TD1001: The best RF protector for applications not requiring dc on the coax.

CONTENTS

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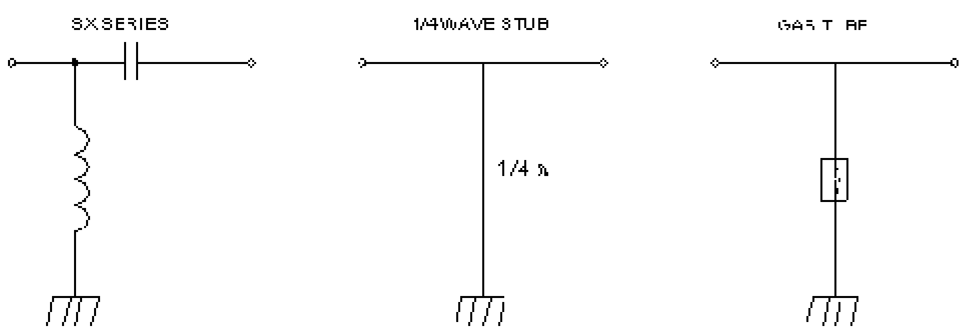
TD1001: The best RF protector for applications not requiring dc on the coax.

Abstract:

DC-Blocked RF lightning protectors have significant advantages over non-dc-blocked (Quarter-Wave stub and straight gas tube) protectors. The condition of dc-blocked or not, pertains to the RF path from center pin to center pin. Units were tested for RF performance, surge attenuation characteristics and surge suppression capabilities. Results show that dc-blocked protectors have broadband RF performance over a wide spectrum of frequencies, 80% higher surge attenuation and 1,000,000 times lower let-through energy than non-dc-blocked.

Introduction:

This report will show that dc-blocked RF lightning protectors are superior in RF and surge performance. RF lightning protectors are designed using either dc-blocked or non-dc-blocked technology. To compare these technologies we will use a PolyPhaser DSX protector (dc-blocked), a Quarter-Wave Stub (QWS) type protector and straight gas tube (SGT) (non-dc-blocked). The SX and QWS are designed for RF systems where dc power is not included on the coax. The SGT unit can also be used for system with dc supply on the center pin. For this comparison we will use the SGT unit as in a non-dc type application. The comparison is made to show that dc-blocked protectors outperform non-dc-blocked protectors in RF, surge attenuation and surge suppression capability. Each unit was tested for RF performance including bandwidth, Voltage Standing Wave Ratio (VSWR) and Insertion Loss. Units were also tested for surge performance, including attenuation at lightning frequencies (dc to 1 MHz) and let-through voltage and throughput energy.



Technology and Testing Overview:

After making the decision to provide lightning protection for a RF system, one must now make the decision which technology will best suit the application. One such application is RF systems where there is no dc on the coax. Some RF systems add dc onto the coax to power up Tower Top Electronics, active antennas or other type equipment requiring dc power. This paper addresses the applications with RF distribution only.

There are an increasing number of manufacturers selling RF lightning protectors. However, two technologies are most prevalent amongst the designs. The most common is the non-dc-blocked, where a dc-shorting device (Quarter-Wave or gas tube) is connected in parallel with the center conductor. The RF path for this type of protector is a straight connection between center pins. The second technology uses a dc-shorting device (similar to the above); however the RF path is dc-blocked. This dc-block is designed in such a manner that a specific frequency band is attained with low VSWR and insertion loss.

The units were tested for RF performance (VSWR and Insertion Loss) and surge attenuation using a network analyzer (HP 8753E). The analyzer is calibrated for the correct connector, load and frequency range. Surge suppression capabilities are tested using the Haefely PSURGE 6.1; units were tested to IEC 61000-4-5, 8/20Âµsec waveform, 6kV/3kA (2â„¦ source impedance). The let-through voltage result is directly read off the display, whereas the let-through energy (Joules) is derived from integration of the let-through surge over time, divided by the impedance of the Unit under Test (UUT).

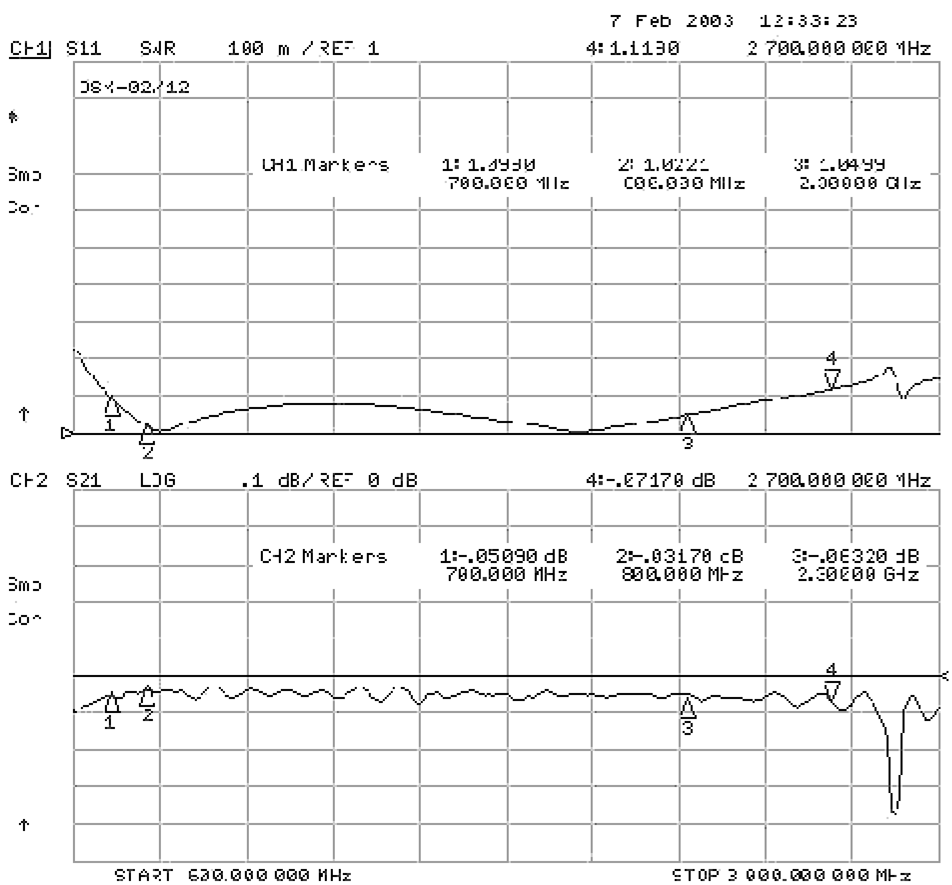
Test Results:

The PolyPhaser DSX displayed a maximum VSWR of 1.1 to 1 and a maximum Insertion Loss of 0.1dB from 800 to 2300 MHz. A QWS protector has a very narrow bandwidth (typically 10 to 20% of center frequency), with VSWR of 1.22 to 1 (max) and 0.1dB maximum Insertion Loss. A SGT protector has a wide bandwidth (some from dc to 3.0GHz) with VSWR of 1.22 to 1 and 0.2dB Insertion Loss. The values for the QWS and SGT are typical values published for those type protectors.

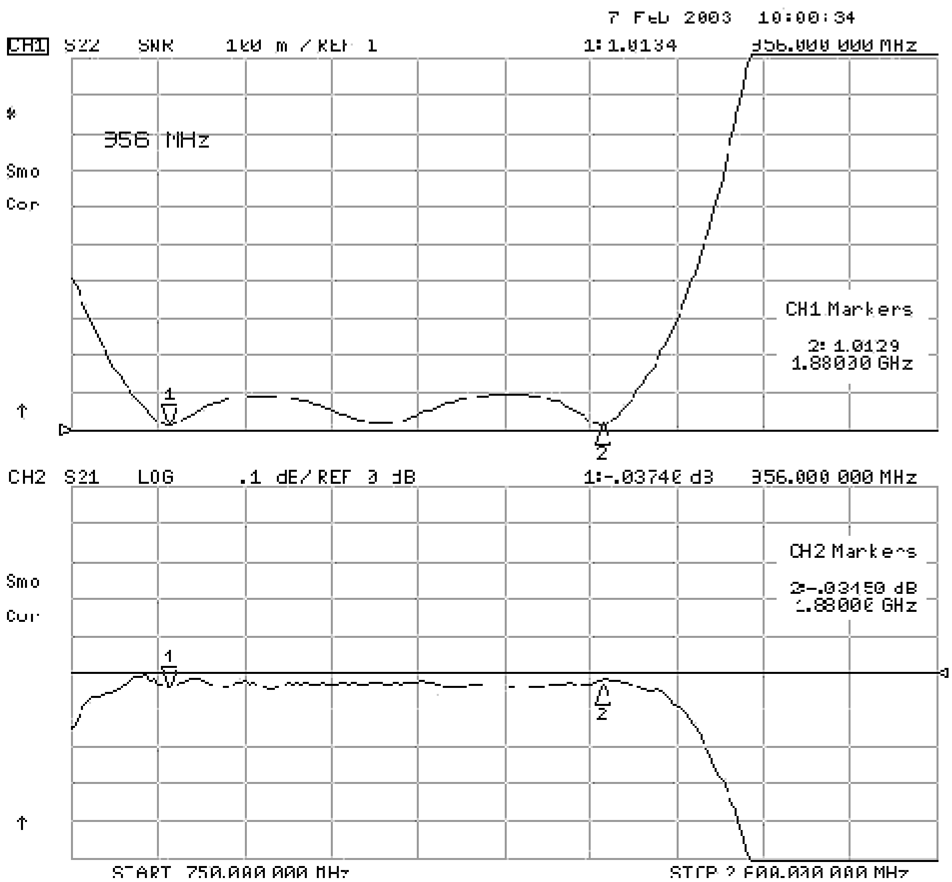
To characterize a protector for lightning surge attenuation (lightning frequencies from dc to 1MHz), we tested the units at 1MHz (Lightning Frequency component). The DSX displays approximately -98dB attenuation versus -55dB for a 1900MHz QWS. Because the SGT is designed to pass low frequencies (dc) there is no attenuation of the lightning frequencies.

Applying a 6kV/3kA 8/20Âµsec waveform to the protector resulted in let-through voltages (energy) of 195.313mV (6.29pJ) for the DSX, 6.875V (7.36ÂµJ) for the QWS and 684.375V (1.58mJ) for the SGT. NOTE: scaling on oscilloscope adjusted to maximize visual result.

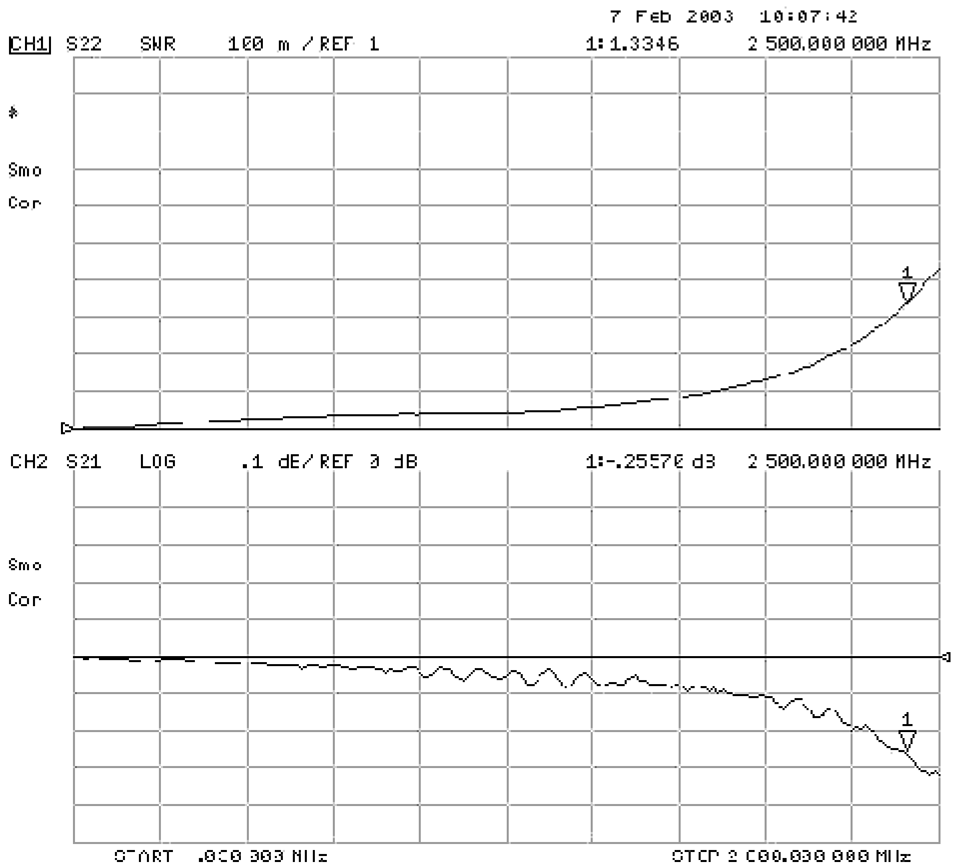
DSX - VSWR (top) and Insertion Loss (bottom)



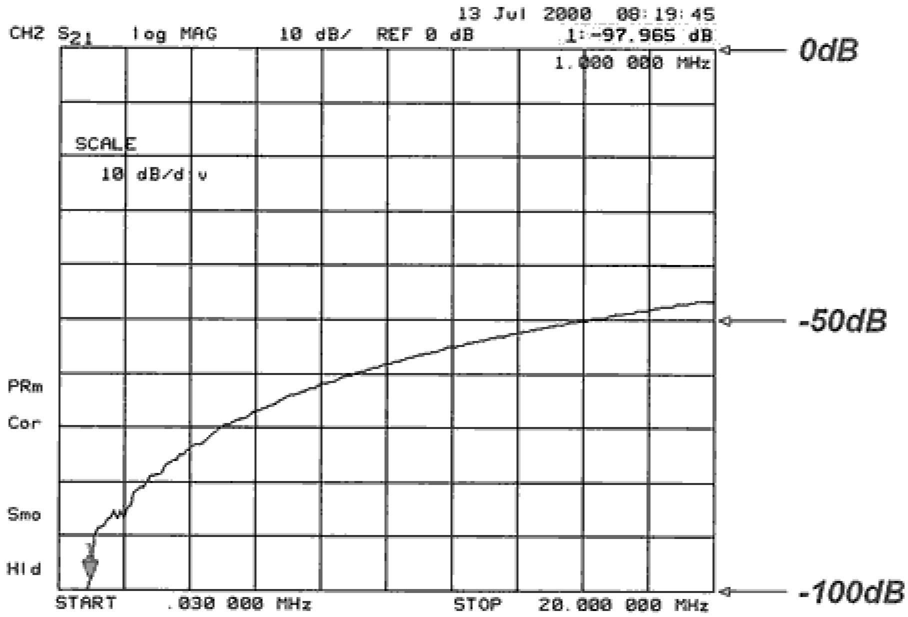
QWS - VSWR (top) and Insertion Loss (bottom)



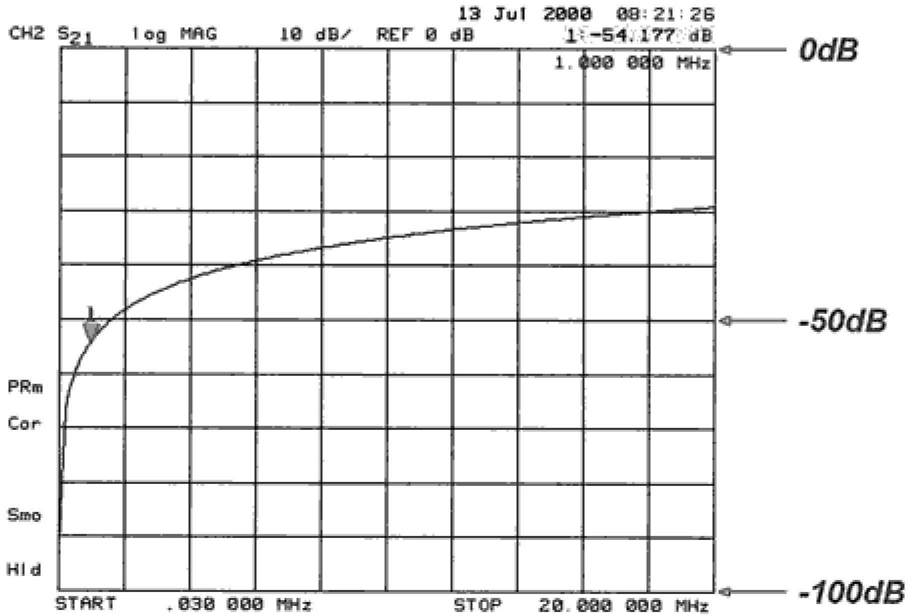
SGT - VSWR (top) and Insertion Loss (bottom)



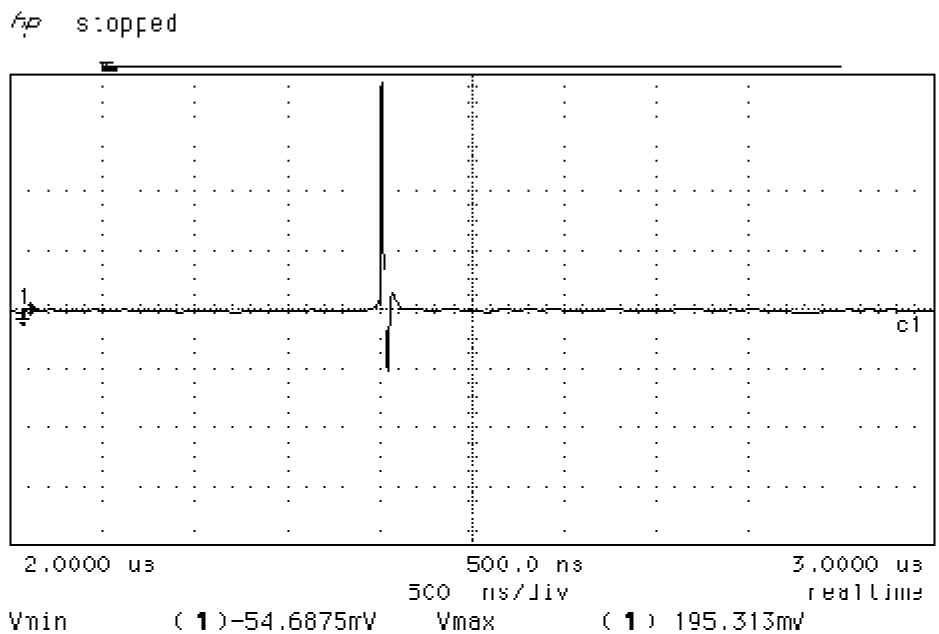
SX (-97.965dB) surge attenuation



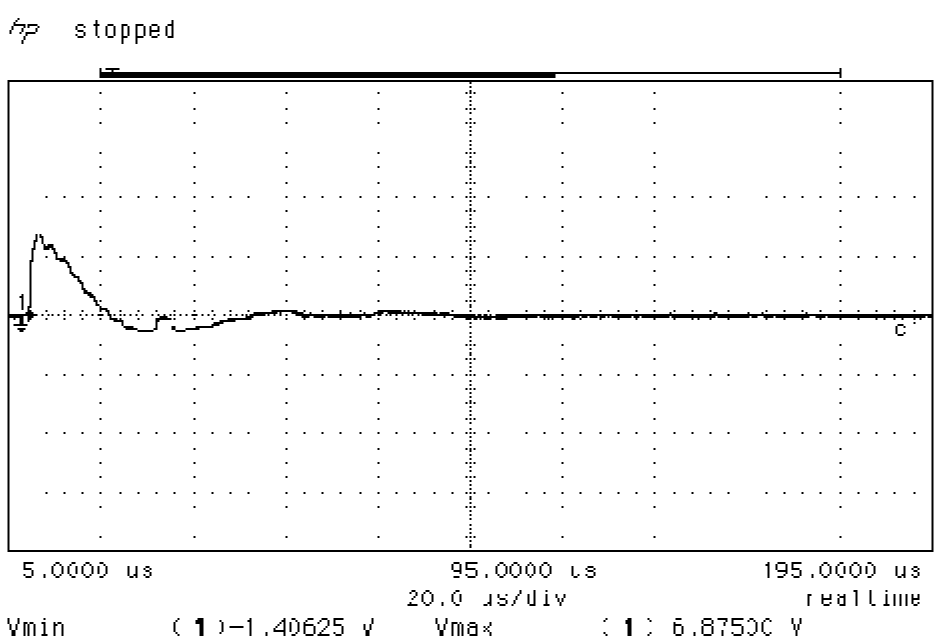
QWS (-54.177dB) surge attenuation



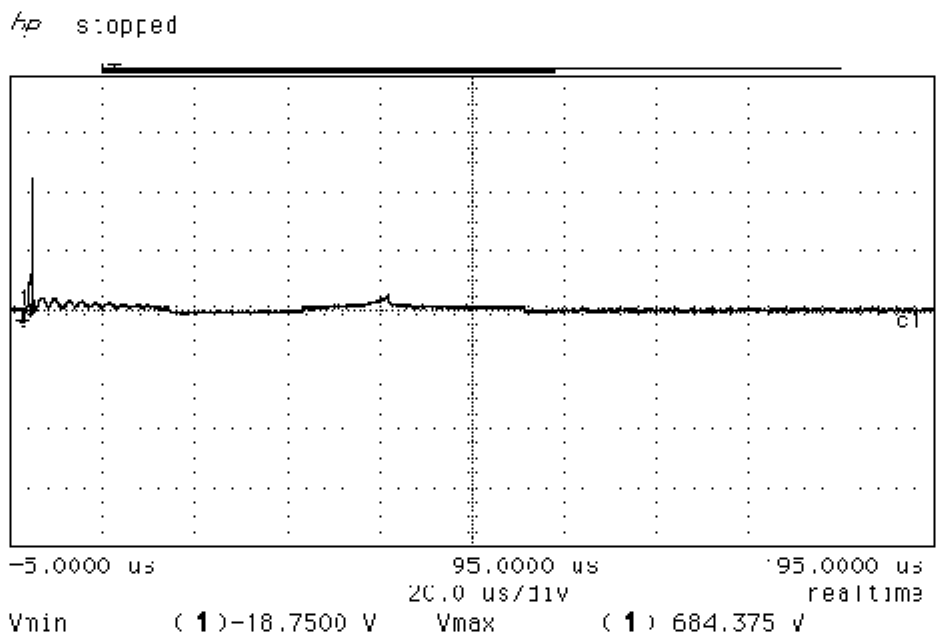
SX let-through voltage (Scale: 50mV/div)



QWS let-through voltage (Scale: 5V/div)



SGT let-through voltage (Scale: 300V/div)



Conclusions:

1. Both DSX and SGT have wide bandwidth, while the QWS has specific operating frequency bands. Bandwidth alone does not affect surge performance.
2. The DSX attenuates lightning frequencies at almost 10,000 times the amount of that of the QWS. Due to the dc-pass design of the SGT, there is no attenuation.
3. The let-through voltage of the DSX is 35 times lower than the QWS and 3,500 times lower than the SGT.
4. The throughput energy of the DSX is 1,000,000 times lower than the QWS and 1,000,000,000 times lower than the SGT.

Nomenclature:

1. RF Bandwidth: Measured in Hertz, MHz (megahertz is 1,000,000 Hertz)
2. Voltage Standing Wave Ratio: amount of reflected signal due to impedance mismatch
3. Insertion Loss: measured in Decibel (dB)
4. Attenuation: measured in Decibel (dB)

TD1002: The best RF protector for applications requiring dc on the coax

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TD1002: The best RF protector for applications requiring dc on the coax.

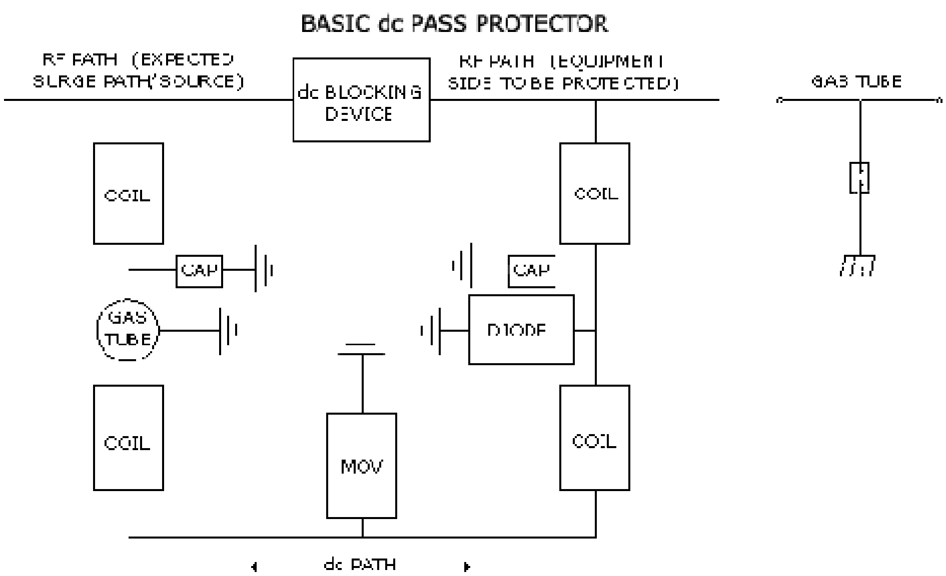
Abstract:

Hybrid dc-pass RF lightning protectors have significant advantages over straight gas tube protectors. A hybrid dc-pass protector uses a dc-blocked RF path with multiple protection stages. A straight gas tube does not block the RF path and utilizes a single gas tube in shunt with the center pin. Units were tested for RF performance and surge suppression capabilities. Results show that hybrid protectors have broadband RF performance over a wide spectrum of frequencies and 1,000 times lower let-through energy than straight gas tube protectors.

Introduction:

This report will show that hybrid dc-pass RF lightning protectors are superior in surge performance and equivalent or superior for RF performance. RF lightning protectors used to pass dc are designed using either hybrid or direct protection. To compare these technologies we will use a PolyPhaser DGX protector (hybrid) and Straight Gas Tube (SGT) direct protection. The GX and the SGT are designed for RF systems where dc power is supplied on the coax. The comparison is made to show that hybrid dc-pass protectors outperform gas tube protectors in total RF and surge suppression capability. Each unit was tested for RF performance including bandwidth, Voltage Standing Wave Ratio (VSWR) and Insertion Loss. Units were also tested for surge performance, including let-through voltage and throughput energy.

PolyPhaser GX series block diagram (SGT circuit)



Technology and Testing Overview:

After making the decision to provide lightning protection for a RF system, one must now make the decision which technology will best suit the application. This paper addresses RF systems which add dc onto the coax to power up Tower Top Electronics, active antennas or other type equipment requiring dc power.

Many manufacturers sell dc-pass RF lightning protectors. However, only two technologies are most prevalent amongst the designs. The most common is the direct, where a gas tube is connected between the center conductor and shield ground. The RF path for this type of protector is a straight connection between center pins. The second technology uses a hybrid circuit including a dc-blocked RF path. This dc-block is designed in such a manner that a specific frequency band is passed with low VSWR and insertion loss. The hybrid circuit utilizes multiple stages of protection; components may include diodes, Metal Oxide Varistors (MOVs) and gas tubes. The units are designed for a specific operating voltage allowing for a precise level of protection. (Clamping will typically start at 15% above the operating dc voltage).

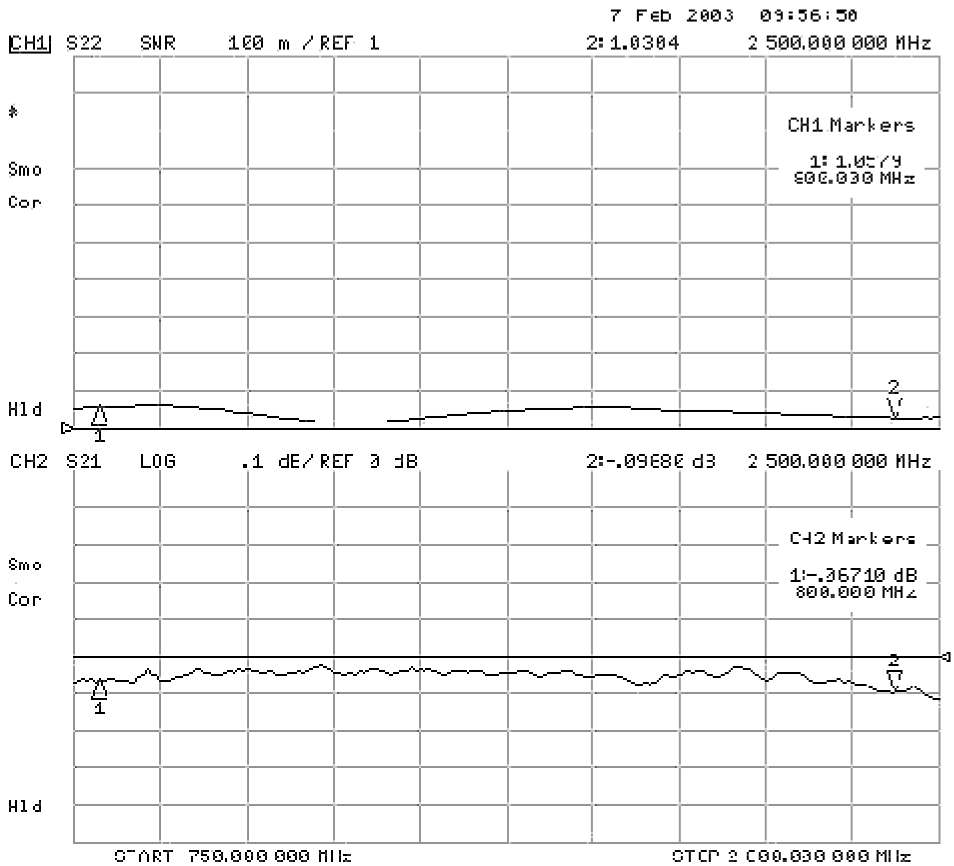
The units were tested for RF performance (VSWR and Insertion Loss) using a network analyzer (HP 8753). The analyzer is calibrated for the correct connector, load and frequency range. Surge suppression capabilities are tested using the Haefely PSURGE 6.1; units were tested to IEC 61000-4-5, 8/20µsec waveform, 6kV/3kA (2? source impedance). The let-through voltage result is directly read off the display, whereas the let-through energy (Joules) is derived from integration of the let-through surge over time, divided by the impedance of the Unit under Test.

Test Results:

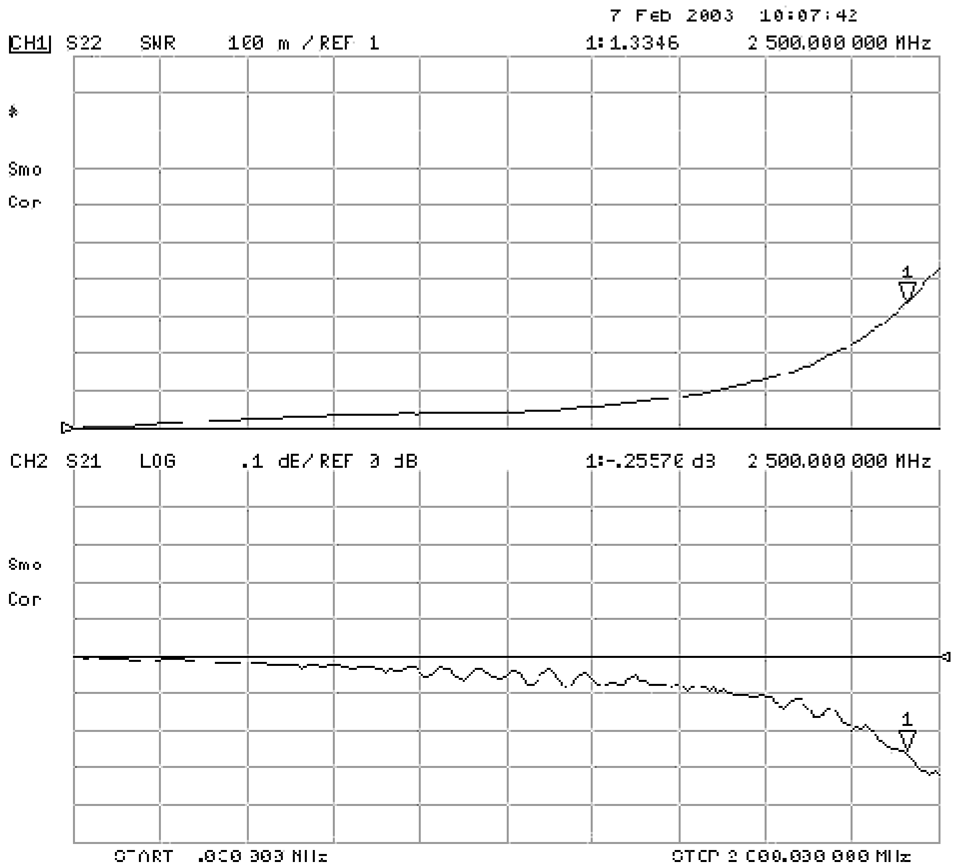
The PolyPhaser DGX displayed a maximum VSWR of 1.1 to 1 and a maximum Insertion Loss of 0.1dB from 800 to 2500 MHz. A SGT protector has a wide bandwidth (some from dc to 3.0GHz) with VSWR of 1.22 to 1 and 0.2dB Insertion Loss. The values for the SGT are typical values published for those type protectors.

Applying a 6kV/3kA 8/20µsec waveform to the protector resulted in let-through voltages (throughput energy) of 12.3438V (176µJ) for the DGX (based on 6Vdc unit) and 684.375V (1.58mJ) for the SGT. (NOTE: scaling on oscilloscope adjusted to maximize visual result.)

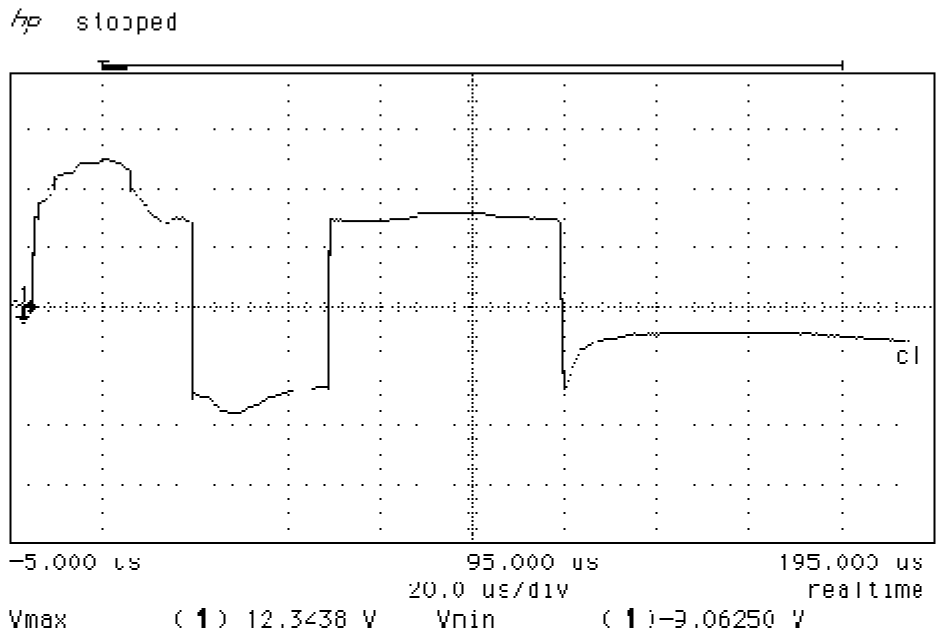
DGX - VSWR (top) and Insertion Loss (bottom)



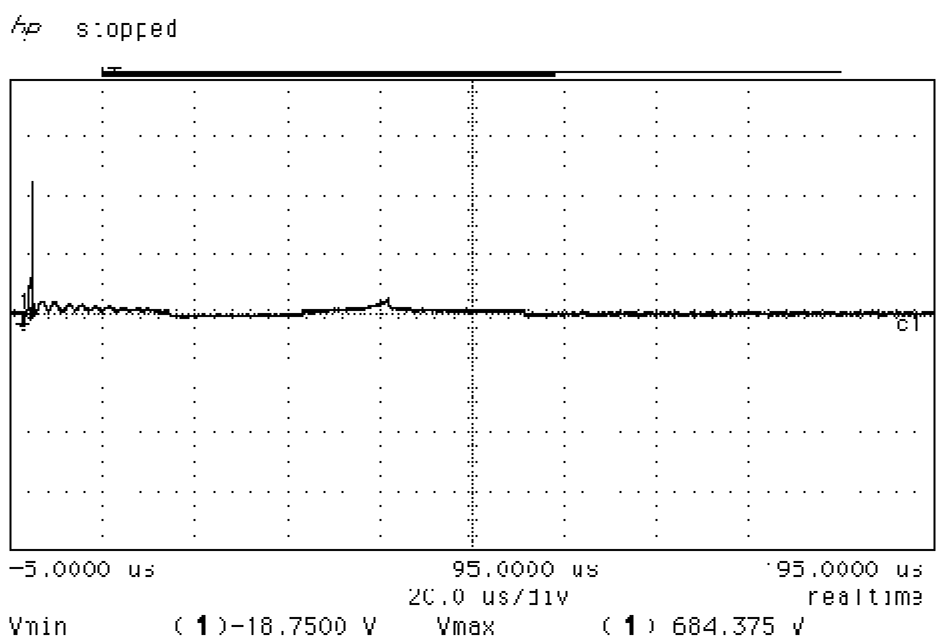
SGT - VSWR (top) and Insertion Loss (bottom)



GX let-through voltage (Scale: 5V/div)



SGT let-through voltage (Scale: 300V/div)



Conclusions:

1. Both DSX and SGT have wide bandwidth. Bandwidth alone does not affect surge performance.
2. The let-through voltage of the DSX is 58 times lower than the SGT.
3. The throughput energy of the DSX is 1,000 times lower than the SGT.
4. The SGT is not advised for protection of TTE. Active electronic components, placed few inches from gas tube, will clamp the surge voltage and not allow the gas tube to respond.

Nomenclature:

1. RF Bandwidth: Measured in Hertz, MHz (megahertz is 1,000,000 Hertz)
2. Voltage Standing Wave Ratio: amount of reflected signal due to impedance mismatch
3. Insertion Loss: measured in Decibel (dB)
4. Attenuation: measured in Decibel (dB)

TD1003: How to make a "single point ground" when the ac power breaker panel is placed away from the coaxial cable entrance / master ground bar.

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TD1003: *How to make a "single point ground" when the ac power breaker panel is placed away from the coaxial cable entrance / master ground bar.*

Notes:

The "ground" connected to the site ac power protector should be referenced to the single point (coax cable ground bar, bulkhead or "PEEP") ground. Assuming a tower strike, the inductive peak voltage drop across the current carrying ground leads (preferably copper strap) from the high ground bar to earth at the entrance panel would elevate the potential at the high ground bar compared to the (lower) earth ground connection. The high ground bar is directly connected to the equipment cabinet(s) through the coax cable shield(s).

The important thing is that all equipment ground connections should rise and fall in potential at the same time with no other paths (through equipment?) to a lower ground potential. If there are no other paths, and the potentials rise and fall together, there will be no current flow through the equipment and damage probability would be minimized.

Since the AC power protector is actually "switching" the incoming surge energy through it ("shunting" around your equipment to earth), where the ac protector is grounded becomes very important.

If the ac protector and ground connection is on the opposite wall connected to a ground rod or ring, there could be damage from current flow from the elevated coax cable shields, through the equipment racks, back to the ac power ground on the opposite wall (that has not yet been elevated in potential) due to ground potential propagation delay around the ground ring. There could be an additional danger from the energy coupled to parallel or nearby conductors. The peak potentials could be additive and cause serious damage.

A protector mounted on the opposite wall and grounded locally to the below grade ground ring would only protect from incoming energy on the secondary ac power drop. Energy from a tower strike would elevate the equipment cabinet potential via the coax cable shields and current could flow from elevated chassis ground returns up through power supply or battery charger circuitry on its way to the outside world via the yet to be elevated ac secondary connection. The equipment could be destroyed.

If the protector ground was connected to the (elevated) single point ground bar and true single point connections were maintained:

• The equipment protector reference ground would rise and fall with the master ground bar (Bulkhead or "PEEP") potential.

• The ac power protector could protect your equipment power supplies from incoming energy on the ac power lines AND from direct or induced energy incoming from the coax cable(s) during a tower strike.

A practical way to do a retrofit would be:

• Remove wiring from the output of the ac meter box to the main/sub breaker panel.

• Extend the wiring from the output of the meter box around the inside/outside of the wall to a new main breaker/disconnect switch mounted inside next to the single point ground. Extend the wiring from the new breaker/disconnect switch back to the existing main/sub panel. Use EMT conduit both ways. Make sure both ends of the EMT are grounded.

• Connect an IS-PM240-BP protector to the hot leads in the new disconnect switch. Strap the protector case ground to the site single point ground. NOTE: An IS-PM240-BP is shunt type protector. For higher levels of protection and RF-EMI filtering, use an IS-IL240-BP 100 or 200 amp version. This device installs in series with the output wiring from the new disconnect switch.

If you already have ac power shunt type protection installed at the main ac input - leave it there. It won't upset the single point ground integrity and will provide a measure of extra protection from a secondary ac drop strike.

There have been instances where what appears to be an ac power line strike isn't! If the earth grounding system does not have an adequate transient response, and if the tower strike rise time and current was very fast and high, the local ground potential at the site would quickly rise (Ground Potential Rise _ GPR) compared to the outside world. If the GPR were higher than the potential on the ac power lines, the protector could turn on (backwards) and there could be current flow out bound on the large ac secondary conductors. The protector might survive (or not) and there could be battery charger / power supply damage. An adequate ground system, designed for lightning fast rise time current pulses, is essential for long term equipment survival.

Last Reviewed: 01/03/03

TD1004: How to economically improve soil conductivity.

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TD1004: *How to economically improve soil conductivity.*

Notes:

Government-sponsored testing of various backfill grounding materials shows "coke breeze" as the number one choice based on the conductivity as well as the cost. GTL Inc. completed tests for Fluor Daniel with results submitted to NEXRAD (Next Generation Weather Radar), a doppler weather radar project of a tri-agency (NWS, FAA, and U.S.A.F.). Findings indicate that of the three materials tested, only two were conductive when frozen with no moisture. Coke breeze was one of the two.

Backfill material is often used for mountain tops where grounding conditions are poor. Coke breeze offers a backfill solution since it can be compacted to 95% and offers the best conductivity at moisture levels between 5% and 20%. Above this level, the coke breeze came in a close second. The testing followed ASTM G 57-78 in performing the Wenner Four-Electrode Method of Soil Resistivity Measurement.

Coke breeze is a waste material from burning coke (byproduct from coal), and is very economical.

Last Reviewed: 01/03/03

TD1005: Lightning protection inside the equipment is not always a good idea

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TD1005: Lightning protection inside the equipment is not always a good idea.

Notes:

Since lightning has most of its energy at dc and low frequencies, it makes sense to have a protector that attenuates this region of the spectrum. This is why dc continuity protectors cannot provide the same level of protection as dc blocked units. When looking at the level of protection necessary for equipment, most equipment is sensitive to overvoltage stress. This stress can cause immediate damage or latent damage. Immediate damage is obvious, but latent damage represents the partial destruction of a component or semiconductor junction. Later, this weakened part will fail (probably on a blue sky day) and no correlation will be made to the lightning event that caused the damage.

Each piece of equipment has its own overvoltage tolerance level. Most equipment manufacturers have not tested for this level and thus do not know the statistical maximum for their products. Some manufacturers (and some dealers) engage in shortsighted thinking and believe that lightning strikes will create more sales of replacement equipment. In this day of customer service, it is important to build quality into the equipment design. This has led a few manufacturers to some level of protection and is a step in the right direction. But direct lightning protection can't be accomplished inside the equipment and the level of built-in protection can mislead the buyer into thinking the equipment is safe under all conditions. The best protection is a multi-level protector or cascaded multiple protectors. Each one will handle its portion of the threat.

Direct strike protection should be "built in" to the installation, not into the equipment. Each equipment location has its own unique requirements. Some sites have good moist, highly conductive earth while others are on high desert mountains. This should signal the differences in installation and grounding requirements. Just as one site grounding technique can not cover all soil conditions, a single built-in protector should not be relied upon to handle all overvoltage conditions.

All input/outputs (I/Os) must be protected. We recommend these be protected at the entrance to the facility. For the new Personal Communications Services (PCS) and cellular cabinets, this would be at the interface/penetration panel. The most overlooked area is the "sneak path". Some sneak paths are: cabinet to concrete (concrete is a conductor); other I/Os not protected; protectors not bonded together in a low inductance manner; coax lines with no center pin protection; tower lighting and non-single point grounding. When interconnecting to other cabinets, whether in a room or between outdoor cabinets, the grounding must be in common to a single point. This means all cabinets should be bonded to a central ground plate where the I/0 protectors for the system should be located. If this is not done, the individual cabinet I/Os must be protected at each cabinet's single point ground plate. This means more protectors will be required and grounding techniques will be more complex.

Since most cabinets are made of non-ferrous materials, the attenuation of the strike's low frequency magnetic field is non-existent. Every board trace will couple the magnetic field creating a voltage. The voltage level for a given dynamic magnetic field will depend on the capture area, orientation to the field, and impedance of the trace.

Even the grounding cable can radiate the magnetic field into your equipment. Getting the ground conductor from the protector plate out through the metal cabinet or shelter to the earth can be counterproductive if not done right. The conduction of surge current means a magnetic field will be created around the grounding conductor. When penetrating a conductive plane, the metal will intercept some of the magnetic field and set up eddy currents. When the event is over and the magnetic field subsides, the eddy current laden metal will re-induce a back current as the eddy fields collapse.

There are two methods to prevent the formations of eddy currents. The first method is to use an enlarged opening for the cable to exit. Typically, a hole size of 8 inches will have minimal eddies. The second way is to bond to the metal on each side and make it part of the path. Less of the magnetic field will be converted into eddy currents since the metal is now part of the circuit.

Last Reviewed: 01/03/03

TD1006: Lightning protection ideas for active corrosion inhibiting systems.

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TD1006: *Lightning protection ideas for active corrosion inhibiting systems.*

Notes:

A cathodic protection system reduces the corrosive effects of soil on buried steel pipe. Soil conditions such as porosity, conductivity, dissolved salts, moisture, and pH have a corrosive effect on steel. Protection is achieved by the use of either an anode impressed electrical current driving the buried steel gas pipe to a negative potential with respect to the soil, or through the use of a more active metal in the galvanic series as a sacrificial anode. Although both methods are used, anode impressed electrical current is most widely utilized.

A remote dc power supply, with up to 100 volts at 100 amps capacity (should have a properly rated ac protector installed) is connected to a number of below grade anodes (+) arranged in a pattern related to the buried steel pipes to be protected. The anodes setup an electrical field in the soil with the steel pipes acting as a cathode (-). The pipes are driven to a negative potential with respect to the surrounding soil. The consistent negative potential over the surface area of the pipe overrides the local galvanic interaction with the soil.

Reliable measurement of actual impressed pipe voltages to local ground are difficult to obtain without the use of a standard copper/copper sulfate ½ cell to substitute for the missing hydrogen side of the theoretical electrolysis cell formed by the anode - cathode current passing through moisture laden soil.

Typical voltage to ground measurements on the pipe as it surfaces are from 300 millivolts to 3 volts. Occasionally, close to the anode field, the voltage can go up to 5 volts. The typical current required for cathodic protection is approximately 2 milliamps per square foot of exposed buried steel pipe. Most newer pipe runs are wrapped with a corrosion resistant, insulated barrier. Insulation effectiveness is estimated to be 98% (40 microamps per square foot required for cathodic protection).

n wrapped buried steel pipe can be an excellent earth ground. However, it is directly cted via the (-) conductor back to the cathodic protection power supply. Depending on the f the (-) attachment to the pipe, and the length/inductance of the insulated (-) lead back to wer supply, the risk of damage to the power supply should be minimal. A gas tube device bridging the cathodic protection flange insulator, would conduct surge energy into the non ed pipe and earth ground only after its turn on voltage was exceeded. There would be a ic path to earth ground without violating the cathodic protection circuit.

A gas pipe insulated flange uses insulating gaskets and bolt sleeves to isolate cathode protection currents from other ground returns such as power/signal conductors to and from remote measurement/control systems. Without insulating flanges, additional loads would be placed on cathode protection power supplies and measurement signals could be degraded. Insulated tubing connectors (dielectric fittings) and insulated remote sensors also block cathode protection currents. Any lightning protection device bridging the insulator must turn on before the flange or sensor breakdown voltage is approached (assuming 2kv per nanosecond surge pulse risetime).

Last Reviewed: 01/03/03

TD1007: *Pole or wall mounted closed circuit television cameras have special protection requirements.*

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TD1007: *Pole or wall mounted closed circuit television cameras have special protection requirements.*

Notes:

Outdoor Closed Circuit Television (CCTV) Security Cameras can be prime targets for lightning. A lightning strike can destroy the camera and can damage the control console with energy flowing back through the coax and camera power wiring.

When lightning strikes a tower or other large structure, there is a high peak voltage at the strike point with current flowing downward and outward through any path to earth ground. A support pole develops a high L di/dt peak voltage drop along its length to earth ground. A large steel reinforced structure can conduct the energy to earth ground through its steel reinforced concrete footers and electrical ground system. A camera mounted and grounded to a building with steel reinforced construction will usually have less inductance to ground than a camera mounted on a self-supported tower or pole. Less inductance to earth ground means less peak voltage at the camera.

When lightning strikes a wood or other insulating support, whatever voltage is necessary to continue the arc is developed at the strike point to overcome the resistance of the non-conducting structure. This usually has catastrophic results to the equipment on top.

Although very different, identical conditions exist for both examples. A high peak voltage occurs at the strike point with reference to earth ground. The video and power wiring to the camera are insulated from the strike point by electrical circuitry in the camera and the external insulation around the wire. Energy will flow through the camera circuitry in an attempt to equalize the wiring with the instantaneous peak voltage occurring at the strike point.

To protect equipment, there must be a low inductance path to earth for lightning energy and properly rated protectors on all interconnected wiring from the camera to the operating console. A properly rated protector at the camera allows the wiring to be equalized to the peak voltage at the strike point without allowing damaging currents flowing through the camera circuitry. An appropriate protector at the console blocks damaging incoming voltages to the control / monitor console.

A camera mounted on a building should be grounded to the building's structural steel as near the camera as possible. Use 1-1/2 inch (38 mm) copper strap for grounding. If the camera is mounted on a metal pole, it should be grounded to the pole and a proper ground system installed at the base. When mounted on a wood or other insulating support, the camera should be grounded to a minimum 3 inch (76 mm) copper strap running from the camera mount to the ground system installed at the base. An additional 3 inch copper strap would run from a lightning rod or diverter to the ground system at the base. Separate the two straps on opposite sides of the pole and connect together only below grade. Side mounting the camera or providing a diverter above the camera provides some additional protection from a direct strike.

A lightning ground system would be capable of dispersing large amounts of lightning energy (usually electrons) into the earth very quickly. The faster it disperses electrons, the less time there is for damaging surges to flow in the coax and power wiring back toward your operating console.

The ground system under a metal pole could be a combination of a steel reinforced concrete base (Ufer Ground), radials and ground rods. If possible, weld a #2/0 AWG stranded wire to the steel mesh in the base before pouring concrete. Attach this wire to a "J" bolt on top of the pad after the pole is erected. Use another wire welded to the mesh to attach additional radials with ground rods. If the concrete base already exists, attach additional radials with ground rods to any "J" bolt. (Be sure to remove paint and corrosion.) Use a double nut attachment with joint compound. Space additional ground rods at least two times their length from each other and from the "Ufer Ground."

When grounding a wood or insulated support, tie together both 3 inch straps, below grade, to a radial strap and ground rod system. A recommended layout for a "rapid response" low resistance/inductance ground system would be four 8 foot ground rods, one at the base and three spaced 120 degrees and 16 feet out forming an equilateral triangle centered on the base of the support. Each ground rod would directly connect below grade with 1-1/2 inch straps to the rod under the pole.

For example:

Example 1:

A camera powered by 120Vac would require IS-PLDO-120-15A at the camera. If there is insufficient space in the weatherproof housing, an IS-PSP-120 MOV/gas tube hardwired shunt protector at the camera power input can be substituted.

Example 2:

If the camera is powered by 24Vac, a IS-PSP-120 protector can be wired across the primary of the 120Vac to 24Vac power transformer a the console end of the cable.

In both examples, an IS-75BB (75 ohm BNC female connectors) would be inserted in the video coax at both the camera and control console ends. The camera protector should be in a sheltered location unless a weatherproof version is ordered.

"Ground Loops" can occur whenever long video coax runs are used. The symptoms include horizontal black bars (60 Hz hum bars) moving vertically through the picture. Ground loops are created when a potential difference exists between grounds and the coaxial cable is grounded at both ends. Current will flow through the coaxial cable shield and induce an opposing flow in the center conductor. The induced current is usually 60 Hz ac.

The ground loop can be eliminated at the camera by using an IGA-90V (catalog page 68) isolated ground adapter and insulating the camera from local ground at the top of the pole. The IGA-90V isolated ground adapter isolates the IS-75BB path to local ground until a predetermined voltage from coax shield to local ground is exceeded and remains switched to local ground until another lower voltage condition exists. At the control console end, an IS-75BB protects the center conductor. Note that this arrangement will only work for low voltage ac powered (through a transformer) cameras with no safety ground.

In all cases, the IS-75BB mounted on a single point grounding panel should be used at the console end. Prior to connecting to switcher or monitor, add a few turns or coax to increase series inductance. An IS-PLDO-120-15A inline ac power protector should also be mounted to the grounding panel. The control console and power supplies are tied back to the grounding panel via copper strap. Finally, the grounding panel should be connected to an external low inductance ground system using at least 1-1/2 inch (38 mm) copper strap. Do not rely on the third wire ground in the ac wall socket.

TD1008: *Copper ground rods are really copper clad steel! What affects them, their installation and use.*

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TD1008: *Copper ground rods are really copper clad steel! What affects them, their installation and use.*

Notes:

The real reason for copper plating is corrosion resistance. Copper, silver, mercury and gold have high resistance to corrosion, while processed metals (never found free in nature) like aluminum and magnesium are easily corroded. Noble metals like copper become the cathode when joined together with less noble metals in the presence of an electrolyte (water). Less noble metals become the sacrificial anode and corrode away.

Not listed in the galvanic table of metals is Graphite, since it is not a metal. Graphite is even more noble than silver and certainly much nobler than copper. Therefore, if a graphite backfill material is to be used as a ground "enhancer" to surround copper, the copper will he sacrificial to the graphite and will dissolve away into the soil.

The following affect the amount and speed of corrosion both above and below the soil:

1) **Water:** The presence of water mixed with contaminants is the basis of galvanic corrosion. Pure rain water is slightly acidic (pH 5.5 to 6.0). It picks up carbon dioxide as it falls which creates carbonic acid. It can start attacking some metals, even copper, without being in a junction. The ions etched from the copper go into solution in the rain water. As this rain water drips on galvanized tower sections, it will cause the zinc to combine and wash off. This leaves the bare steel to oxidize away.
2) **Oxygen:** This is the main corrosion accelerator. Rain water also picks up oxygen as it falls through the atmosphere. Water provides an excellent carrier of oxygen.
3) **Temperature:** Generally, the higher the temperature the faster the chemical reaction.
4) **Texture of the metal(s):** Glass smooth surfaces are less likely to corrode than rough finishes.
5) **Hydrogen Sulfide:** A gaseous product of exhaust emissions, it combines with rain water creating acid rain.
6) **Chlorine:** Tap water can have an acidic effect on underground materials.
7) **Inert gases:** Helium displaces oxygen and reduces the corrosive effect.
8) **Alkaline:** Although some alkalis tend to increase the rate of

carbon dioxide absorption from the air, which creates corrosive carbonate solutions, slight amounts of alkalinity can reduce corrosion rates.

9) **Salts:** Sodium chloride, found just about everywhere, increases the soil conductivity and also increases the corrosion process in nearly the same proportion to its concentration. Other naturally occurring salts or non natural added salts do the same. Only sodium carbonate or phosphate and potassium ferricyanide form a protective film that prevents further corrosion.

10) **Microorganisms:** Both bacteria and fungus can deteriorate metal. Some will give off acids in trapped water or when they die and decompose into acids.

TD1009: Galvanic action. Corrosive effects of soil conductivity.

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TD1009: *Galvanic action. Corrosive effects of soil conductivity.*

Notes:

Most people have a tendency to use copper as for grounding because it is readily available, relatively economical, a good conductor, and one of the more noble metals. However, it does have a significant drawback. Since it is near the upper end of the table of noble metals, copper when put in direct contact with most common metals, which are lower in nobility, will cause accelerated corrosion of the lesser metal. The significance of being more noble means any other metal buried and connected to your copper ground system will be more anodetic and thus become sacrificial. (Also see Topic: Dissimilar Metals.)

A galvanized (hot dipped zinc) tower on a rebar reinforced concrete base is not at risk with a copper ground system. Since concrete is conductive and forms a Ufer ground, and rebar is a very hard (heat treated) steel which will rust, the rust on the surface of the rebar, which is a non-conductive oxide when dry, will prevent further oxidation. Since concrete readily retains moisture for long periods of time, the rust is actually a good conductor. Further corrosion reduction of the rebar, due to galvanic action, will be limited by this oxide layer.

A buried galvanized tower section (not the "J" bolts) or guy anchor embedded in concrete will have some galvanic currents that could cause the depletion of the zinc coating into the concrete. This will leave exposed steel that will continue to pit and may even de-alloy. This type of corrosion may take 20 to 30 years or more before the structural failure of the tower may occur.

In 1990, several towers were lost in Minnesota alone due to guy anchor corrosion and failure. Some contractors and manufacturers have now gone to the extent of tar/pitch dipping the anchors so this galvanic corrosion does not occur. This means that the anchor is now insulated from the surrounding Ufer ground! Proper guy wire and anchor grounding is essential under these (or any) circumstances. An improperly grounded insulated guy anchor can arc through the anchor’s pitch coating, cracking the concrete with resulting structural failure.

The better the soil conductivity, the more galvanic corrosion could occur. Doping soil with salts can increase the speed of the corrosion. Consequently, it is better to have an extensive radial and ground rod system rather than a smaller ground system with doped soil

For existing towers, look at the ratio of surface areas and ground resistance. The current density for a given current will be greater for material with a smaller surface area. The more extensive the copper grounding system close in around the anchor or tower base, the more the current density and galvanic corrosion on the anchors or tower base for a given earth resistance.

If you follow the recommended PolyPhaser method of using radials and ground rods that lead away from the tower base, guy anchors, and equipment building, the resultant distributed surface area and current must return through ever increasing ground distance/resistance. This makes the currents smaller than a ground system using concentric rings or a ground grid.

It may appear obvious that the use of similar materials would eliminate the galvanic problem While this is true, galvanized ground wire and ground rods are not normally recommended since the electric utility company will probably use a copper clad steel ground rod. Replacing the utility rod may be dangerous or impractical.

Another alternative is to install an active cathodic protection system. The system consists of a power supply (lightning protected of course) and a buried sacrificial anode element, such as zinc. The power supply will electrically elevate the tower section or anchor (negative) forcing galvanic currents through the sacrificial zinc anode (positive) element. The anode will deplete over time in the soil instead of your tower and guy anchors. If magnesium were substituted for zinc, the power supply can be eliminated since magnesium is more anodetic that galvanized steel.

Last Reviewed: 01/07/03

TD1010: Oxidation and Joint Compounds.

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TD1010: *Oxidation and Joint Compounds.*

Notes:

There are many different types of metals and each has desirable properties. However, when two dissimilar metals are joined to make an electrical connection there can be problems. Corrosion will begin when the connection is exposed to moisture or any other liquid acting as an electrolyte.

Corrosion is an electro-chemical process resulting in the degradation of a metal or alloy. Oxidation, pitting or crevicing, de-alloying, and hydrogen damage are a few descriptions of corrosion. Most metals today are not perfectly pure and consequently, when exposed to the environment, will begin to exhibit some of effects of corrosion.

Aluminum, as used in PolyPhaser's coaxial protectors, has an excellent corrosion resistance due to a 1 nano-meter thick barrier of oxide film that instantaneously forms on the metal. Even if abraded, it will reform and protect the metal from any further corrosion. Any dulling, graying, or blacking that may subsequently appear is a result of pollutant accumulation.

Normally, corrosion is limited to mild surface roughening by shallow pitting with no general loss of metal. An aluminum roof after 30-years only had 0.076mm (0.003 inch) average pitting depth. An electrical cable lost only 0.109mm (0.0043 inch) after 51-years of service near Hartford, Connecticut. Copper such as C110 used in our equipment shelter coax cable entrance panels has been used for roofing, flashing, gutters, and downspouts. It is one of the most widely used metals for atmospheric exposure. Despite the formation of the green patina, copper has been used for centuries and has negligible rates of corrosion in unpolluted water and air. At high temperatures some copper alloys are better than stainless steel.

If copper were joined to aluminum or copper to galvanized (hot dipped zinc) steel with no means of preventing moisture from bridging the joint, corrosion loss will occur over time. This is the accelerated corrosion (loss) of the least noble metal (anode) while protecting the more noble (cathode) metal. Copper, in this example, is the more noble metal in both connections. (See the Noble Metal Table for a ranking of commonly used metals.)

Where the connection is with galvanized steel, the zinc coating will be reduced allowing the base steel to oxidize (rust), which in turn will increase the resistance of the connection and eventually compromise the integrity of the mechanical structure.

The aluminum will pit to the copper leaving less surface area for contact. The connection could be become loose, noisy, and even allow arcing.

This type of corrosion problem can be prevented by using a joint compound, covering and preventing the bridging of moisture between the metals. The most popular compounds use either zinc oxide or copper particles embedded in silicone grease. As the joint pressure is increased, the embedded particles dig into the metals and form a virgin low resistance junction void of air and its moisture.

The use of a joint compound is the recommended means for joining our coaxial protectors to our bulkhead panels for non-climate controlled installations. We have tested this compound with a "loose" 1 square-inch (6.5 sq-cm) copper to copper joint and have found it to handle a 25,500 ampere 8/20 waveform surge with no flash over and no change in resistance (0.001 ohms). We have even moved the loose joint before and after the surge and experienced no change in resistance.

The connection of a copper wire to galvanized tower leg should be avoided even if joint compound is used. The primary problem here is the low surface-area contact of the round wire with the (round) tower leg. Consider using a PolyPhaser TK series stainless steel clamp. The TK clamp will help increase the surface area of the connection as well as provide the necessary isolation between the dissimilar metals. Use joint compound on exposed applications of the TK clamps. For an even more effective connection, use copper strap in place of wire with the TK series clamp.

Silver oxide is the only oxide (that we know of) that is conductive. This is one reason why PolyPhaser's N-type coax connectors are all silver with gold center pins. Copper oxide is not conductive and the proper application of joint compound will prevent oxidation.

TD1011: Does your equipment room have a single point ground?

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TD1011: *Does your equipment room have a single point ground?*

Notes:

Equipment racks and cabinets can provide an unwanted path for lightning surge energy. The common practice of bringing the antenna cable into the top of the cabinet and securing (bolting) the cabinet to the floor could damage the equipment.

Concrete floors, particularly those at grade level, can provide a conductive path to earth ground during the strike event. Any surge energy arriving on the coaxial cable, power and control wiring, or inadequate equipment ground system could find a lower inductance path to ground through your equipment and conductive concrete floor.

Your first line of defense is on the outside of the building. The value of a good tower ground/radial system (5 ohms or less) cannot be over emphasized. Most of the surge energy from a tower strike event is dispersed away from the building and equipment by the tower ground system. The remaining energy on the coaxial cable shield and center conductor can be directed safely to earth by using a PolyPhaser entrance bulkhead and proper coaxial protector. The entrance bulkhead provides a single point low inductance connection to the building's perimeter ground and the tower radial system.

Your second line of defense is inside the building. Connect all overhead cable trays and equipment ground conductors back to the entrance bulkhead creating a single point ground system. AC power line protectors and control/data line protectors are connected to the single point ground to complete your defensive strategy.

A lightning strike is a series of fast rise time "pulses" that become a constant current source once the path to ground is established. A typical pulse has a rise time of 2us to 90% of peak and a 10 to 40us decay time (to the 50% level). Three pulses per event is the median. The average current is about 18,000 amps for the first pulse, then dropping to half that value for the second and third pulses. Ten percent of all strikes will exceed 60,000 amps on the first pulse and one percent will exceed 120,000 amps. For the following discussion, a 2us by 18kA negative strike pulse will be considered.

When lightning strikes, a tremendous rush of electrons move down the tower and out into the ground/radial system. Since we are dealing with a fast rise time event, the inductance of the tower and paralleled coaxial cables become the primary factor in determining the amount of instantaneous peak voltage developed between the strike point and the bottom of the tower.

The peak voltage drop can be calculated from the formula: E = L di/dt; where L is the total inductance of path (tower and coaxial cables in uH); di is 18,000 amps (average strike current, abbreviated 18kA); and dt is 2us (rise time).

When the coaxial cable leaves the tower at any elevation above grade level, a voltage divider is created at the take-off point to ground. The divided current, conducted by the coaxial cables towards the building, places the equipment in series with the energy path if the bottom of the rack is grounded.

Lets look at a practical example of a typical cell site installation, consisting of a 150 foot [45.72 M] by 35 inch [889 mm] triangular tower and three 1-5/8 inch [41.3 mm] coaxial cables. The tower and coax cables would have a combined inductance of approximately 15uH assuming that the cables ran from top of the tower to the grade level ground. During a typical 18kA strike event, a 135kV voltage drop would exist between the top of the tower and ground.

Even though the bulkhead entrance panel and appropriate protectors at a single point ground window do their job by conducting shield and center pin energy to ground, equipment damage or interruption may still result since shunt path currents could traverse your equipment cabinet.

In the real world, most coax lines do not run all the way to the bottom of the tower; but usually leave the tower at a convenient height to make an entrance near the ceiling of the equipment room. For example, if the coax lines were to leave the tower at the 10 foot [3.48 M] level, traverse 10 feet horizontally to the equipment building, attach to a ground bar via a ground kit prior to entering the building, and connect to the perimeter/tower ground system with two #6 AWG copper wires, the additional series inductance in parallel with the lower 10 foot section of the tower is calculated as follows:

Three parallel coax lines bent (+90°) leaving the tower = 0.05uH
Three parallel 10 foot lengths of 1 5/8 inch coax = 1.33uH
Ground kit and ground bar bends = 0.3uH
Two #6 AWG copper wires to earth ground = 2.2uH

The inductance of the 10 foot horizontal coax run and ground bar to earth ground is 3.88uH (3.9uH rounded for simplicity). The inductance of the lower 10 foot section of the tower without any coax lines is 2.7uH. When these two parallel inductors to ground are combined (3.9uH and 2.7uH), the lower section of tower has an inductance of 1.6uH.

The following questions may then be answered regarding conditions during the strike event.

> Peak voltage at the 10 foot level on the tower: E=L di/dt = 14.4kV
> Current through the ground bar to ground k(E/L)dt = 7.385kA
> Peak voltage after the ground bar (at the protector): E = L di/dt. 9.231kV

Since the coaxial cable shield is connected to the ground bar via the ground kit, 9.2kV would be present on the shield and will be conducted directly to the antenna connector on your equipment rack. After charging the rack's capacitance, the entire peak voltage would appear at the rack/concrete interface. Depending conductivity of the concrete and rebar placement with respect to the charged rack, 9.2kV could be sufficient voltage to arc through the concrete creating a conductive path and allowing current to flow through the equipment racks. The preferable alternative is to allow all racks to rise and fall with the overhead ground system potential without any other paths to ground. For this to happen you must insulate the racks from the conductive flooring.

Rack cabinets can act as a "faraday shield" with respect to the components inside by either converting the magnetic field energy into a voltage feeding your single point ground system or as a conductor between the overhead ground system and a conductive floor breakdown path. The breakdown path will produce a large voltage drop and magnetic fields inside the cabinet which are likely to destroy components.

To insulate rack cabinets from a potentially conductive concrete floor some installations place cabinets on wooden platforms. Others use isolation kits (0.062 [1.6 mm] phenolic insulating material and isolation grommets - PolyPhaser RACK ISO-KIT) for racks that must be physically secured to the floor.

The PolyPhaser Entrance Bulkhead serves as a low inductance entry ground, entry plate, and mounting point for PolyPhaser center pin protectors. Cable trays and system ground wires inside the building should be connected to the bulkhead to provide true "single point" grounding.

If a PolyPhaser Entrance Bulkhead with its two 6 inch [152.4 mm] copper straps were used in the previous example, the inductance path would be lowered to 2.7uH, and the voltage at the entrance bulkhead would be reduced to 5670 volts. With three copper straps the voltage would be even lower. The more surface area to ground the better.

Nothing can stop a lightning strike! How you direct the energy is the difference.

PolyPhaser CORPORATION

TD1012: A discussion of antenna placement for reduced lightning risk and suggestions for LNA protection.

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TD1012: *A discussion of antenna placement for reduced lightning risk and suggestions for LNA protection.*

Notes:

The first consideration for a GPS antenna is a clear view of the sky, preferably 360 degrees. In the usual installation, the GPS antenna is located low and close to the equipment building roof. If an outdoor cabinet, the antenna is mounted on the cabinet or very low on the adjacent monopole/tower. A direct lightning hit to the above mounted antenna is unlikely. Mounting on an equipment building roof or cabinet is the safest place since the potential rise on the outside of either of these structures would be more or less equal with the potential on the inside. The PolyPhaser protector is there to equalize the differential in potential that occurs between center conductor and shield of the coax cable on its way from the antenna to the receiver.

The zone of protection from various lightning rod types is an arguable topic. Many claims are made for different configurations. I'll assume a single point Franklin rod. If below about 60 feet we can assume a 45 degree "cone of protection". If above, we could apply the "rolling ball" theory.

If the GPS antenna is mounted on the monopole/tower, (since this is the structure we expect to be hit) there will be an inductive voltage drop occurring during the event that will be distributed down the structure to earth ground. This voltage drop is the result of the fast rise time lightning current pulse traversing the inductance of the structure. ($E = L\,di/dt$). If the GPS antenna is mounted on this structure it will be elevated to a potential higher than the equipment building or cabinet. There will be current flow on the shield and center conductor of the coax cable towards the receiver. A coax cable grounding kit or PolyPhaser integrated ground entry panel will direct the shield currents toward earth. A PolyPhaser protector will "turn on" and direct any current on the center conductor towards earth. Proper shield grounding and center conductor protection are essential to receiver survival.

Questions regarding GPS LNA protection in the antenna are valid but usually not considered in this application. The antenna element at GPS frequency is usually "grounded" and does not have the capture area to couple much energy to the input, the problem is with the output. In roof or cabinet mounting there is not the potential that could occur with a monopole/tower mount. If the GPS antenna support structure is elevated in potential (due to its inductance), the GPS antenna / LNA will also be elevated to a potential determined by the voltage distribution across the structure, and the height of the GPS antenna mounting on the structure. Since the coax shield is usually common with the GPS antenna mounting bracket, current will flow down the shield. The voltage differential at the top of the coax between the shield and the not yet elevated center conductor will appear across the LNA output circuitry. The LNA output could be destroyed in the attempt to bring the center conductor up to shield potential. If another protector were installed at the output of the LNA, any voltage differential between center conductor and shield would "turn on" the protector. Current flow that would have gone through the LNA output now goes through the protector. The LNA would survive. The top protector could be combined with a voltage "pick-off" for power to the LNA. We have protectors in this configuration. There have not been many failures (that we know about) with LNA's. The higher the GPS antenna is mounted on the support structure, the more probability of damage.

Last Reviewed: 1/7/03

TD1013: Ground resistivity and "fall of potential" tests. What the results could mean.

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TD1013: *Ground resistivity and "fall of potential" tests. What the results could mean .*

Notes:

Any properly applied lightning protection device is only as effective as the ground system attached. Ground resistance is usually measured using the 3-stake fall of potential method. Theoretically, the final measurement achieved on the completed ground system is the same resistance to any other ground system on earth. A good ground system measurement would be between 5 and 10 Ohms. A well designed 5 Ohm ground system is usually considered optimal for a lightning ground system.

A 4-stake resistivity measurement should be done ahead of the actual ground system installation. This procedure tells the engineer which areas within the system's geographic confines have the most conductive soil and at what depth this occurs. The results will be expressed as resistance (in Ohms - cm/m) and will determine the ground system's design.

The ground system's final 3 stake fall of potential ground resistance reading is the impedance of the system measured with approximately 100 to 300 Hz source potential. The obvious concern of this measurement is how well the ground system will handle electric utility ground faults. There must be enough current flow in to the earth to trip the applicable ac circuit breaker. Unfortunately, there is yet no way we can directly relate this 100 Hz measurement to the energy/frequency distribution range of a lightning event. Information gathered by PolyPhaser Corporation indicates that a properly designed 5 ohm ground system usually works well for lightning.

There are additional ways to reduce the ground measurement at low frequencies. Additional buried conductive surface area and chemically treating the soil are possibilities. With very small sites, a chemical ground rod activated by rain water or a water drip system, attached to the end of a 1½ inch [33.1 mm] copper strap used as a radial from the tower base, is a good alternative. Two to four chemical ground rods and radials extending out from the tower base and connected to the fence line should reduce the low frequency ground measurement and enhance the lightning handling capabilities as well. The galvanized fence posts at small sites could be extended in length with added below ground section used as additional grounding surface area interconnected with the tower ground loop / chemical ground rod system. Connect all fence posts together with a below ground conductor. Some consideration need be given to the mixing of galvanized and copper grounding components. It is always "trade-off" between a lower resistance and better transient response vs. long term corrosion effects. However, consider the fence posts are there and are indirectly a part of the ground system already.

When a single long "ground well" is used in rock or poor conductivity top soil, the series inductance of the top section of pipe "chokes off" current flow to the more conductive lower section causing rapid local ground potential rise. Outbound currents from this higher potential can cause damage to circuitry bridging both potentials.

From a practical point of view, grounding specifications at ac power line frequencies must be met using the fall of potential method. But to be effective as a lightning ground, the ground system must also be designed for a rapid response in the RF range between 10-100 kHz. This usually means large surface area low inductance conductors connected to multiple ground radials with ground rods along their length.

Very high potential differences can occur from "point a to point b" on the same ground system due to the ground system/earth's combined impedance at the strike's higher frequencies (Ground Potential Rise – GPR). Since this is a complex topic, I'd best refer the reader to www.gpr-expert.com. They offer a complete explanation beyond this document's scope.

TD1014: Where the lightning energy goes and what can happen. Ground Potential Rise (GPR).

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TD1014: *Where the lightning energy goes and what can happen. Ground Potential Rise (GPR)*

Notes:

A lightning ground system should be capable of dispersing large amounts of electrons from a strike over a wide area with minimum ground potential rise. It should be capable of doing this very quickly (fast transient response).

- Ground potential rise (GPR) means any difference in voltage between the strike's local earth sphere of influence and the "outside world."
- Outside world means any other ground outside of the lightning strike's local sphere of influence.
- By spreading electrons out over a wide area with a fast transient response ground system, the ground potential rise (step potential) for any smaller given area would be reduced.
- The speed, or transient response, of the ground system would be dependent on the 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.
- Copper strap has lower inductance per unit length and more surface area in contact with conductive soil than the equivalent amount of copper in a circular conductor.

Local ground potential rise (GPR) can be the source of damage to any equipment interconnected to the outside world. A local ground potential rise looks for any path to the outside world. Some of these paths could be through your equipment.

- Any signal line with a ground return through the input/output circuitry is subject to damage. The local elevated potential would seek to equalize the signal conductor through your circuitry, and use it as a path to a lower potential. Local and remote interconnected equipment would be at risk.
- Any insulated signal lines are subject to damage as is the source power supply.
- A coaxial cable shield can carry a large amount of current at speeds exceeding 90% the speed of light with possible damage at both ends.
- The velocity factor of the coaxial cable center conductor with a fast rise time pulse can vary from 66 to 90% the speed of light. The directly applied or induced voltages on the center conductor would "roll off" and arrive after the shield pulse, producing large differential voltages

between shield and center conductor.

• Secondary ac power conductors are a two way “street” for electrons. They are usually large low inductance conductors. A strike to the power lines some distance away can conduct damaging energy to equipment. Also, a strike to the tower or building can produce a local ground potential rise with damage to your equipment from energy attempting to “escape” to the outside world through the ac secondary conductors.

A good source for more information on GPR is: www.gpr-experts.com

TD1015:. The two views presented here represent a "purist" approach and a compromise.

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TD1015:*.The two views presented here represent a “purist” approach and a compromise.*

Notes:

When a large conductor such as a tower has high peak current flow through it (such as a lightning strike), an intense magnetic field is created around the tower. This field radiates out orthogonally from the tower. Since the building or cabinet is usually close to the tower, equipment in the enclosure is subject to intense moving magnetic fields.

Just as a generator produces voltage and current flow from moving a coil within a magnetic field, so is voltage and current flow produced when a moving magnetic field cuts across a conductor. Wiring and circuit board traces in the equipment can have induced voltages present many times greater than the component’s rated specifications. Even if this does not cause an immediate failure, components repeatedly stressed beyond specifications can have a shortened life. This can show up as “blue sky failures” (latent damage: equipment fails for no apparent reason).

When connected to grounded metal door frames, window frames, vents, air conditioners, or any non active metallic vertically aligned conductors, the “halo” will attenuate the magnetic field in the building. The vertical conductors intercept the magnetic field, convert it to voltage, and direct it through corner (or more) downconductors to the below grade perimeter ground loop. The remaining magnetic field is attenuated compared to its initial intensity.

(1) The halo should not be interconnected with or used as a ground connection for any active electronic equipment. Do not attach the halo to the single point ground, equipment racks or the entrance panel / bulkhead / hatchplate / coax line ground bar.

The PolyPhaser entrance panel also functions as a large surface area grounding point for the coaxial cable shields and electronic equipment (single point ground). Any outside / inside ground bar with a connection to the coax cable shields will rise in potential far above local ground during the fast rise time lightning strike. The combined network of inductances formed by the tower, horizontal coax run, and entrance panel straps / ground bar conductors, could cause an E= Ldi/dt voltage drop of several kilovolts between the coax shield ground (high) and local earth ground (low). If the equipment is between these two potentials, it could be a path for damaging energy (Always insulate the rack from conductive flooring).

When the halo is connected to the entrance panel / ground bar that will be elevated in potential, or the top of equipment racks, there are additional paths to earth ground through the halo's vertical conductors and corner downleads. There will be current flow through all attached conductors. When this occurs, the halo and anything attached that is carrying current, radiates an additional magnetic field component inside the building. This field is additive to the tower's radiated magnetic field. The halo, instead of attenuating magnetic fields in the building, becomes an antenna, radiating an additional magnetic field, increasing the probability of immediate or latent damage. Keep the halo separate from coax and single point grounds!

(2) There are some compromises to the single point ground that can be implemented to increase safety (at some sacrifice of magnetic field attenuation effectiveness).

- Install an overhead, insulated from the wall, cable / buss bar connected only to the single point ground and extending out and around the inside walls of the equipment room (a buss bar "halo"). 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 buss bar. If any of the connected metallic objects are grounded there will be an L di/dt peak voltage drop through the entire path. 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.

There will be additional magnetic field in the building as a consequence of current flow through the buss bar and connected object to ground, and probable multiple current flow paths through interconnected I/O ports between equipment. If the 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. Properly rated protectors for all I/Os' must be installed and grounded to the entrance port (single point ground) for equipment to survive in this configuration.

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).

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TD1016: An overview of Lightning Protection for Ham Radio Stations.

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***TD1016:** An overview of Lightning Protection for Ham Radio Stations.*

Notes:

Proper lightning protection for a ham radio station can involve more variables than any other type of radio site. The antenna location will establish the grounding requirements, while the station location will drive the protection requirements.

The primary rule for surviving a lightning strike is still the same no matter which of the many possible variations you have: all equipment elements must be connected to a single, low impedance ground system. This includes the antenna, the antenna support (pole, tower, etc.), and all of your station's input and output protectors. (I/O's: antenna, power, telephone, rotor, etc.).

Let's examine the significant elements of a good grounding and protection scheme to help you construct an installation that will survive a direct lightning strike.

We begin with choosing the antenna location. This and the antenna type will dictate the size and location of the earth system needed to disperse the strike's energy. The sooner the ground system is able to spread out the energy, the better the chances of preventing it from traveling to your equipment. Almost 90% of strikes will be electrons that, due to like charge, repel and spread out. The antenna ground system provides the interface to the earth body. As we will see later on, the ground system is formed by a set of ground rods interconnected below grade with bare radials.

Also fundamental to a good protection scheme is the creation of a single point ground within the ham shack. This single point ground is used to mount all of the protectors and to provide a ground for all of the equipment chassis. This interior single point ground is connected to an external ground system (composed of radials with ground rods) with a low impedance copper strap. The antenna ground system and the ham shack single point ground system must be interconnected. This interconnection should be below grade and with a bare low inductance conductor. The coax cable shield must not be the only interconnection between ground systems.

Three Techniques:

Every conductor has measurable inductance. Similarly, ground conductors exhibit normal inductance before they go below grade.

Once in the ground, the inductance of a bare conductor is shunted by the earth's conductivity.

If the soil at the grounding location is not very conductive, three things can be done to help the situation.

- Increase the surface area of the conductor, decreasing its normal inductance.
- "Dope" the soil to increase its conductivity shunting the inductance of the in-ground bare conductors.
- Install additional bare radial lines with ground rods which will effectively parallel the inductance and reduce the overall system inductance.

In some locations it may be necessary to utilize all three of these techniques for the best results. Let's examine each one.

1) Conductor Surface Area:
The most effective material for a ground system conductor is copper strap. Copper as a metal is a good electrical conductor, only moderately attacked by ground and air borne acids, and should have a life span measured in years.

Since lightning has a large portion of its energy in the LF range, it will behave like an RF signal. (See "Lightning Overview" and "Coaxial RF Protectors" for a more detailed discussion) That means the energy will only mostly conducted on the skin of the conductor (skin effect). Thus, the surge current will only ride on the outermost surface of the conductor. Such currents following a round-member conductor will not make extensive use of its large cross sectional area. With a 1-1/2 inch [38.1 mm] or larger flat strap of at least 26 gauge (0.0159 inches) [0.4 mm], both surfaces will conduct the surge.

2) Soil Doping:
Water in its purest form is an insulator. Ionic salts when mixed with water make ions. The earth is a conductor because of the number of ionic salts present in the soil. Therefore, conductivity can be improved by adding more ions to the soil.

Soil doping can be done by either adding water or a saline solution to the soil around the grounding system. If the soil already has a sufficient amount of naturally occurring salts, adding water will free the ions and improve conductivity. The more ions (salts) available, the less water that will be needed to reach a given level of conductivity.

If few natural ions are available, salts, such as Epsom salts, can be added to the soil to increase the conductivity. Depending on the amount of rainfall, doping the ground system radials with 4 pounds of salt per linear foot and 20 pounds per rod may last approximately two years.

3) Ground Radials:
Radials are the most cost effective grounding technique considering system impedance, material cost, and installation labor. If one radial gives "X" resistance, then two will deliver an equivalent "parallel rule" plus 10%. This rule only holds true when the soil has the same conductivity over the entire radial area. After the first two radials, you will need to double the number of radials each time to continue with the parallel-plus rule.

Radials do have a limit on their effective length. If the surge energy has not been launched into the soil within the first 75 feet [22.86 meters), the inductance of the radial will prevent any further effective prorogation. Therefore, as a general rule, all radials should be at least 50 feet 15.24 meters] long and no longer than 75 feet.

Ground rods should be placed along the entire length of each radial. The most cost effective spacing between rods for normal (grassy) soil is two times the length of a rod into the ground. If 8 foot [2.44 meters] rods are used, they should be placed on 16 foot [4.88 meters] centers.

If the soil is not normal (e.g., very dry or sandy), the separation may be reduced in order to minimize the interconnect inductance. It doesn't hurt to have the rods too close, it only costs more in material and labor.

Ground Measurement:
Since most soils are stratified, the best way to determine the effectiveness of a ground system is to measure it. The simplest way to determine the sub-layer conductivity is to measure the first ground rod, one foot at a time, as it is hammered into place. This technique can provide a profile of the lower layers relative to the first foot. Most earth resistance meters measure only dc or low frequency ac

resistance of the ground system. Although the lightning strike is dc, due to the fast rise time to peak current, there is significant RF energy. Since there is a high frequency component, the inductance (effecting transient response) of the ground system is important. Without using very expensive specialized test methods, the only way to ensure a low impedance ground system is to follow the suggestions given for conductors, doping and radials.

Tower Considerations:
No one should consider using a non-conductive structure for an antenna support. Only conductive towers or metal poles should be used for mounting antennas. If the tower or pole has sliding contacts (crank-up or push-up), the joints should be bonded using short sections of copper strap attached with PolyPhaser TK clamps. Normal self - supported and guyed towers will not need such jumpers.

Guyed towers are better from a lightning protection perspective if the guy anchors are grounded properly. Because the anchors are located away from the tower base, at least some of the strike energy will traverse the inductive guy wire to the ground. The more the strike energy is divided, the less there is to go to your equipment.

Dissimilar Metals:
Copper should never touch galvanized material directly without proper joint protection. Water shedding from the copper contains ions that will wash away the galvanized (zinc) tower covering. Stainless steel can be used as a buffer material. However, be aware that stainless steel is not a very good conductor. If it is used as a buffer between copper and galvanized metals, the surface area of the contact should be large and the stainless steel should be thin. Joint compound should also be used to cover the connection so water cannot bridge between the dissimilar metals.

Magnetic Energy:
Lightning has a large magnetic field associated with its typical high current pulse. The magnetic field will couple to all nearby conductive materials. There are two ways to minimize the amount of magnetic energy coupling, shield your equipment or place some distance between the equipment and the likely strike location.

A galvanized steel sheet may be used as a shield to attenuate the magnetic field pulse by 10dB.The steel should be at least 30 gauge

(0.016 inch) [0.41 mm] and should be connected to the ground system.

Distance is the other means to limit magnetic field coupling. The strength of a magnetic field diminishes at the rate of one over the distance squared. Since a moderately high tower is much more likely to be struck than any other nearby structure, the placement of the tower with respect to your equipment deserves significant consideration. Factors that should be considered are not only the magnetic energy which will radiate from the tower, but also the benefit of the distance in terms of the inductive loss provided by the length of the orthogonally run coax. This added inductance of the coax line will buffer the energy entering your equipment area. In addition, the extra distance will provide a little more time for the tower ground system to dissipate the strike energy and thus have less to share with your equipment.

Both of these factors indicate there should be a reasonable >20 feet [>6 meters] separation between the tower and the operating equipment.. For towers already located closer than this, it may be necessary to utilize some shielding to minimize the magnetically induced energy.

Antenna Location:

A ground mounted vertical antenna is very similar to a ground mounted tower. Both have a low impedance connection to the ground system. However, if the antenna or tower is mounted on a roof, the inductance inherent in the conductors to the ground system will be very significant. So significant, that voltages in the order of several hundred thousands volts could be present during a strike. To reduce the inductance in the ground conductors, increase the surface area / circumference of the conductor (wider copper strap) as well as the number of conductors.

For roof mounted antennas and towers, multiple down conductors can be spread over the roof and brought down to ground in multiple locations. This will require a ground system run completely around the building (a perimeter ground). As an added benefit, this multiple down conductor approach will reduce the mutual coupling between down conductors and provide a low, unsaturated perimeter ground to absorb the conducted surge. The magnetic fields will also be divided and could, in theory, cancel in the middle of the building. This will help minimize magnetic energy coupling into the wiring inside the building.

Coax Grounding:

Since the tower is a conductor and is well grounded, all of the coax lines should be grounded (using a grounding kit) at the top of the tower close to the antenna and at the base of the tower before they come toward your equipment.

During the strike event, the tower and the coax lines will mutually share the strike energy. If the coax lines are not grounded as they leave the tower or they are completely isolated from the tower, more energy could traverse the coax toward your equipment than is conducted to the ground system by the tower. Such a large inductive voltage drop may cause arching between the coax lines and the tower that could cause deterioration (pin holes in the coax for moisture to enter) or destruction of the coax lines.

Notice the word "bottom" in this section. Since all towers have some inductance, leaving the tower at a point above ground will allow some of the strike current to continue on the coax line (both the center conductor and shield) toward your equipment. Once at the equipment, the current will follow the chassis to the safety ground. This could elevate the equipment cabinets to deadly voltages, deadly for both people and components.

Even though the inductive properties of the coax cable appear to be beneficial, and extra inductance can be created by adding a few turns to the coax; don't do it. The added turns can also act like an air wound transformer coupling more energy into the line. Make sure coax lines leaving the tower remain at right angles to the magnetic field surrounding the tower.

Control and Coax Line Protection:

Rotor control lines should be protected using a protector at both the top of the tower where the lines go to the control motor and inside the shack at the single point ground panel.

If it is not practical to protect the lines at the single point ground panel, they may be protected at the bottom of the tower. The protected lines should then be placed within EMT (metal) conduit that is grounded only at the tower-base end. The EMT will act as a faraday shield from the tower's magnetic fields and will minimize the amount of induced energy.

Single Point Ground:

The next step in a good protection scheme is to provide a single point ground, a plate where all of your equipment I/O protectors can be located. The panel is best located near the ground to keep the inductance of the ground conductor low. However, if this requires the plate to be far from your equipment and if the magnetic fields of a nearby tower can easily couple into the interconnecting wires and cables, then the panel should be located close to your equipment.

An alternative to the single point ground plate is to use a rack panel. This is recommended only if all of the I/O protectors are mounted on the panel and the ground connection is directly to the panel and not to any other piece of equipment.

The grounding of the plate or panel is very important. A low impedance path to ground is a necessity and only copper strap should be considered. Since the strap is flat, its susceptibility to magnetic fields is only towards its edges. To prevent coupling, the strap should be oriented with the flat side parallel to the tower (the most likely strike point and magnetic field source). The single point ground plate should also be oriented with its flat side parallel to the tower for the same reason.

In the equipment room, each piece of equipment must be bonded to the single point ground panel with a low inductance strap. This will maintain all chassis at the same potential during the strike event and minimize chassis-to-chassis current flow. The power, telephone and coax line protectors on each of the I/O's must be mounted on the single point plate. This will minimize I/O to-I/O current flow.

Additional protectors may be used to protect the opposite side entrance locations for the power and telephone lines. They will provide added protection for jointly used equipment such as answering machines, appliances and etc. Ideally they should also be grounded and connected by a buried bare conductor to the ground system.

Remember that surge energy can enter your shack in either of two ways: from a strike down the road coming in on the power/telephone lines or from a strike to your tower. In either case, high quality protectors will dump the energy into the ground system. Because of varying propagation times, if the protectors are electrically spread out from each other, they cannot work in unison to keep the voltage levels between the equipment I/O's within a tolerable range for equipment survival.

No Sharp Bends:
Route all ground straps and grounding conductors so they have a gentle bending radius. Bends sharper than 8-inch [203.2 mm] radius

will add unwanted inductance to the desired ground path. Even for conductors buried in the ground, try to prevent sharp bends.

Protectors:
Coax protectors should be units that have dc blocking on the center pin. This serves as a high pass filtering that prevents the lightning's low frequency energy from continuing to your equipment. The strike energy is picked off and diverted into the ground system in a controlled way. The dc blocking ensures the operation of the protector regardless of the input circuitry of the equipment.

Did you know that spark gap protectors with dc continuity will not work on receivers and shunt fed duplexers? The shunt to ground inside a receiver (coil to ground for static draining) prevents the low frequency lightning energy from turning on the dc continuity protector. The coil shunts the energy to ground all right, but it is at the wrong place. If the coil can't handle the energy (half the coax surge energy is on the center pin), the coil will open up and the current will translate to a large open voltage source capable of arcing anywhere within the radio.

Lightning protection can be summed up simply: You have control of the lightning strike energy and not Mother Nature. Once control is lost, all can be lost.

The basement is the best location for the ham shack. It is closest to ground and will have the lowest inductance connection to the grounding system. Because it is below grade, some magnetic shielding may occur. Most basements have concrete floors. Since concrete is a conductor, your equipment must not sit directly on the concrete. Doing so will allow surge energy to enter the shack and find a ground path through your equipment to the floor. Insulate your equipment with material that does not absorb water. Wood is not a good choice. Polypropylene is better than nylon to use as a full footprint sheet insulator. Obviously, you should not be on the concrete floor touching the equipment when a storm is near!

The first floor is the next best location. The magnetic shielding is less than the basement and the inductance to ground is higher than the basement. If your tower is close to the building, the recommended grounding strap, running down the outside wall, may inductively couple some energy from the tower. This is also true for other lines such as coax, tower lights and rotor lines. The longer this parallel run, the more energy will be coupled. Our recommendation is to protect these lines at the tower base then run them in EMT (electrical metal tubing) steel conduit. The conduit should be grounded to the tower base ground point. This will act as a faraday shield for the cables inside. Do not run unprotected lines in the EMT. The protectors must be grounded to each other as well as to the tower ground. The best way to do this is to place the protectors inside a weatherized NEMA type box. Make sure the box is grounded, as well as the inside mounting plate. To do this correctly, remove the paint from the box's outside and inside surfaces at the ground point and use proper joint compounds to weatherize the connections. Stainless hardware may be used. Crimp lugs must be crimped, soldered and weather covered. Solder (60/40) will not hold up to sunlight and ozone without protection. Use a short section of strap to bond between the inside surface of the box and the inside protector mounting plate.

High Rise Buildings:
Our definition of a high rise building is different than the upper stories of a house. The antennas on a high rise are not on a ground mounted tower, but are usually attached to the building structure. Therefore, a single point grounding plan is a must for a high rise equipment room. Grounding both the antenna and the single point ground connection in the equipment room is easy for buildings with structural steel frames - just bond to the building steel. Buildings other than steel construction are not as simple. Some high rise buildings have a fire riser with a straight run to the basement where a super charger pump is usually connected. The riser may be used as a ground path if the pump's power is protected and a strap jumper installed to take the strike energy past the pump's gasket on both its input and output ports. If the riser is over 50 feet away, it may not be the best ground path to use. Check for other paths such as existing building lightning rods with down conductors or large electrical conduits. Do not use drain pipes or vent stacks. If none are available, regardless of the path distance, and it is impossible to run a strap down the side of the building, then the antenna just can't be grounded! When an ungrounded antenna is hit by lightning, the energy will traverse the coax line to your single point equipment ground location. This may be many meters from earth and the inductance/ resistance voltage drop will be very large (hundreds of thousands of volts).

The ideal plan is a single point ground with no sneak paths. Sneak paths are loops that allow lightning current to flow into the equipment room. The easiest sneak paths to miss are the safety ground and the concrete floor (discussed above). The safety ground can be fixed by adding a distribution panel and protector at the single point ground location or, for small sites, a plug-in protector grounded on the single point ground panel. All I/O's (input/output) must be protected at this single point. The next thing to measure is distance. During a strike, distance equates to voltage drop to earth, the entire room of equipment will be elevated. The sharp corners of equipment cabinets can breakdown the air, causing current to flow. This will be a very low current unless another path is found by these streamers. Heater vents and electrical conduits that are not grounded to the single point can become such paths. It is a good idea to bond (ground) all conductive objects within 1 meter of any single point earthed equipment in the room.

Tower mounted equipment is similar to the above high rise situation. The I/O's must be protected and the protectors must be located and bonded together. Single point grounding should be easy to do if the equipment is mounted inside a metal enclosure.

Antenna Support:

Ground mounted vertical antennas require the same type earthing for lightning protection. A vertical antenna's impedance is half of a dipole's. Don't stop short of a good ground plane. The better the ground plane for RF, the better the earthing for lightning. This is assuming that the RF ground plane is in the ground.

If you have a antenna tuner fed long wire and the pole is just supporting the antenna wire, it would be a good idea to have the grounded straps extend higher to intercept a strike or to divert energy to ground if the wire is struck. This can be done by either placing a high voltage gas tube between the long wire and the straps or by making an arc gap between the wire and the ground straps. A gas tube will not be adversely affected by temperature, humidity, pollution, or wind, while the air gap will be affected. It may be difficult to calculate the voltages present at the gas tube and it will change when switching bands. A rule of thumb is for about 7kV. An air gap would be about 0.175" at sea level with 50% humidity and grows larger with elevation/humidity. (Humid air is less dense)

Another gas tube or gap may be added closer to the antenna tuner. For dipole antennas with baluns, use the same gas tube technique. Place gas tubes around the balun. Place one across the balun at the dipole wires and one from each side of the balun to the ground straps. This will protect the balun from a strike to the dipole wires. The more strike energy you can divert to the ground before it

reaches your equipment, the better off you and your equipment will be.

Just a word to those who tell us that they are safe from lightning because they always disconnect the coax from their equipment. When asked what they do with the disconnected line(s), they usually respond that it is placed on the floor. Now if you stop and think about the last few thousand feet that the lightning has jumped, you can see the fallacy of their thinking. In fact, they made it worse since arcing involves ignition temperature plasmas inside your house. True, the radio may still work, if it survives the house fire. Throwing the coax out the window is not a solution, especially if the coax has already entered the house from the antenna or the antenna is roof mounted without a ground path. Grounding switches will not last long with direct hits unless other good ground paths are provided. Grounding the antenna line and not disconnecting the coax shield can still allow strike energy to be shared with the equipment The shield connects to the chassis and if a single point ground is not present with power/telephone protectors, the equipment will be damaged.

Power/Telco entrance:
Full protection for a ham shack must cover not only strikes to your tower, but also hits from down the road to utility lines. By using single point grounding, your ham equipment will survive the hit to your tower. If the outside (tower/perimeter) ground has a low impedance at lightning frequencies, most of the strike energy will be dispersed into the ground and little energy will enter the shack. This is fine, but what if your ground has deteriorated over time or was never very good because of yard size?

The ground system can absorb only so much energy before it becomes saturated. In 90% of the strikes, a traffic jam of electrons will be coming down your tower. If they cannot spread out in a reasonable time frame, the back up pressure (voltage) will find or create another path. The ground system, if too small in area, will cause more energy to traverse the cables and other lines to the shack. The I/0 protectors can keep the voltage levels between the single point ground and the signal line(s) at survivable limits, but the energy is only diverted elsewhere. This could be the house phone lines and power lines.

Other house appliances may be at risk. When the ground system is saturated, the energy is actually coming from the (utility) ground system and can go through your TV, for example, in an effort to leave the area by way of the cable TV drop. Satellite dishes will also have the same problem. The best way to protect the rest of the house is to provide protection at a single point. The easiest single point will be at the power and telephone entrance. The utility ground rod (which should have been already interconnected to your ground system) is used by both the power neutral and the telephone protector installed by the phone company. By placing a power mains protector and a secondary phone line protector at this location, the entire house will be protected. The cable TV or outside antenna coax should be rerouted and a good coaxial protector installed at this point. The cable company installed protector is usually just a grounding block earthing only the outside shield and does nothing to the center conductor energy that can have as much energy as the outside shield! As the ground system rises in potential from a strike, the protectors will take the ground system energy and place it on the power, telephone, and cable TV lines while keeping the voltages between earth and the active lines within the limits of equipment survival.

The utility ground rod for the house should have already been interconnected to your ground system. What if this can't be done? If this is not done, the energy from the tower strike will traverse the house safety ground wires to this rod, causing problems. The reason to interconnect them in the ground using bare conductors was to reduce the inductance of the interconnecting path. It is true that the house wires are a parallel path and there is nothing we can do about it. If the interconnect path is better (lower inductance and resistance) the majority of the current will bypass the house wiring. The only alternative is to provide a copper strap path through the house. This may not be a sufficiently low inductance path and it will radiate to other wires/equipment inside the house.

The power and telephone feeds to your house can be either aerial or underground. Most people think underground is better from a lightning standpoint. Buried underground, it will not be hit directly, but if a nearby tree is hit, the amount of energy coupled through the conductive ground medium can be almost equal to a direct hit. By being underground, the shielding effect to the wires is not great. The buried depth does little when compared to the depth low frequency strike energy penetrates. When you consider the cost of underground utilities, these and the aesthetics must be weighed.

Ground System Materials:
Solid copper wire/strap and copper clad steel rods, makes copper the most commonly used earthing material. Your below grade ground system should be made with the same material throughout.

Mixing of materials, like galvanized rods with bare copper radials, will create a battery action and the zinc of the galvanized rods will become sacrificial, dissolving into the soil. This leaves bare steel to rust and not provide an optimum connection to earth. (Note: when wet, rust can conduct, but not very well.) Using stainless rods in order to prevent corrosion will not provide the best conductivity. Since stainless wire will be required to interconnect the rods, the resistance of the system will increase. An all aluminum ground system should only be considered in very acid soil conditions and even then it should be chemically tested for other attacking soil compounds.

Joints between copper radials and copper clad rods should be made by exothermic welds or by using joint compounds in high compression clamps. Solder connections, even torched silver solder connections will not last as long as the above. An exothermic weld is created when a graphite mold around the connection is filled with copper oxide and aluminum powders. An additional starter powder ignites the exothermic process. The resultant molten copper is deposited into the lower mold cavity where it burns away any oxides and creates a larger fused connection. The larger cross sectional bond decreases the resistance and increases the surface area, reducing the inductance of the joint. Since the materials are all the same, the connection will last as long as the rest of the grounding material. High pressure clamps provide a meshing of copper to copper since the material is soft (malleable). The use of joint compounds further enhances the weather tightness of the bond. The high pressure will need to come from another material stronger than copper.

If you find a rock layer is making the ground rod insertion difficult and you can't remove the rod to start over a few feet away, the best idea is to cut off the rod and connect it to the system. A rock layer will hold water and salts so the conductivity above should be good. Making more connections to areas of higher conductivity will reduce the overall impedance of the ground system (resistance and inductive reactance).

The ground system has a resistance and an inductance value. (It has capacitance too!) The amount and location of the inductance can choke off the effectiveness of radials. When a radial is in poorly conductive soil such as buried in a dry, sandy layer, the radial inductance can be calculated as being in air (a very poor conductor). When the radial runs in highly conductive moist soil (or doped soil), the inductance of the wire is shunted by the soil's conductivity, making it unimportant.

Since copper strap has lower inductance than wire, it is recommended for the radial run. The strap's extra surface area reduces the inductance and the sharp edges allow for a high E field concentration forcing more charge into the soil. Short multi-point (like barbed wire) type grounding systems have been tried and have not been as effective as the sharp edge of copper strap for ground rod interconnecting material or for radial runs without rods. Copper strap radials have been proven successful on bare mountain top solar powered sites where ground rods could not be used. The strap edges helped disperse the strike's deposited charge to the tower by arcing onto the mountain surface, saving the solar powered radio equipment at the site.

Adding ground doping material to your radial trenches and rods can be helpful. Stay away from gels and other chemicals that can shorten conductor life. All add-on conductive earthing materials do little except make your copper conductors larger (more conductive surface area). This gives some percentage of improvement but it still must interconnect to conductive soil where it has both salts and moisture. If the soil is dry around the earthing material, the connection to earth will be poor, regardless of the advertised claims. If the area is not large enough, the earth connection will suffer. By increasing the area of your ground system with the addition of more radials, the same improvements can be obtained for less money.

Longevity:

After doing all this work, Mother Nature still has a way of making anything we do temporary. Once a ground system is in the ground it will start to age. Copper and other metals are attacked by acids, while aluminum is attacked by bases. Other chemicals may be present in the soil causing decreased effectiveness of the grounding materials. This is why maintenance testing is important. While some ground systems last 30 years, others don't even last two years! There are two ways of finding out if your ground system is in need of work. One is after a lightning strike and is too late! The other is to measure the system. An old timer once told me that he tested a ground by disconnecting it from everything and connecting it to power "hot" through a 30 amp fuse. If the ground was good, the fuse would blow. This is not the way to test a ground and it could change the soil conductivity by attempting such a test. The proper way is to use an earth resistance meter providing a fall of potential type test. Be careful when connecting a ground system to your electrical utility ground rod. Depending on ground conductivity, harmonic and other currents, there could be current flow causing a spark when connected.

Finally!

Most of the above topics are covered in more detail in our other technical documents. Read on! (73, KF4MT)

TD1017: Insulated poles used in place of a conductive tower force more current down the coax toward the equipment.

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***TD1017:** Insulated poles used in place of a conductive tower force more current down the coax toward the equipment.*

Notes:

Wood or fiberglass support structures are not a good idea. They are an insulator. The cabinet earth ground, coaxial cables, and conduits attached to the support would be the only conductive path for lightning energy. If a wood or fiberglass pole must be used, the first step is to provide an alternate 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 [152.4 mm] copper strap as an earth ground conductor, would provide a low inductance/large surface area conductive path to an earth ground system. Coaxial cable shield grounding kits could be applied above the cabinet with 1½ inch [38.1 mm] straps around the cabinet to the downward conduits from the cabinet. The 6 inch copper strap earth ground lead should be routed on the opposite side of the pole from the coax and conduits.

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 “pattern” is indicative of its magnetic field susceptibility boundaries.

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 extending out from the edges. The strap’s field “pattern” is also indicative of its magnetic field susceptibility boundaries.

If downward circular conductors 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 will conduct most of the current to earth ground with little reverse EMF developed on the conduits.

- If the Cabinet is pad mounted, 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 through cabinet current flow (recommended). The conduits and/or coaxial cable shields should be grounded at the base of the support. The remaining energy would go to earth down the cabinet’s internal earth ground conductor. The usual center pin/shield propagation differential voltage would occur and could be equalized by an appropriate dc blocked 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 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 ground conductors. The additional coax and 180 degree turn would add series inductance. Current flow through equipment would be minimized and a bulkhead type center pin protector could be used as a bottom connector.

TD1018: Local Area Network (LAN) protection problems. Discussion and suggestions.

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TD1018: *Local Area Network (LAN) protection problems. Discussion and suggestions.*

Notes:

The IS-50BB/18 coaxial protector is designed to conduct energy between center conductor and the protector's metal housing when a voltage differential of greater than +/- 18 Volts occurs. Lightning induced energy is directed through the protector to earth, rather than going through the connected circuitry on its way to earth. This "shunting" action saves the equipment from damage.

The IGA 90V (in this application) is attached to the metal housing of the IS-50BB/18 and isolates the protector's metal housing (to a 90 Volt differential) from the conductive surface to which it is mounted (earth ground). The purpose of this configuration is to isolate earth ground from the coaxial cable shield to eliminate ground loops during normal operation.

When a lightning event occurs, the voltage on the coax center conductor and shield quickly elevate in potential creating a voltage drop across the equipment with current flow through the equipment causing damage. When protected by the above products, the center conductor to shield differential will not exceed 18 Volts and the shield to local ground attachment will not exceed 90 Volts.

Your Questions:

“How can I test the protector? I read > 315 kOhms through it.”

The only true test would be with a low current high potential tester to determine protector turn on. The resistance measured above is typical for the 50BB/IGA90V combination before gas tube turn on.

"What are your recommendations on the grounding of units? Our problem was to decide which end to be grounded (as one end is to be isolated) or to ground both?"

Due to the long distance of the coax, does it make sense to isolate one end? How the protectors are grounded is the most critical aspect of a lightning protection system. The protector assembly (IS-50BB/18 & IGA90V) must be attached to a large surface area, low inductance conductor, connected below earth, to a fast transient response, low impedance (at lightning frequencies) ground system. The IS-50BB/18 is normally isolated from earth ground by the IGA-90.

During a lightning event, large fast rise time currents are directed toward earth. Any conductor in series with this path will develop an E= Ldi/dt voltage drop across its length. From the formula, the actual voltage drop across the conductor is a function of the conductor's inductance, the stroke peak current, and the stroke current rise time to 90% of peak value. The IGA-90 will turn on during a strike, effectively grounding the protector.

"Each of the buildings have Air Terminations (lightning rods). The grounding panel of the IS-50BB is bonded to the down conductor of the Air Terminal. So does the electrical earth. What are your recommendations on the grounding of units?"

Do not bond the protector grounds to the Air Terminal down conductors! Route separate low inductance conductors from the protectors directly to earth ground. The Air Terminals send up an upward going streamer in the presence of a downward moving step leader. When they connect, a path for the main lightning stroke is established. The Air Terminals are designed to attract a lightning stroke to themselves rather than the building structure. This reduces damage to the building structure, but concentrates the stroke current on the Air Terminal's down conductor. The fast rise time, high current pulse creates a distributed voltage drop across the length of the down conductor. This instantaneous peak voltage can be hundreds of KV!

If any other "ground" conductor were connected to the air terminal's down conductor somewhere along its length, a very high voltage (referenced to earth) could occur at that connection. This high peak voltage could exceed the "turn on" threshold of both protectors and switch energy back through the connected critical circuitry towards chassis ground. This potential difference would cause current flow through the critical circuitry towards any other building ground connection. The circuitry would probably be destroyed in the process. If there were separate protector ground conductors, connected below earth to the ground system, this would not occur.

"Which end of the coax to be grounded or to ground both ends? Due to the long distance of the coax, does it make sense to isolate one end?"

You really don't have a problem! The IGA90V protectors are isolators. If you use them, they will not connect to "ground" until 90 volts is exceeded.

Use IS-50BB/18 & IGA90V protectors at both ends of every LAN coax between buildings.

TD1019: What is Lightning? How does it affect a struck object?

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TD1019: *What is Lightning? How does it affect a struck object?*

Notes:

The precursor to a lightning event is called a "step leader." It consists of a low current, (200 amp) barely visible filament, extending from the charge center of the cloud towards its mirror image potential (cloud to cloud or cloud to earth). We will discuss a cloud to earth path.

The step leader will traverse a statistically averaged 50 meters in 1 microsecond, then pause for 49 microseconds until the next jump. There can be branching out from the original step leader to many 50 meter jumps. Since the step leader is a conductive ionized path, the furthest out end(s) of the step leader are at the same potential as the cloud charge center. As the branches reach out toward earth, a strong voltage difference (gradient) is established between the step leader's end and any object on earth (representing the charge center's opposite potential). As this gradient becomes more intense, the air above any structure on earth begins to ionize, or - breakdown. If the structure is pointed (like a lightning rod) it breaks down air sooner do to the point discharge effect (corona). As the breakdown continues, the structure sends up an "upward going streamer" (an opposite polarity ionized path) towards the approaching step leader. When they meet, a conductive path from cloud to earth is established for the main series of strokes to follow. The step leader timing above is from observation of effect. Different charge accumulations within the cloud will change step length and timing somewhat. This effect is also called a “stepped leader”.

The sequence then is: The energy from the cloud charge center is dumped in to the established conductive channel until electron migration within the cloud cannot keep up with discharge. Then all the existing step leader branches that have not been "completed" discharge back through their respective paths towards the completed path to earth. This is seen as a large earth stroke and many smaller branches discharging back to the main stroke. The smaller branches seem to be reaching for earth, but have already been suspended incomplete for some time. The energy of their back discharge illumines near the main stroke, and the illumination continues outward until the entire branch is discharged. There can be several additional strokes as the electrons in the cloud center migrate towards the discharge path. The first stoke is usually twice (or more) the current of the following additional strokes. This is because the first stroke is also discharging the incomplete step leaders (and other unknown factors).

There are a number of theories regarding multiple strikes. Two are presented below:

- The inability of the cloud to continuously discharge at a high current rate due to limited electron mobility inside the cloud. Electron flow towards the charge center cannot keep up with the demand for necessary potential to continue the strike.
- Since any conductor generates a magnetic field around it, the lightning conductive path is no exception. As the current rise occurs within the channel, an increasingly intense magnetic field is forming around the conductive gaseous plasma. This increasingly intense magnetic field could begin to constrict the cross section of the plasma. If the plasma is constricted, its inductance is increased. As the inductance is increased, the ability to sustain high current flow is reduced until the cloud charge center can no longer provide the potential to overcome the inductance. The initial stroke is over. The standing magnetic field collapses and dumps its energy back in to the path. Once the standing magnetic field has collapsed, the channel is ready for another burst of current. This “cycle” continues until the cloud is discharged to a potential where it can no longer generate the potential required.

Lightning is a "constant current" source. It will develop whatever voltage is necessary (within cloud charge center limitations) to overcome the resistance of the struck object. Series path inductance or cloud electron migration will sooner or later stop it.

Even though the strike is dc, the typical current waveshape of the strike includes a very fast rise time to peak current flow. It is this characteristic that creates havoc with electronics. Read through the various topics in the technical area for a more complete understanding of this phenomenon.

TD1020: Dissipation Arrays and pipe cleaners, do they work?

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TD1020: Dissipation Arrays and pipe cleaners, do they work?

Notes:

The idea of preventing a lightning strike goes back to 1754 when the master himself, Ben Franklin, was still experimenting. Prokop Divisch installed 216 earthed points on a 7.4 meter wooden frame, and a few years later it was suggested by Lichtenberg that catenary's of barbed wire over a house could prevent a strike. The idea of using multiple points to discharging a cloud and neutralize its charge has been thought about and tried for years.

R. H. Golde suggested an umbrella shaped barbed wire device could be used on very tall towers to prevent the normally occurring streamers. Golde's concept is to meticulously form a uniform field shaped element taking into account the electrostatic effects of surrounding points. If all points are positions with the correct outward looking angle, it could spread the E field out much like a corona inhibitor on a high voltage power supply. Since it is made of discharge points, unlike the rounded corona inhibitor, the electrostatically inducted voltage from the tower/ground system will be spread to limit the size of the upward streamer. The effect on the downward approaching stepped leader is nil. As the stepped leader approaches the array of points, the E fields will increase above the ability of the size of the array to prevent the transition from ion-maker to streamer producer (glow to arc transition).

This is similar to (but not the same as) reaching the limit of the corona inhibitortor on a high voltage power supply. The air breaks down and a major streamer/arc leaps outward. The larger the array means the larger the support structure. (Ice and wind tower loading also increase.) More charge can now be stored on this structure before the array can bleed it off into the wind. This can result in larger streamers from the array as E fields increase with the approach of the stepped leader.

However, recently a few people have claimed success. They claimed first to discharge the cloud. When that was proven impossible, they claimed to prevent a strike from occurring. Various branches of the U.S. government have tested several multiple point arrays over the years without any success. One report was completed by the Office of Naval Research, NASA, and US Air Force in 1975.

A 1,200 foot tower at Eglin AFB, was fitted with a multipoint system and sustained eleven hits in three months. Five were photographically recorded while seven other strikes were monitored, using NASA's magnetic links, as having had strikes in the 30 to 48kA range. The report also contains a video lightning strike sequence from a monitor showing NASA's Kennedy Space Center 500 foot meteorological tower, equipped with a multipoint array, being hit by lightning.

As the height of an object is increased, the number of strikes increases. This was proven in the middle of this century with testing at the Empire State Building. Most of the strikes to this structure were caused by upward streamers triggering the strike. A more recent test of multipoint arrays was done in the late 1 980's by the FM (terminated on 1/11/90). The FM report also concludes that the tower arrays under test were struck and damaged. The report further includes photos of the video tape of the strike and the NASA magnetic links current measurement for one strike was 8kA for one down conductor and 10kA for the other. Other damage to the facility was listed together with eyewitness accounts.

Few array suppliers will agree whether it prevents a strike 100% or just minimizes the chances of a strike. Another argument is whether to ground the array and how important the ground is to the array operation.

Some of the arrays on the market consist of small rounded or cylindrical brushes that when hit, splatter molten metal as far away as 10 meters. This can be a fire hazard. The FAA report quotes the eyewitnesses to the August 27, 1989 strike to the Tampa ATC Tower: "sparks like the slag you get when arc welding."

Mother Nature produces a large variation of strikes. The larger strikes will have larger E fields and the stepped leaders will be longer. This means the larger strikes will overwhelm the array and upward streamers will reach out and grab the stepped leader anyway. Perhaps the array will slightly delay the streamer, making another target (if there is one) more attractive?

The real solution for lightning protection is to have control of the strike energy. To do this, a well-designed ground system will be a better investment than cluttering up the top of the tower.

TD1021: How to minimize lightning produced magnetic fields in the equipment building.

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TD1021: *How to minimize lightning produced magnetic fields in the equipment building*

Notes:

Lightning's high current means that the associated magnetic fields will radiate and cross couple energy to wire runs inside the equipment building. Too often sites are designed to have a good 5 ohm ground system, but the building is placed right next to the tower with little or no magnetic shielding. The distance between the tower and the building is usually kept small so that the transmission lines are short and have minimal loss. Closer tower spacing increases the current the building's perimeter ground system must conduct to earth. It also allows stronger magnetic fields to transverse the building.

Aluminum buildings do little to attenuate this magnetic flux. Concrete with steel mesh or rebar, which is ferrous, will attenuate only some of the field. Steel shipping containers, either single or double walled, will act as a Faraday shield for both radiated (plane wave) RF energy and for magnetic (H) fields. The containers will also provide a good uniform ground for your equipment from anywhere inside.

The only other alternative is to use distance (one over the distance squared) to attenuate the strike's powerful H field from getting right to the circuit board or chip, causing upset or damage. Distance will also add length to your transmission lines adding desirable inductance, and allowing additional time for the tower ground system to handle the tower surge current.

The inductance benefit of the additional transmission line in the path to the hut will force more surge current down the last bit of tower, from the last grounding kit to the tower ground, instead of over the coax lines to the building. This distance based inductance is not the same as adding inductance by making drip loops with your coax. The loops can couple more energy than they limit. The magnetic fields can be captured and "multiplied" by the alignment and turns ratio of the loop(s). Please note that a straight run from the tower with is orthogonal to both the magnetic and electric fields and cannot capture any additional energy.

Appropriate application of inside equipment room "halos" can also reduce the magnetic field. See "Halo" Topic

TD1022: Causes and Cures of Passive Intermodulation.

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TD1022: Causes and Cures of Passive Intermodulation

Notes:

With increasing demand for mobile communications, the need for greater channel capacity and more sensitive receivers have made Passive Intermodulation Distortion (PMD) more of a problem than ever.

There are many causes of PMD in a communications system. One that directly affects PolyPhaser and its products are connectors and connections to them. The following list was compiled from several articles on PMD.

- Restrict connector materials to copper and copper alloys.
- Connector body plating of silver or white bronze with a minimum plating thickness of 6u m (0.0002 in.).
- Avoid use of stainless, nickel, or ferrite in signal path.
- Quality machining - minimum finish of .4 mm.
- Properly designed interface at connect, panel, and contact surfaces.
- Avoid crimp connections - all connections should be soldered. Clamp and solder outer contacts for best static and dynamic performance.
- DIN connectors are less susceptible to Intermodulation than N connectors.
- Avoid hermetic seals containing Kovar.

Connectors used by PolyPhaser including 7/16 DIN are supplied with gold center contact pins.

PolyPhaser tests for intermod with a Summitek Model SI-1900A Passive Intermodulation Distortion Analyzer

TD1023: Multiple I/O port protection, Single Point Ground considerations.

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TD1023: *Multiple I/O port protection, Single Point Ground considerations.*

Notes:

One of the basic ideas in developing a protection strategy is not allowing stray energy to flow through the equipment. There are several ways to accomplish this. One is to totally disconnect the equipment! Another is to provide some form of impulse protector for each of the equipment's Input or Output (I/O) ports. These ports are usually the ac power connection, a telephone or control line, and an antenna transmission line. A protector on each of the I/O's will protect that path from damage. However, it is also necessary to be careful about voltages that may exist between the I/O's during a strike event.

For example, if each of the protected I/O's of a remote transmitter are connected to a different ground, which could happen very easily in the best of installations, the following situation will exist during a strike event that could damage the transmitter.

The transmission line is grounded at its protector as the line enters the building. The power line to the transmitter is protected and grounded at the distribution panel where the power line enters the building. The telephone line is also protected and grounded where it enters the building. The protection on each of the I/O's at the building entrance is good practice and has the advantage of keeping the strike energy toward the outside of the building and away from the transmitter.

Each of the I/O's are an entrance point for strike event energy. During a strike event, the energy will propagate along a conductive path (power line, transmission line, or telephone line) until it meets the protector. The protector will shunt the majority of the strike energy to the earth ground. The earth immediately surrounding the ground point will begin to take up the energy charge and dissipate the energy by propagation within its “sphere of influence” (see ground systems topic). The local earth ground will rise in potential (see GPR) for a few microseconds. For a brief instant, one port of the transmitter is elevated above ground while the other ports are at ground potential due to other protector connections not yet elevated.

As the surge energy attempts to go to earth ground using the transmitter as a connecting path to the other grounds, it is likely to also use some of the internal circuitry as a current carrying conductor and cause equipment damage. A complicating factor is that the other I/O protectors are at a distance with respect to the equipment. The greater the distance between the protectors, the more serious the problem.

Another complication in this scenario is the inductance of the conductor between the I/O protector and the ground system. The inductance will determine how much of the strike energy is conducted into the ground system and how much is left to elevate the transmitter chassis. Since strike energy is a high frequency pulse, a low inductance path to ground becomes a critical factor. Copper strapping is preferred over large diameter wire as an inter-connecting media. Copper strap has a large circumference and low inductance per unit length. The strike energy, like water, will follow the easiest (least inductive) path to ground. In the above example, each of the I/O protectors is connected to separate grounding points. This can be corrected, but will require some physical rearrangement of the transmitter installation.

First and foremost, there should be only one ground system .

Second, the individual I/O protectors need to be co-located on the same electrical ground plane. This means establishing a single point ground system within the equipment building. An ideal way is the PolyPhaser Bulkhead Panel, PEEP, or Single Point Ground Panel. The single point ground system will keep all the I/O protectors at the same level with respect to each other.

Third, the transmitter equipment chassis must be insulated from conductive flooring and connected to the ground plane using a low inductive connector.

TD1024: Special considerations for connecting roof top sites to "earth ground".

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TD1024: *Special considerations for connecting roof top sites to "earth ground".*

Notes:

In most urban high rise sites a low inductance earth ground connection is impossible to achieve. A connection to the steel structure of the building is the preferred method to connect a single point ground.

In some poured concrete buildings there is no steel structure, only reinforcing bar in the concrete. If local building codes permit, attach the single point ground to any exposed rebar.

Long inductive ground conductors down the building can also be used for the final earth ground connection. This is a poor way, but sometimes the only way to ultimately connect to earth ground. When using this method, (or any method) protect every interconnection to the outside world. Power mains, telephone, control lines, or any other outside connection must have a protector referenced (connected) to the single point ground.

When a strike occurs, the top of the building will quickly elevate in potential (compared to the outside world). Depending on the earth ground connection, the following could occur:

- Connected to building structural steel - The elevated potential first charges the capacitance of the structure. The capacitance absorbs some of the fast rise time energy and disperses it throughout the structure and down to the building footers and any interconnecting conductive pipes. The equipment on the roof is elevated in potential with a relatively fast decay to ½ peak voltage.
- Connected to building reinforcing bar - The elevated potential propagates through the tied together re-bar bundles and conductive concrete towards the footers and interconnecting pipes. There is usually dc continuity through the rebar bundles to the footers. The roof top equipment is elevated in potential more quickly (than above) with a slower decay time. There is more "time" for damage to occur.
- Connected to a standing water pipe or "fire riser" – First, get permission to connect to this conductor. Make sure there is continuity all the way down – no PVC fittings or insulating gaskets. Bypass basement pump flanges with copper strap

and protect the pump motor windings with an ac protector. The standing water pipe is usually a large diameter pipe with circumference / surface area much greater than a typical earth down-conductor. Use this method with caution.

• Connected to a single (or more) earth downconductor - The elevating potential quickly saturates the current carrying ability of the single (inductive) downconductor. The equipment is elevated to a high potential and stays there until the single downconductor can "drain" away the charge. The equipment is held at high potential for a much longer period of time than any of the above options.

If there is a "lightning rod" system installed, it is OK to connect to the lightning rod system downconductors as an earth ground as long as the protected equipment is also on the roof. Code requirements will probably insist on this connection. If the equipment cabinet is on the roof, the potentials will be the same. If the equipment is located on the lower floors, do not connect to any lightning rod system downconductor. They will probably be at a higher potential than the building potential on that floor. Find structural steel, re-bar or route a separate downconductor, through the building, away from the lightning rod system's downconductor(s). The only common point should be at the physical earth connection.

TD1025: Ground system longevity vs pH of Soil.

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TD1025: *Ground system longevity vs pH of Soil*

Notes:

When constructing a tower, a complete soil analysis should be made to determine the structural integrity of the proposed tower. But do you know that both soil resistivity and pH can also be done at a minimal cost?

Soil resistivity measurements are required to design the grounding system, while the pH can determine what materials should be used for maximum longevity. Copper is the most often used material for grounding. Copper is attacked by acids which have a pH of less than 7. Most soils east of the Mississippi range form pH 7 (neutral) to less than pH 4. West of the Mississippi, generally the soil pH is higher (alkaline) than pH 7. Copper in Western soil will last a long time.

It is interesting to note that aluminum is not used in the Eastern United States, even though it is not attacked by acids. It would, however, be attacked by Western alkaline soils. Acidity in soils is a result of the natural processes of weathering under humid conditions. In areas of high rainfall, soluble salts and colloidal bases are removed from the soil resulting in higher acidity. The amount of acidity is a function of rainfall, drainage, vegetation and the nature of the soil present.

Soil Testing Steps:
Testing soil pH is simple. You will need a swimming pool pH tester, some clean cloth, a glass and distilled water. Take one teaspoon of soil at your grounding system depth. Place in a clean glass and add water to cover the sample by 1 inch and mix well with the spoon. Let sit for ten minutes, then, keeping the sediment in the glass, strain the liquid through a double or triple thickness of the clean cloth into the pool tester container as per the test equipment's instructions. Test normally. This should provide a coarse level of soil pH.

If you have a pH of 4 and are using copper, the soil will make the materials short lived. Typically, good ground rods only have about 0.02 inch of copper cladding. Additionally, corrosion or galvanic (mixed metal unions) will also reduce the life of a metal in soil. Knowing the soil pH is a start to determining how long your grounding system will last.

TD1026: Telephone room grounding and protection.

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TD1026: *Telephone room grounding and protection.*

Notes:

Consider this scenario (from a consulting report): There was no earth ground in the telephone room, only an ac “safety ground”

Lightning strikes somewhere across the street close to a below grade cable vault. If this were a negative strike (most are), the ground potential in the immediate area of the strike rises far above the “outside world” potential (outside world means all earth away from the immediate strike area). The elevated excess of electrons from the negative strike “fan out” looking for ways to equalize potential with their surroundings. As they move away from the strike area they gradually are equalized with local earth potential. The amount of peak voltage drop measured longitudinally from any two points on a radial away from the strike area is known as “step potential.” This phenomenon is also called “Ground Potential Rise” (GPR).

GPR results from the earth’s inability to rapidly absorb the entire large current / high frequency pulse to the struck object and turn it to heat. This inability is a consequence of the varying impedances of the earth (resistance, inductance, and capacitance of the soil in immediate area) to the fast rise time current pulse in the strike’s sphere of influence.

Moist earth is conductive and has a velocity of propagation that varies with its conductivity. However, copper (as in telephone cables) is much more conductive than earth. Since there is an elevated potential in the strike area, the potential difference across the cable insulation to the (yet to be elevated) copper conductors exceeds the rated breakdown voltage of the outer sheath. An arc is established through the sheath rupture and the inner conductors are also elevated in potential. This elevated potential is rapidly propagated through copper conductors towards the telephone equipment room. The telco installed protectors turn on as the elevated potential arrives at the protection panel, but as soon as the capacitance of the ground wiring is charged, the high inductance of the total ac power safety ground path chokes off current flow. As the current flow is choked off, the voltage rises on the protector panel and all connected equipment. Damage occurs when the rapidly rising voltage exceeds the breakdown rating of various components in series with a path towards a lower potential. Your equipment becomes a path when there is a high inductance ground connection. All this happens in microseconds.

The telephone cable would not need to breakdown to have damaging energy at your equipment. With high earth current circulation from a strike in the telephone cable's vicinity, there could be large amounts of energy coupled to the conductors. The resultant elevated voltages caused by a poor ground path in the telephone room could still cause the above scenario.

The damaged cards in equipment were all related to inputs / outputs, yet the ac power supplies feeding the cards were not damaged. This again points towards twisted pair circuits as the energy path to damaged equipment. The first line of defense is the telco protection panel, but the panel must be connected through a low resistance / inductance conductor to a properly designed ground system. There was no adequate ground available in the telephone room.

A separate low inductance ground conductor must be routed from the telco protection block to a low resistance, fast transient response ground system. Additional protection devices should be considered for critical equipment input/outputs.

TD1027: Exploring the need for tower down conductors.

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TD1027: *Exploring the need for tower down conductors.*

Notes:

Numerous grounding standards require a copper down conductor run along the tower length to a ground rod or to the grounding system. Perhaps the writers of such standards thought that copper was a better conductor than the tower, or since the tower was made of steel (ferrous material), the added inductance would impede the lightning strike energy from flowing to ground. The joint between the tower sections could develop resistance? Regardless of the reason why, such standards still exist.

These standards address both types of installations: one with the top lightning rod grounded to the tower and one with the lightning rod insulated from the tower. With the latter, it is impossible to prevent the insulated rod/down conductor from arcing back to the tower. The instantaneous voltage drop due to the inductance of the downconductor can be hundreds of kilovolts. Much more current will flow down the tower than the isolated downconductor.

To prove this theory, we placed a 10-foot (3 m) section of Rohn 25 tower over PolyPhaser's “Big Bertha” lightning simulator. We bonded a 10-foot section of insulated #2/0 cable to the surge input side of the tower. The other ends were monitored for the amount of surge current for each path. The setup was 'shot' with 5000 volts. The results show the tower section had four times the #2/0 cable current! Only 19.7% went down the #2/0 cable and 80.3% traveled on the tower

In another test, we took a 10-foot section of Times Microwave LMR-1200 Coaxial cable and bonded it to the same tower section over Big Bertha. This coax has a larger diameter than the #2/0 cable but we wanted to show the advantage of using a coax cable rather than a grounding conductor. The coax conducted 30.9% of the current while the tower conducted 69.1%. Using a good coax cable can do double duty - as a useful transmission line and a conductor for lightning current. The next step is to properly protect the equipment using PolyPhaser products and proper grounding techniques.

After a lightning discharge has jumped 2 miles (km) to hit your tower, do you really believe a 3 inch (76 mm) standoff insulator can direct it to a different ground connection? Also consider if the copper wire is bare, naturally occurring rain, which is slightly acidic (pH 5.5-6.0), will remove some copper ions on contact. When these ions drip onto the tower, the galvanized coating (zinc) will wash away, resulting in rust and decreasing the life of the tower.

There could be other reasons for a separate downconductor such as:

- Making a low noise HF receiving antenna from an insulated tower in a high rf environment.
- An impedance matching (Gamma Match) connection to a grounded tower used as an antenna.

But not to “protect” the tower from lightning!

TD1028: An interconnected concrete tower base can help the tower ground system.

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TD1028: *An interconnected concrete tower base can help the tower ground system.*

Notes:

Concrete is a fair conductor and can be used safely and effectively to augment the tower grounding system. The concrete's ability to quickly absorb moisture and release it slowly over a long period of time makes this possible. The pH of the released moisture in turn enhances the conductivity of the surrounding soil.

It is a common misconception to think that a lightning strike will blow up a concrete pad. However, consider first, a myth-perpetuating case of an improperly designed earth ground system where the tower leg "J"-bolts are imbedded directly into the concrete pad. In this case, due to the poor nature of the tower ground system, each of these J-bolts will actually share a significant amount of strike current which in turn will flow through the concrete. Since the surface area interface between the J-bolts and the concrete is small, and the surge current density from the strike very large, the corresponding heat generated by the energy transfer can turn the concrete moisture into steam and possibly crack the pad. We have only seen this happen once on a mountain top in the Nevada desert. However, a few poorly implemented occurrences can give a valuable technique a bad reputation.

If during construction, all rebar in the concrete pad becomes an integral part of the ground system, the overall surge current density will be several orders of magnitude lower than the myth-perpetuating case above. With the surge current distributed over all of the rebar there will be little opportunity to develop the temperatures necessary to vaporize the imbedded moisture. The pad will not crack.

To successfully implement a Ufer ground system it is necessary to bond each of the independent pieces of rebar together. This is best accomplished using an exothermic process. Failure to weld all elements of the rebar could allow for a spark gap between the unconnected elements and thus an opportunity for localized heating of the imbedded moisture. The electrically unified rebar is connected to the tower leg. The buried ground system radials, used with ground rods to further disperse the strike energy, are also bonded to the rebar. The Ufer ground, enhanced by the local earth resistance, will be lower due to the leaching of the concrete pH into the earth that in turn lowers its impedance at lower frequencies. The better the ground system, the more current flows through the tower leg into the Ufer ground. Also, since the strike charge is all of the same polarity, it naturally wants to spread out. With the large surface area of the rebar closer to the earth than the tower J-bolts, the current passes easily through the concrete to get to earth where it continues to spread out even further.

A Ufer ground should not be used alone. We always recommend that radials with ground rods be used as the main ground system and that the Ufer ground be used to further reduce the ground resistance of the system. Many tests have been done, dating back to 1968, that prove the Ufer is a safe and effective way of augmenting a ground system.

TD1029: How to “ground” the coaxial cable shields as they enter the equipment building.

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TD1029: *How to "ground" the coaxial cable shields as they enter the equipment building.*

Notes:

Any input or output (I/O) line can carry surge current that can harm equipment. Of the primary I/O lines (power, phone, and coax), the coax line(s) from the tower can bring in more surge current to equipment than any other source. The large surface area of the shield, the correspondingly low inductance of the coax line, and the proximity of the coax to the tower present the fast rise time lightning current pulse with an ideal path towards the equipment.

If the bottom coaxial cable ground kit (where the coax leaves the tower) is at any elevation above the earth, the inductance of the tower section between that ground kit and the earth is sufficient to cause a substantial voltage drop. The resultant voltage on the coax will drive current on the coax line to the equipment where the electrical safety ground provides a path to ground. Once the surge is inside the building and on the equipment chassis, it is almost too late to try to protect the equipment.

The best way to prevent such coaxial currents from reaching your equipment is to keep them from entering the equipment building. This may be accomplished by installing, on the outside of the building, a panel connected to the ground system with large surface copper strap(s). The large surface area strap is necessary to provide a low inductance path to ground for the surge energy as well as provide for the high frequency component of the strike energy. Each coaxial line as it enters the building is attached to the panel with an additional ground kit before connecting to a protector.

A PolyPhaser bulkhead entrance panel provides all of the necessary attributes required above. The bulkhead panel has a weather protected built-in grounding kit that will handle a wide range of coax lines. The low inductance ground connection is provided by multiple 6 inch [152.4 mm] wide copper straps attached with a sandwich bar to the 0.125 inch [3.2 mm] thick solid half-hard copper bulkhead. The panel is designed to mount/ground a PolyPhaser coaxial protector facilitating cable installation. The overall physical installation of a bulkhead entrance panel is shown in the PolyPhaser online catalog. Please note the below grade interconnection of the bulkhead panel with the other elements which comprise the grounding system.

TD1030: Elliptical Waveguide (EW) and Waveguide Coax Jumper Protection.

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TD1030: Elliptical Waveguide (EW) and Waveguide Coax Jumper Protection.

Notes:

This discussion covers EW (elliptical waveguide), the EW flange to coax adapters, and the method of coupling TE (transverse electric) or TM (transverse magnetic) waves in the EW to a coax cable center conductor.

The lightning caused surge current on a waveguide will be on its outer surface area. The EW is usually bonded to the tower at the bottom where it turns to the entry panel, and again at the entry panel as it enters the equipment building. If that is done, most of the current causing potential will be removed by the time it enters building except whatever potential remains as a consequence of the Ldi/dt voltage drop across the entry panel copper straps to the below grade perimeter ground.

If the equipment racks are grounded at the top and insulated from conductive flooring with no I/Os at the bottom, there should be no significant current flow from through the coax jumper to the rack. Although the coax jumpers provide a conductive path from the elevated potential single point ground entry panel, they are in parallel with top grounding conductors, and after charging the rack's capacitance, current flow through the jumpers and ground conductors should stop.

A coaxial lightning protector is designed to limit center conductor throughput energy and equalize a shield to center conductor potential differential developed across the typical radio equipment antenna I/O due to impedance differences between shield and center conductor (as in "unbalanced coax transmission lines") when a fast rise time, high current pulse transverses both the coax shield and center conductor.

A smaller differential voltage can also occur when current flows through the coax shield only. A "reverse EMF" is induced on the center conductor due to magnetic field and capacitive coupling through the cable's insulating dielectric. Induced voltages can also occur when a strong external moving magnetic field pulse "cuts" across the coax shield (or any conductor).

An EW transfers transverse standing electrical (or magnetic) wave energy to a solid conductor (such as a coax cable center conductor) using a probe inserted at a precise location in the EW (usually at maximum standing waves, depending on the freq/mode in the waveguide). A 90 degree perpendicular probe [TE] is usually voltage fed/excited open circuit, and length is usually an even fraction or multiple of the operating wavelength.

A lightning strike to the tower would cause current flow on the surface of the EW. Most of the current would be directed to ground through the tower ground kits and entrance panel copper straps. A small current pulse would be directed from ground conductors and the EW through the flange to N adapter and the coax jumper shields to the rack top. If the rack bottom were ungrounded, the pulse would be short and low current.

Since the "probe" inside the terminating section of waveguide is open circuit with a small capture area, current caused elevated potential on the waveguide would not be transferred to the center conductor. There would be no current pulse on the center conductor other than induced energy from the small coax shield pulse or an external moving magnetic field influencing the EW or coax shield.

Unless the jumper is very long (don't ask, there are too many variables – greater than a meter?), the equipment input very sensitive to spikes (call the manufacturer), or you get a very high current, multiple stroke lightning event (unlikely), using a coaxial protector at the equipment I/O on the jumper from EW to equipment is optional. In most areas of the country I wouldn't, in central Florida I'd think about it.