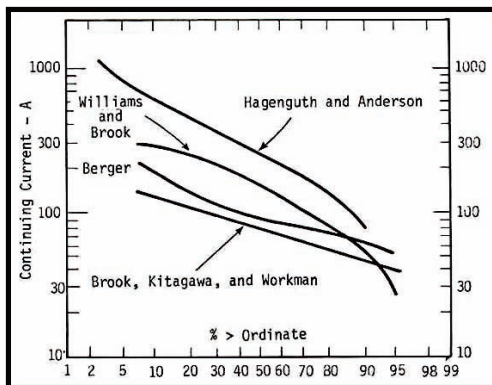
Multiple Return Strokes

A Lightning event can have as many as 30 (very rare) additional lower current return strokes based on the impedance of the conductive channel and the charged cloud's ability to migrate electrons to the discharge area. A typical Lightning event might have 2 or 3 lower energy return strokes. Total energy conducted through the struck object will be elevated to higher levels as the number of return strokes increases.

Continuing Current Strokes

Any one (or more) of multiple return strokes can have the pulse decay extended from 35 to 550 milliseconds. During the extended time line, continuing lightning currents can cause damage to equipment that might have survived the initial series of short duration, high current pulses. The short duration, fast rise time pulse on the coaxial cables will create a dv/dt voltage drop that, along with the dc resistance of the cable, will reduce current flow to equipment. But the long duration dc "surge" following a fast rise time event will be reduced only by the dc resistance of the cables. There can be from 30 to 1000 Amps delivered to the coaxial cable entry panel for 35 to 550 Milliseconds. Proper entry panel grounding is essential.

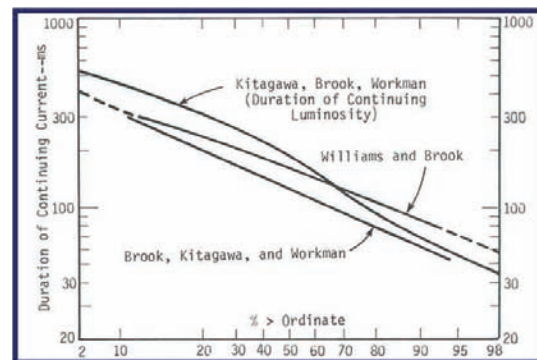
Duration & Amplitude of Continuing Currents



Max. 1000A

Min. 30A

0 to peak current with 96% confidence level



Max. 550m-sec

Min. 35m-sec

0 to peak current with 96% confidence level

Ref: N. Clanos and E.T. Pierce, "A Ground Lightning Environment for Engineering Usage", Contract L.S.-28170A-3, Stanford Research Institute, CA

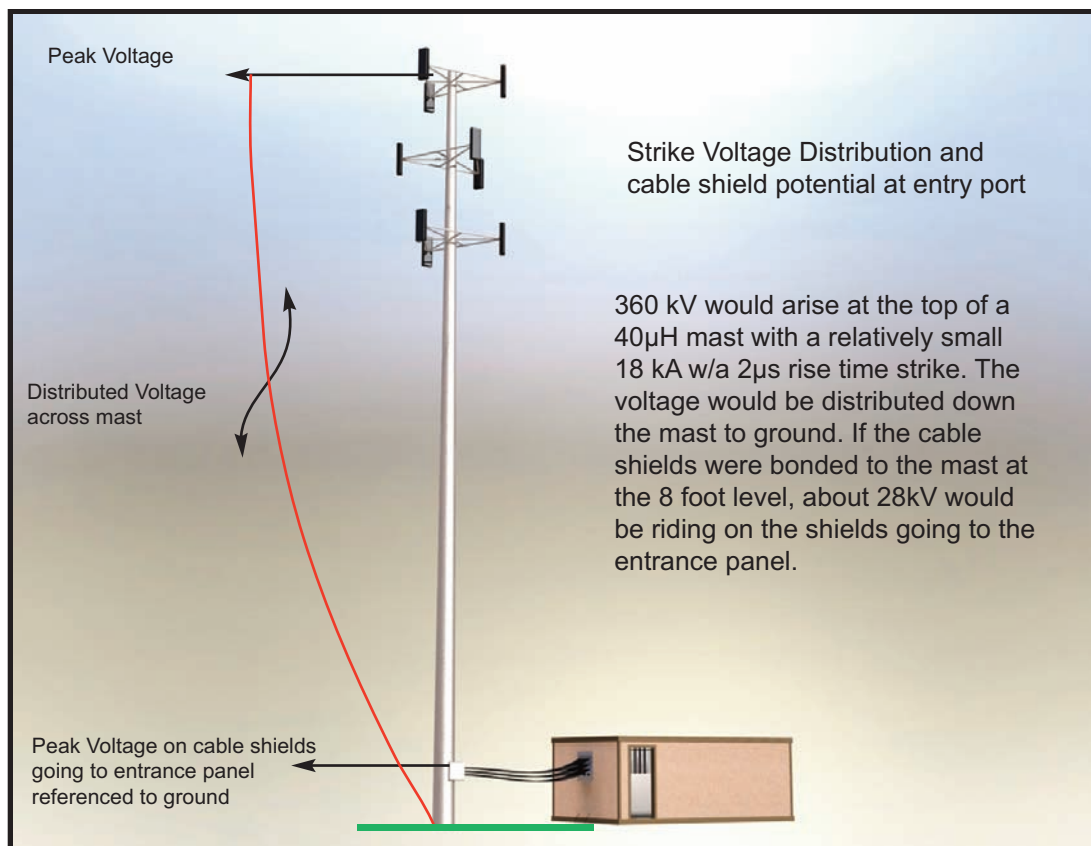
Continuing currents could be caused by the discharging of unused previously extended step leaders in to the lightning channel, and the collapse of the channel's surrounding magnetic field once the cloud charge potential cannot overcome the channel's impedance to earth.

Protection techniques for equipment connected to the antenna feeder cable

The coaxial antenna feeder cable is the primary source of damaging lightning energy to equipment at a communications site. When struck by lightning, the tower acts like a voltage divider. For a few nanoseconds, there will be a high peak voltage at the top referenced to zero voltage at the base. Current will then flow through the tower and all attached conductors. The rise time and amount of current directed toward the equipment will be determined by:

- Strike characteristics
- How high above earth the coaxial cable shields are grounded to the tower before they turn towards the building / cabinet entry.
- The inductance of the tower with coaxial cables, and below without coaxial cables
- The series inductance of the coaxial cables turning to enter the building/cabinet
- The parallel inductance of the building /cabinet entry conductors to ground

If the bottom coaxial cable ground kit (where the coaxial cable leaves the tower) is at any elevation above the earth, the overall inductance to earth of the tower below the ground kit, the series inductance of coaxial cables to the building, and the paralleled entry panel ground conductors, is sufficient to cause a substantial peak voltage drop. The resultant voltage on the coax shield will drive current to the equipment where the electrical safety ground provides a path to ground through the

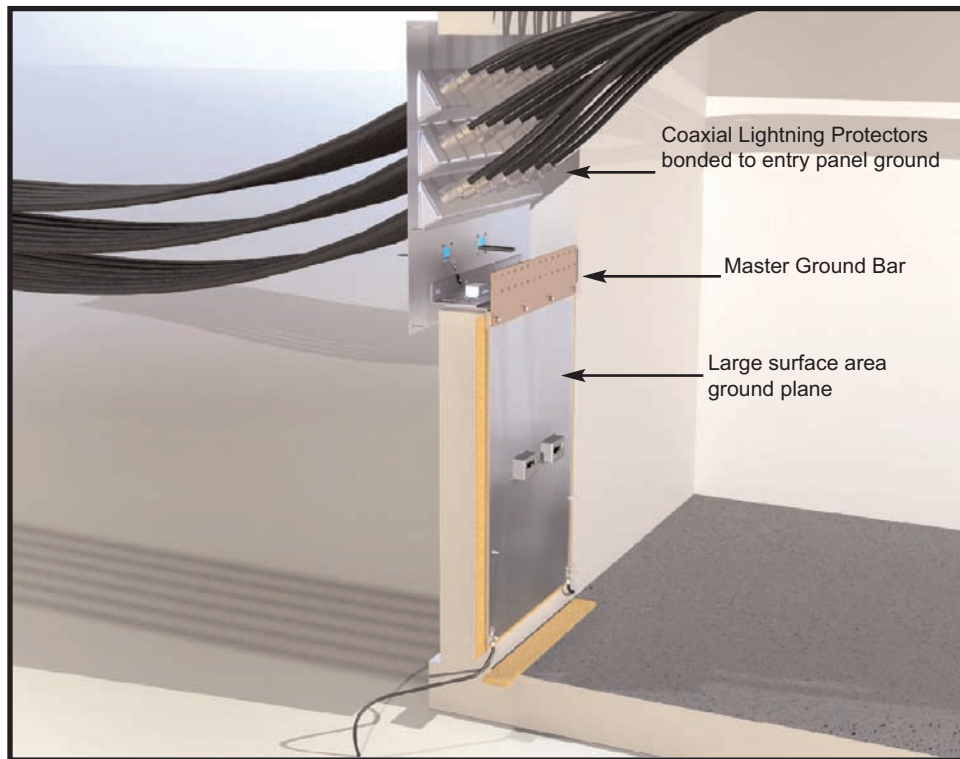




The best way to prevent lightning caused coaxial shield currents from reaching equipment is to minimize the peak voltage at the building entry panel. This may be accomplished by installing, on the inside of the building, a continuous panel bonded to the ground system or a panel with large surface copper straps. The large surface area strap is necessary to provide a low inductance path to ground for the entry panel's peak surge energy as well as provide for the high frequency component of the strike. Each coaxial line as it enters the building is attached to the panel with a grounded protector/feed through or an additional ground kit before connecting to a protector.

A recommended entry system would provide a continuous surface area "single point ground" plate from the coaxial cable entry to the ground system. A continuous surface area ground plate:

- Keeps inductance low
- Minimizes inductive voltage drop during lightning event
- Improves MGB (Master Ground Bar) performance
- Provides a low impedance single point ground return path for lightning transients

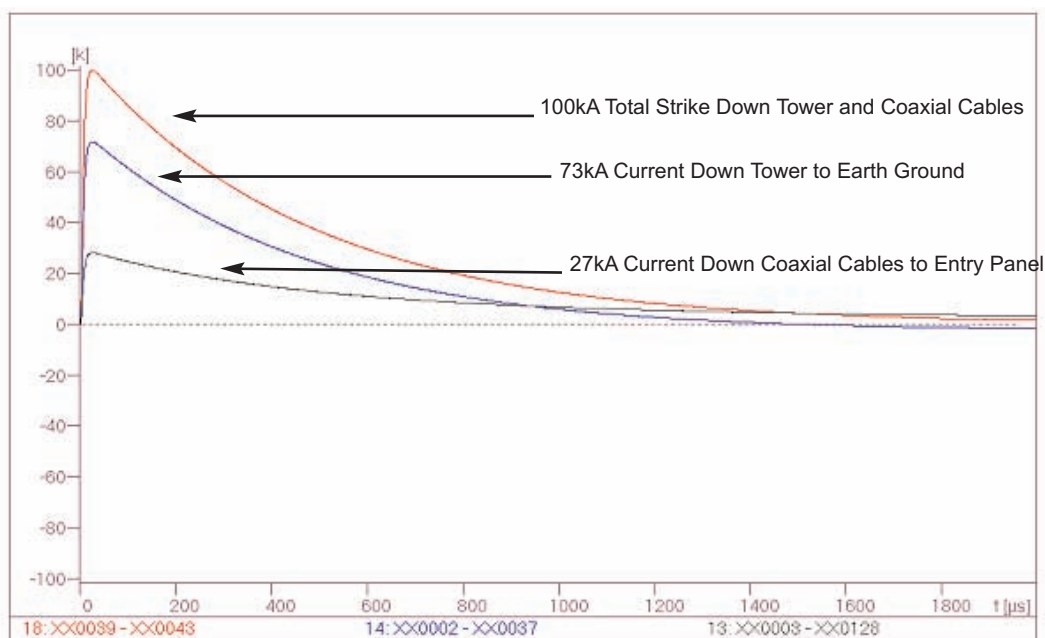


In a 100kA strike computer simulation, the amount of strike current delivered to the entry plate is determined by:

- The tower's inductance to earth below where the coaxial cables are bonded to the tower and turned toward the entry panel,
- The inductance of the paralleled coaxial cables directed to the entry panel,
- The inductance / impedance of the entry port / master ground bar to ground at lightning transient frequencies .

The amount of current on each of the (same sized) coaxial cables would be determined by the peak current on all coaxial cables at the elevated coaxial cable shield / tower ground connection, divided by the number of coaxial cables routed to the entry panel.

Lightning Strike Current Division



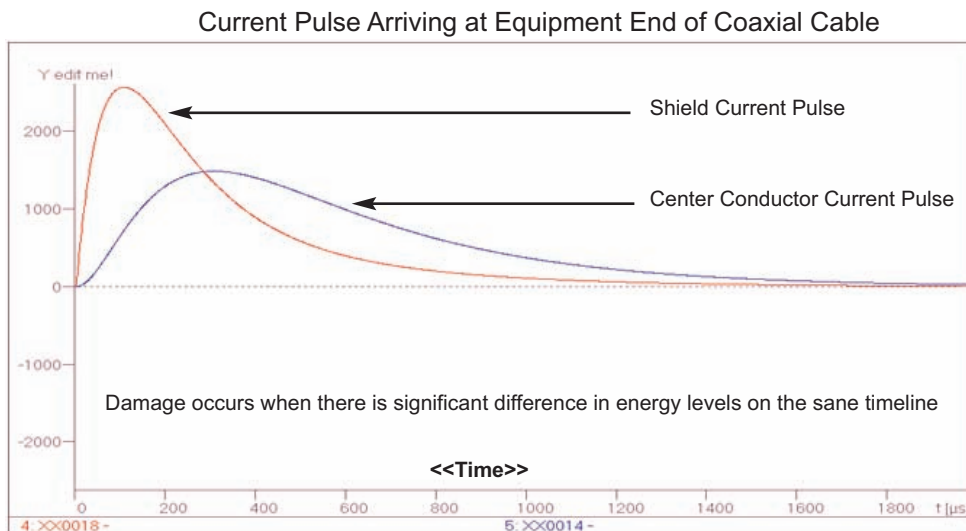
Most of the lightning energy goes down the tower to earth with current divided between the entry port ground system and the earth ground connection. If coaxial cables on the tower were turned towards the entry panel at a lower point on the tower and shields were bonded to the tower there, less potential and current flow would be applied to the entry panel or master ground bar. Always direct cables to the entry panel at the lowest practical location on the tower.

The 27kA on the feeder cables divided by the 18 coaxial cables shown in the concept drawing equal 1.5kA per cable. A 7/16 DIN connector body could handle the coaxial cable shield current to ground and eliminate the requirement for shield grounding kits and an outside master ground bar. Isolate the "ice bridge" / cable tray structure from the entry panel. Only coaxial cables, dc power (if required), data cables, and tower light wiring should complete the circuit between the tower and entry panel.

Why are coaxial cable lightning protectors required?

During a strike, a difference in potential arises between the coaxial cable shield and the center conductor at the equipment end of the cable. A coaxial cable will transfer rf energy efficiently from point a to point b with minimum losses at the operating frequency. But as the cable length is extended it attenuates higher frequencies according to the manufacturers specifications per unit length. The cable, in effect, becomes a low pass filter.

There is another factor called “velocity of propagation”. This term defines how fast, as a percentage of the speed of light (s.o.l.), an rf signal will propagate through a conductor. Typical specifications might be 98% s.o.l. for the cable shield, and 88% s.o.l. for the center conductor. These percentages are logically called Velocity factor (V_f). An analysis of all the parameters involved is beyond the scope of this paper, but can be understood with the following graph.



When lightning strikes the tower, the shield and center conductor at the antenna are simultaneously elevated in potential. Since there is more surface area on the shield, the propagation velocity will be faster, and high frequencies will not be as attenuated as on the slower propagating center conductor. This difference in propagation time and high frequency roll off of the fast lightning pulse rise time creates the voltage differential and subsequent damaging current flow through equipment.

A lightning protector does not stop, arrest, or confine lightning energy. A coaxial cable lightning protector equalizes the elevated potential on the shield with the yet to be elevated potential on the center conductor. Its first purpose is to reduce the potential on the elevated shield (with a proper ground connection) causing reduced current flow through the equipment chassis. The protector then applies the remaining shield potential to the yet to be elevated coaxial cable center conductor through an appropriate mechanical rf isolation device. If the shield / chassis and coaxial cable center conductor are immediately brought to the same potential across the equipment's input circuit, there will be little or no current flow through the input due to propagation caused delayed center conductor current. The input circuit will likely survive the strike. A “filter type” protector adds a mechanical dc blocking device (“capacitor”) to the center conductor to further reduce energy throughput to the equipment during a strike.

Site Grounding Principles

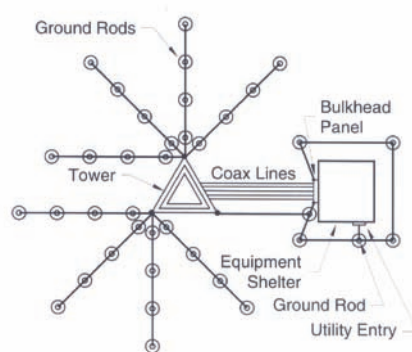
We have examined lightning characteristics, sources of damaging energy, and how to save equipment from damage using large low inductance conductors draining off strike energy to ground. Coaxial cable and other lightning protectors present a lower impedance, preferred path to ground for individual circuit protection. In all cases proper grounding and protection techniques offer alternatives to uncontrolled lightning damage. But what is “ground”? The earth (referenced as “ground”), is the electrical “return” for lightning strike energy. It is nature’s balance for a continuing sequence of natural phenomena.

Why is a lightning ground system different from an ac power ground?

A lightning ground system at a communications site should be capable of dispersing large amounts of electrons from a strike over a wide area with minimum ground potential rise (GPR). GPR means any difference in voltage within the strike’s local sphere of influence (step potential). The lightning ground system should be capable of doing this very quickly (fast transient response). By spreading electrons out over a wide area, the step potential for any smaller given area would be reduced. The speed, or transient response of the ground system would be dependent on the geometry and combined inductance of the below grade conductive components, and the resistivity/conductivity of the soil “shunting” those components. The lower the inductance of the system components and soil resistivity, the lower the impedance at higher frequencies, the faster the ground system could disperse electrons. A lightning ground system is an excellent ac power ground. An ac power ground might not be a very good lightning ground.

Strike energy to the tower base, and energy through the coaxial cable shields to the entry panel ground can quickly saturate a ground system and elevate potential throughout the site referenced to the “outside” world. Ac power lines, telephone, data, control and alarm lines all represent a path to a lower potential for incoming strike energy. Unfortunately, valuable equipment might be in between the strike energy and a lower potential.

One or two ground rods for a residence, a ground loop around a commercial building, or a loop and three ground rods around the base of a communications tower might meet code, but will not disperse the strike energy quickly enough to keep the GPR low. Effort and money spent up front on proper grounding will reduce downtime and equipment damage. If attention is not given to grounding, it’s a save now pay (more) later situation.

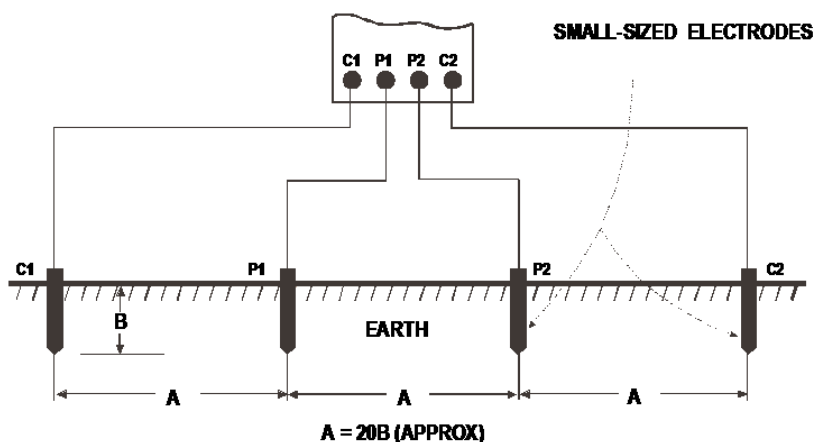


Connecting all ground rods together forming a “single point” ground system.

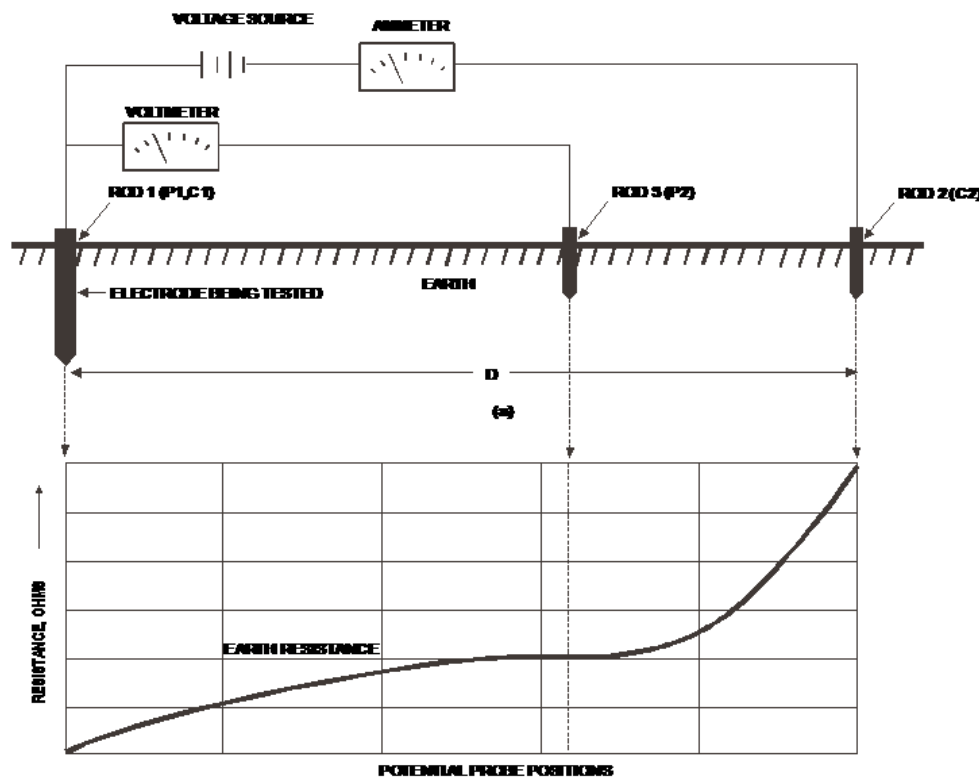
How do I know if I have a “good” lightning ground?

The first thing is to find and inspect it. If it's a minimum installation to meet code, it's not good enough. There are ground “resistance” testers available to give you a measurement value. For example, a residential ground is acceptable at 20 Ohms and 5 Ohms is good enough to be considered an adequate tower ground measurement. But here's where things get foggy.

There are two types of ground testers in use today. The first is the traditional “Fall of Potential” tester where three or four rods are driven into the earth, connected back to the tester, and a calibrated ac current (100-300 Hz) is passed between them in ways to facilitate the kind of measurement required. The returned data is interpolated into value called Ohm-m or Ohm-cm (not Ohms per meter).



After the ground system is designed using the 4-stake resistivity measurement results above, performance after construction can be verified by using the 3-stake fall of potential measurement (FOP) below. Ground “resistance” is the meter reading when rod 3 is at 0.618 the distance of rod 1 to rod 2 and the graph “flattens” as shown below



Then there is the “clamp-on” on ground tester that couples ac energy into each ground rod or “system” of rods and radials and calculates a reading directly in Ohms based on the timing and waveshape of the “reflected” energy. Although the fall of potential measurement with driven rods is considered more accurate, the clamp on device is easier to use and shows results close (opinion) to the FOP tester.

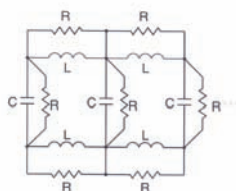
Most measuring devices use an ac source current in the low frequency range to calculate the earth impedance of the grounding component or system. So the returned measurement is really the impedance at specific frequencies between 100-300 Hz. This is a useful measurement for an ac power company or an electrician, but a communications technician should regard these measurements with suspicion.

Although lightning is dc current event, the fast change from no current to peak current will cause a dv/dt voltage drop across any conductor. Direct and magnetic field coupled damage can be severe. A multiple strike event pumps energy into a ground system that, unless properly designed with a fast transient response, will quickly saturate causing a rapid rise in GPR even though it might measure 5 Ohms with a ground tester.

If we convert from a time domain measurement in μS (see rise time graphs) to a frequency measurement in Hz, we find considerable energy from 100Hz, peaking at 50-100kHz and rolling off up to 1MHz caused by the fast rise time dc current pulse. There is still detectable energy up and through the wireless range of frequencies that can damage sensitive receiver rf input circuits.

How is a lightning ground system evaluated?

Consider the lightning grounding system as an rf circuit. Ground rods have a series inductance bridged by earth's resistance. Connecting ground rods along buried conductors (radials) presents a series inductance (bridged by earth resistance) with additional ground rods along the radial's length. The additional ground rods can be considered in parallel, all bridged by earth's resistance. Multiple radials with ground rods are all electrically in parallel to further reduce inductance. Multiple buried conductors (radials and rods) with attention to geometry and materials will net a good reading on a ground resistance tester and have an enhanced transient response as well.



There are many marketing driven versions of what will “save” equipment. Some say “buy our product and lightning will not strike your tower”, or put our product in the ground and you won’t need rods or radials, or yes, our protectors are guaranteed 100% to protect your equipment from lightning damage (what is really guaranteed?).

Summary

A lightning protection “system” for a wireless communications site is a scientifically based, common sense integrated set of:

- Grounding design measurements ... Ground system design based on targeted FOP impedance using soil Ohm-m resistivity measurements, depth / length of radials, and length / diameter of rods and how many of each, all configured to IEEE ground system design parameters. To ensure a fast transient low earth ground, multiple rods and radials should be chosen to reach targeted FOP impedance.
- Tower to entry port coaxial cable ... Bend away from tower towards equipment at lowest practical height above ground . Do not connect tower cable tray to entry port. Only active rf, dc, data, and tower lighting should complete the tower to entry panel circuit.
- Entry panel ... provides coaxial cable connector termination, lightning protectors, and a low inductance, large surface area conductor to a “single point ground” connection. The entry panel is your “last chance” to reduce damaging incoming currents from the tower or coaxial cables.
- Install lightning protectors on all circuits subject to damaging currents. All protectors should be bonded to the site “single point ground”.

Any shortcut during design and installation of any part of the lightning ground system reduces the level of protection of the whole (“weakest link”).

About *TIMES MICROWAVE SYSTEMS*

Times Microwave Systems, was founded in 1948 as the Times Wire and Cable Company. Today, the company specializes in the design and manufacture of high performance flexible, semi-flexible and semi-rigid coaxial cable, connectors and cable assemblies. With over 60 years of leadership in the design, development, and manufacture of coaxial products for defense microwave systems, Times Microwave Systems is the acknowledged leader, offering high tech solutions for today's most demanding applications.

Cable assemblies from Times Microwave Systems are used as interconnects for microwave transmitters, receivers, and antennas on airframes, missiles, ships, satellites, and ground based communications systems, and as leads for test and instrumentation applications.

As a highly specialized and technically focused company, Times Microwave Systems has been able to continually meet the challenges of specialty engineered transmission lines for both the military and commercial applications, drawing upon our:

- Thousands of unique cable and connector designs
- Exceptional RF and microwave design capability
- Precise material and process controls
- Unique in-house testing capabilities including RF shielding/leakage, vibration, moisture/vapor sealing, phase noise and flammability
- Years of MIL-T-81490, MIL-C-87104, and MIL-PRF-39012 experience
- ISO 9001 Certification

In 2010, Times Microwave Systems introduced its Times-Protect™ line of lightning and surge protection solutions to address the challenging needs of wireless systems in the 21st century.

With over 60 years of Times Microwave Systems aerospace cable and connector technology experience and unparalleled design expertise, Times Microwave Systems' staff of Field Applications Engineers can help to provide the right solution for your interconnect applications.

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