A Lightning Protection System for Wireless Telecom Sites

Site grounding is the foundation for effective lightning protection at communications sites.

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Several factors affect successful implementation of lightning protection for wireless networks, such as understanding lightning-stroke characteristics, antenna site layout conditions, structural protection, equipment protection and construction of a low-impedance ground system designed for fast lightning transient response.

Proper grounding and bonding design play a critical role in the operation of every surge protection device installed on a communications site. Proper design applies without exception to all radio-frequency (RF), data, telemetry, AC and DC input/output ports. Every lightning-protection device's primary function is its ability to limit the differential voltage across an equipment I/O port while conducting as much event current as possible to earth ground. Performance of every surge protection device will be affected not only by the manufacturer's specification, but also to a great extent by the installation method. Surge protection device performance differs significantly between a bench test and an on-site test where the ground resistance and inductance of all grounding and bonding connections, not to mention the undefined protected load impedance at the lightning frequency, are determining factors.

The lightning event

More than 2,000 thunderstorms occur throughout the world at any given time. (See Figure 1.) They produce about 100 lightning flashes per second. Any lightning strike can destroy a radio system that isn't properly grounded and protected. With ever-increasing dependence on computers and communications networks, protection from system disruptions becomes essential. Understanding the principles behind

High-resolution, Full-climatology Annual Flash Rate

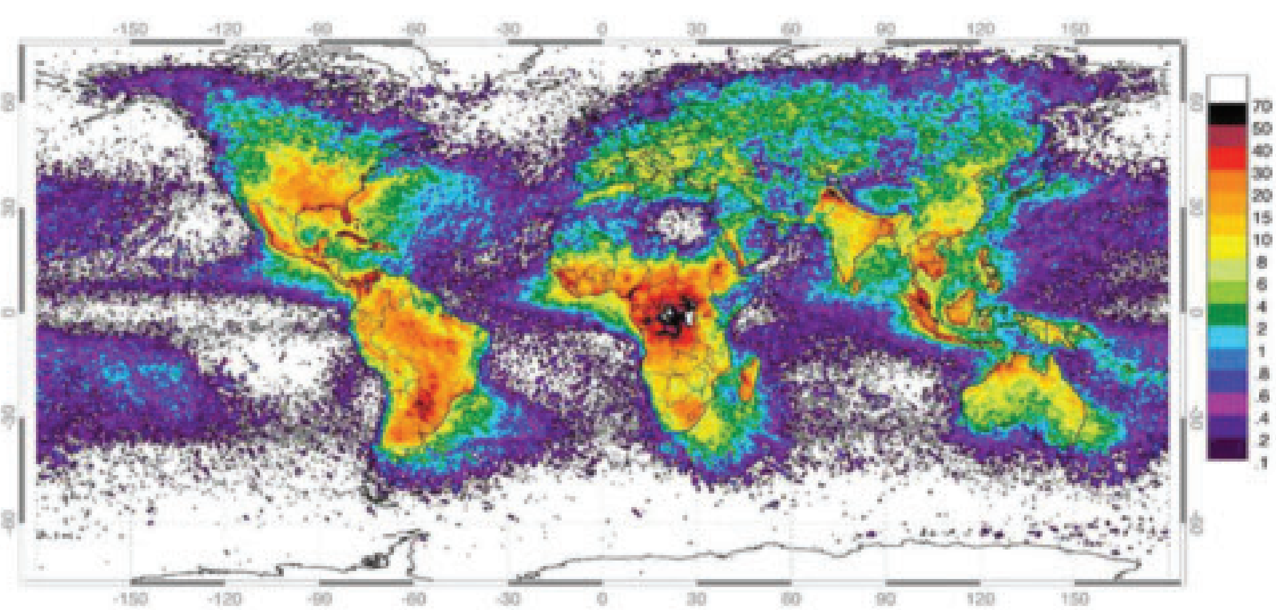

Figure 1. This map shows the global distribution of lightning from April 1995 to February 2003 using the combined observations of the NASA OTD (4/95–3/00) and LIS (1/98–2/03) instruments.

a lightning event helps users properly design system protection.

As heated air migrates upward into a freezing region, it creates constant collisions among ice particles in the thundercloud driven by rising and falling air columns, causing static charge buildup. Eventually, the static charge becomes sufficiently large to cause the air to break down. 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 established, the main series of strokes follow.

Statistical nature of lightning

The most basic forms of lightning are cloud-to-cloud, intracloud and cloud-to-ground. There are positive and negative forms of this event. The step leader polarity indicates whether the strike will have positive or negative characteristics. To understand the statistical nature of the event, system designers must evaluate the following characteristics.

The current wave shape. This specific wave shape shows the rate of current rise to 90 percent of peak value (front time), and diminishing current duration to 50 percent of peak value (time to half value). (See Figure 2.) The current wave shape consists of the di/dt high-frequency component, as well as the DC content. To provide specific frequencies associated with this wave shape, Fourier analysis should be performed. Taking into account the 1–10 microsecond (μs) rise times, the event could be characterized as DC – 1 MHz.

Peak current analysis. International research data compiled during the past 40 years captures values and distribution parameters of lightning currents. Looking at 50 percent distribution, the typical event will carry peak currents in the 10–50 kiloampere (kA) range. While planning for site protection, these values are helpful in analyzing protection needs for grounding design, as well as determining ratings for protectors applied on all I/O ports.

A lightning event can have as many as 30 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 two or three low-energy return strokes. Total energy conducted through the struck object will be elevated as the number of return strokes increases.

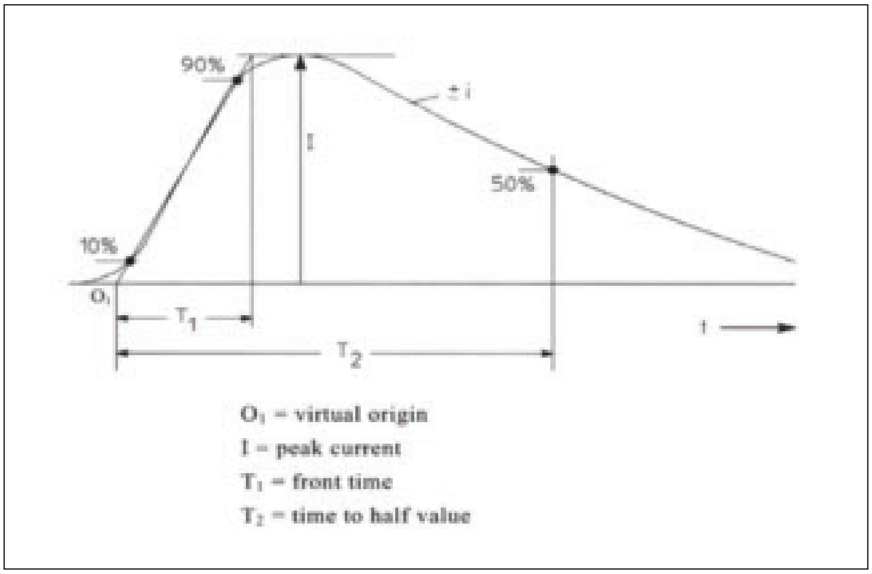

Figure 2. Definitions of short-stroke parameters. Typically, T_2 is less than 2 milliseconds.

Continuing current. Any one of the multiple return strokes can have the pulse decay extended from 35 to 550 milliseconds. During this extended time, continuing lightning currents can cause damage to equipment that might have survived the initial series of short, high-current pulses. The long-duration DC surge following a fast rise-time event will be reduced only by the DC resistance of the cables. From 30 to 1,000 amps can be delivered to the coaxial cable entry panel for 35–550 milliseconds. Proper entry panel grounding is essential.

Current rise time. The rate of rise time to peak lightning current ranges from a fraction of a microsecond to about 10 μs. Understanding this characteristic is important once one observes the inductive voltage drop associated with the rate of current rise. By taking into account the lightning peak current, its rise time and the tower inductance with coaxial cables, it is easy to determine how much differential voltage will be present. Let's assume 18 kA peak lightning current with 2 μs rise time conducted to ground by a 150-foot tower with approximate inductance of 40 microhenries (μH). The $V_p = -L_{di/dt}$ formula becomes handy. The calculated total inductive voltage drop across the tower will amount to about 360 kilovolts (kV). This voltage can be responsible for flashover among towers, cables and grounding jumpers, and can destroy coaxial cable insulation. Tower and coaxial cables will act as a voltage-divider network. The associated lightning currents will divide themselves among the tower, cables and other conductive surfaces of the installation. Figure 3 illustrates this inductive voltage-drop phenomenon.

Site grounding principles

Coaxial cables and the tower, together with all other service entries into the communications shelter, present low-impedance preferred lightning paths to ground through individual circuits. In all cases, proper grounding, bonding and protection techniques offer alternative paths for damaging currents. 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 disperse 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). Properly designed and implemented lightning ground systems should be capable of doing this quickly (fast transient response). By spreading electrons 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 depend on the geometry and combined inductance and capacitance of the below-grade conductive components and the resistivity and conductivity of the soil shunting those components. The lower the inductance of the system components and soil resistivity, the lower the impedance will be at higher frequencies. A lower-impedance ground system will disperse electrons faster. A lightning ground system can be an excellent AC power ground, but an acceptable AC power ground might not be a good lightning ground.

Lightning strike energy that reaches the tower base and that travels through the coaxial cables to the entry panel ground can quickly saturate a ground system and elevate the electrical potential throughout the site referenced to the outside world. AC power, telephone, data, control and alarm lines all represent paths to a lower electrical potential for lightning strike energy coming from the tower. Unfortunately, critical equipment might be in place between the lightning strike energy and a lower-potential current-return path.

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 electrical code, but will not disperse the lightning strike energy quickly enough to keep the GPR low.

Effort and money spent upfront on proper grounding will reduce downtime and equipment damage. Additional attention should be dedicated to design, implementation, maintenance and integrity of the site grounding system. All lightning-protection devices, regardless of the technology used in their designs, rely primarily on a low-impedance return path to ground while conducting surge current and controlling the differential voltage to protect equipment. The concept applies without exception to all RF, DC, AC power, telecommunications, data, and telemetry services entering any communications site.

Why Coaxial Cable Ground Kits Are Essential

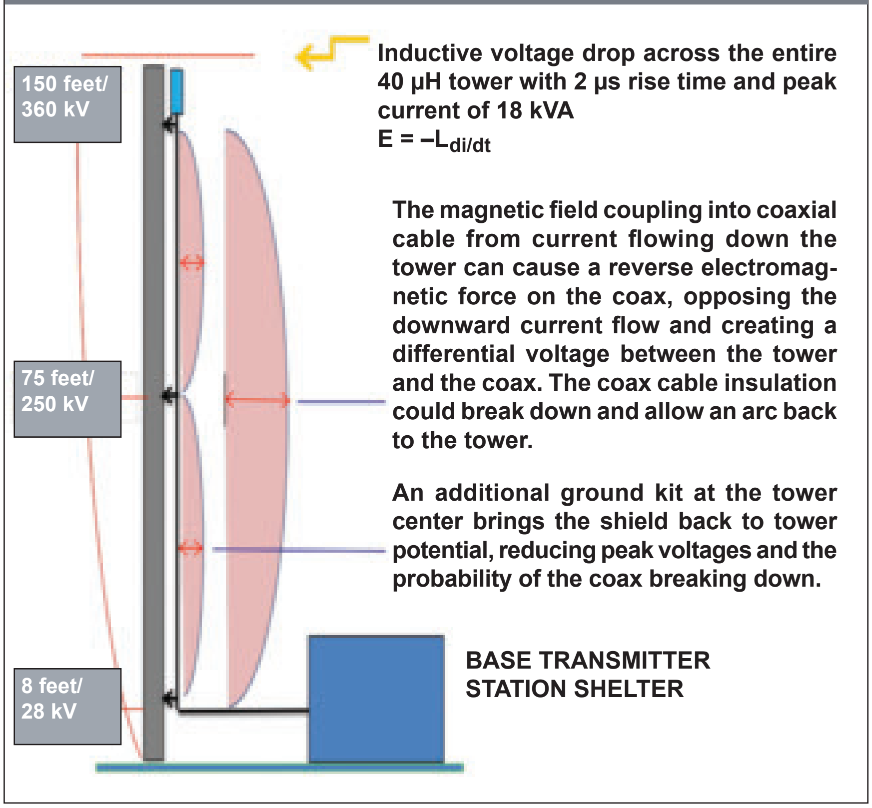

Figure 3. Lightning current divides among the tower, cables and other conductive surfaces, causing an inductive voltage-drop phenomenon.

Radial and Ground Rod System

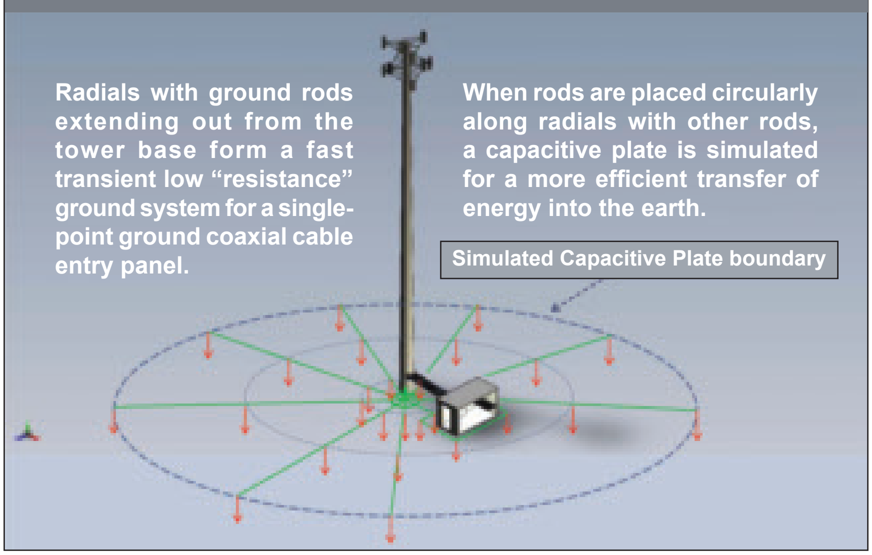

Figure 4. Multiple buried conductors (radials and rods), with attention to geometry and materials, net a good reading on a ground resistance (impedance) tester and also have an enhanced transient response.

Ground resistance testing

How do you know if the lightning ground is good? The first thing is to find and inspect it. If it is a minimum installation to meet code, it may not be good enough. Ground resistance testers are available to provide 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 become uncertain. After the ground system is designed using the four-stake Wenner method resistivity measurement results, performance after construction can be verified by using the three-stake fall of potential measurement (FOP).

There are two types of FOP ground testers. The first is the traditional fall of potential tester that uses three stakes driven into the earth at measured intervals and connected to the tester. A calibrated AC current (100 – 300 Hz) is passed among the stakes in various ways to facilitate the measurement required. Ground resistance is the meter reading when rod three is at 0.618 the distance of rods one to two, and the graph flattens. The returned data is interpolated into value called ohm–m or ohm-cm. Newer FOP meters can give the results directly in ohms

The second type 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 wave-shape 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 that come close to those of the FOP tester.

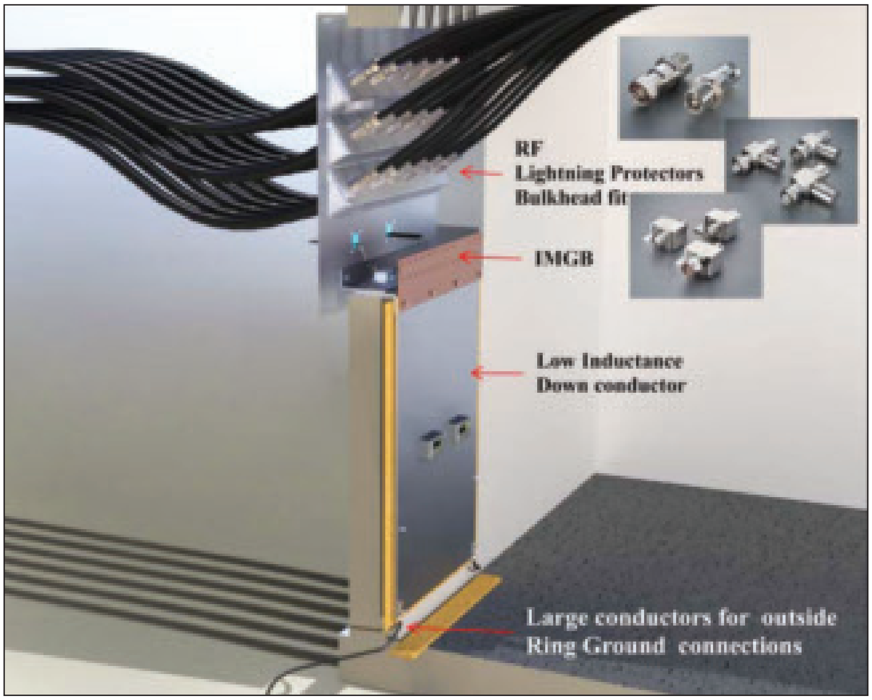

Figure 5. A recommended entry system provides a continuous surface area, single-point ground plate from the coaxial cable entry to the ground system.

Suspicious measurement

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

Although lightning is a 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. The strike event delivers 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.

Consider the lightning grounding system as an RF circuit. Ground rods have a series inductance bridged by the 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 resistance. Multiple radials with ground rods are all electrically in parallel to further reduce inductance. Multiple buried conductors as illustrated in Figure 4 (radials and rods), with attention to geometry and materials, will net a good reading on a ground resistance (impedance) tester and will have an enhanced transient response as well.

The best way to prevent lightning-caused coaxial shield currents from reaching equipment is to limit them from entering the building. This may be accomplished by installing, outside or inside the building, a continuous panel bonded to the ground system or a panel with one or more large-surface conducting straps. The large surface-area strap is necessary to provide a low-inductance path to ground for the entry panel's DC surge current, as well as provide for the high-frequency component of the lightning strike energy. Each coaxial line as it enters the building is attached to the panel with a combination protector and feed-through device or an additional ground kit before connecting to a protector.

A recommended entry system (see Figure 5) would provide a continuous surface area, single-point ground plate from the coaxial cable entry to the ground system. This continuous surface area ground plate will:

- Keep inductance low
- Minimize inductive voltage drop during a lightning strike
- Improve master ground bar (MGB) performance
- Provide a low-impedance, single-point ground by design, not installation
- Make provisions for grounding of all RF protectors on the bulkhead, increasing protector performance
- Accommodate installation of additional surge protectors for DC,data, telephone and telemetry lines with reference to the same single-point ground

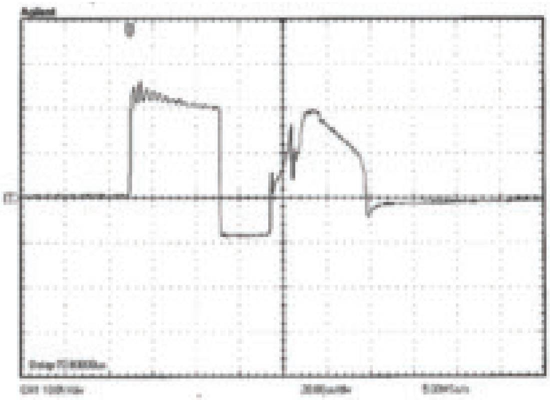

Figure 6. The voltage throughput of an RF lightning protector without the ground lead attached (bulkhead installation) is maintained at about 26 volts peak to peak. Scale: 10 volts per division.

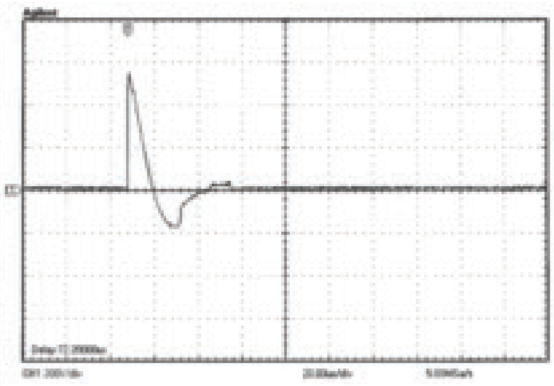

Figure 7. The same protector represented associated with Figure 6, but with 1.5 feet of added grounding conductor, maintains a voltage throughput of about 700 volts peak to peak. Scale: 200 volts per division.

The effectiveness of lightning and surge suppression devices used to protect wireless networks depends on a low-impedance ground return path for conducting surge currents and limiting differential voltages. RF lightning protectors designed to handle high surge currents with minimal energy and voltage throughput to the protected equipment should be used. Installed on the bulkhead with no added ground lead inductance, they reduce let-through voltages to the lowest industry recognized benchmarks.

Grounding conductors can compromise protector performance. The added inductance through 1.5 feet of #1 AWG Cu grounding wire adds about 675 volts to the surge delivered to the protected equipment by a lightning strike. Figure 6 represents the voltage throughput of an RF lightning protector without the ground lead attached (bulkhead installation). In this case, the voltage throughput is maintained at about 26 volts peak to peak. Figure 7 represents the same protector performance with 1.5 feet of the previously mentioned added grounding conductor for a total throughput of about 700 volts peak to peak. The wave shape used to compare both installation and protector grounding methods was the

IEEE 6-kilovolt (1.2x50µs) open-circuit voltage and 3-kiloampere (8x20µs) short-circuit current.

A suitable RF bulkhead addresses this concern through RF protectors installed directly on the bulkhead without the need for additional grounding jumpers. Other services can be routed through the bulkhead, grounded and protected, capitalizing on the single-point ground.

A lightning-protection system for a wireless communications site is a scientifically based, common-sense integrated set of the following concepts.

Grounding design measurements. The ground system design should be based on targeted FOP impedance using soil ohm-m resistivity measurements,

The Times Microwave Systems Smart Panel entry system, photographed at a convention display, offers the recommended single-point ground plate.

the depth and length of the radials, and the length, diameter and number of rods, all configured to the Institute of Electrical and Electronics Engineers ground system design characteristics. To ensure a fast-transient, low-impedance earth ground response, multiple rods and radials should be chosen to reach the targeted FOP impedance.

Tower to entry port coaxial cable. Bend the conductor away from the tower and toward the equipment shelter at the lowest practical height above ground. Do not connect the tower cable tray to the entry port. Only active RF, DC, data and tower lighting AC lines should complete the tower-to-entry panel circuit.

Entry panel. Use the entry panel to provide a termination for coaxial cable connectors and lightning protectors, and for a low-inductance, large-surface-area conductor to a single-point ground connection. The entry panel represents the last chance to reduce damaging incoming currents from the tower or coaxial cables.

Lightning protectors. Install lightning protectors on all circuits subject to damaging currents. All protectors should be bonded to the site's single-point ground.

The installation and grounding methods for all surge protective devices will determine their performance during the lightning event and should be evaluated at the system level as opposed to relying on individual protector manufacturer's specifications. agl