

White Paper

Coaxial Cable Lightning Protectors

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Antenna manufacturers utilize shunt-fed dc grounded antennas as a means of impedance matching and providing some form of lightning protection to their customers. It has been proven that these antennas do work and should be used as a means of diverting a portion of the direct strike energy to the tower and its ground system. Unfortunately this protection is designed to help the antenna survive and not the equipment. A direct hit, or even a near hit, can “ring” an antenna whether it is grounded or not since it is a tuned (resonant) circuit. The ringing waveform will contain all resonances that are present in the antenna and its coax phasing lines. This means both “on frequency” ringing and other frequencies present will be propagating down the transmission line towards the equipment. The “on frequency” energy will not be attenuated by a high Q duplex filter or a 1/4 wave grounded stub being used as a protector. In both instances, the “on frequency” energy will pass right through. Also, if we look at a typical dc grounded/shunt-fed antenna at the top of our 150-foot tower example, both the center conductor and shield will be at the same 243kV potential above ground at the antenna feed. Although the grounded antenna will help prevent arc over of the transmission line, it will have a 6kA peak current traversing its length. The same parallel tower segment will have 12kA. The shared strike current, between the tower and the coax, will contain mostly low frequency components.

The lack of high frequency components is due to both the grounding of the antenna and the inductance of the tower/coax, which acts as a “filter.” The antenna ringing voltages, with much higher frequencies, will ride on top of these lower frequencies towards the equipment. A no grounded antenna will arc over between center pin and shield, creating major high frequency components that will traverse the transmission line to the equipment.

If the coax line were left exterminated as it reaches the master ground bar, the coax could arc over the center conductor to shield even if a grounded antenna were used. This is due to the difference in series impedance at lightning frequencies between the shield and center conductor and the additive ringing voltage. It is important to eliminate or stop this energy from being delivered to the equipment. Since coax lines are rarely left unused, (especially connected to an antenna) these voltages will be converted to current either by a dc continuity coaxial cable arrestor, a shunt fed cavity, or by arcing over dc blocking capacitors inside the equipment.

Contrary to popular belief, lightning energy does not “disappear” in the arrestor/protector box. Simply connecting a protector in series with the coax line and expecting protection from a strike is wishful thinking. Only a properly installed and grounded coax center pin protector can offer any measure of equipment input protection.

The Need For Protection

Skin effect is a physical phenomenon that relates to the limited penetration into a conductor of an RF signal, according to its frequency. This effect is present in coax cable, keeping the RF signal inside and any coupled outside interference on the shield’s outer surface. The effect begins to fall apart as the frequency is lowered and the penetration, which is a gradient, begins to mix the shield’s outside interference energy with the desired inside energy. A ground loop, which imparts 60 Hz onto a desired signal, is causing ac current flow between ends on the coax shield due to dissimilar ground potentials and is low enough in frequency to couple energy through to the center conductor.

With lightning, the main frequency range is dc to about 1 MHz (-3dB). This is in the range that affects the coax transfer impedance. The thicker the shield material, the less the effect of these low-frequency currents.

A test was performed on 50 feet of LMR1200 (7/8") coaxial cable typically used as a feeder. The center conductor and shield on the surge side were shorted to simulate a shunt-fed antenna. The current from the resulting voltage drop across two 0.001 Ohm current viewing resistors at the far end of the cable was viewed using an HP-54522C Oscilloscope. The coaxial feeder assembly was pulsed with a Haefely P surge generator with PHV 30.2 combinational waveform plug-in module. The surge generator was set for a combinational waveform output of 1.2 x 50

Sec at 6kV open circuit voltage and 8 x 20 Sec at 3kAmps short circuit current (in accordance with IEC 1000-4-5 and IEEE C62.41 specifications). The peak output voltage and current indicated on the Haefely were 4300 volts and 1750 amps. (See Figure 1.) The resulting peak currents on the shield were 1531 Amperes positive and 688 Amperes negative. The currents on the center conductor were 234 Amperes positive and 63 Amperes negative. Both the shield and center conductor returned to pre-surge levels within 2 oscillations. A slight propagation delay was noted on the center conductor's peak current referenced to the shield peak current

The same test was performed on 6 feet of LMR600 (1/2") coaxial cable typically used as a jumper. The jumper assembly was pulsed with the same combinational wave shape. The Haefely indicated peak voltage and current outputs were 1020V and 2940A respectively. (See Figure 2.) The resulting current on the coax shield was 1875 Amperes positive and 563 Amperes negative. The current on the center conductor was 969 Amperes positive and 156 Amperes negative. Both the shield and center conductor returned to pre-surge levels after 1 oscillation. A slight propagation delay was noted on the center conductor's peak current referenced to the shield peak current.

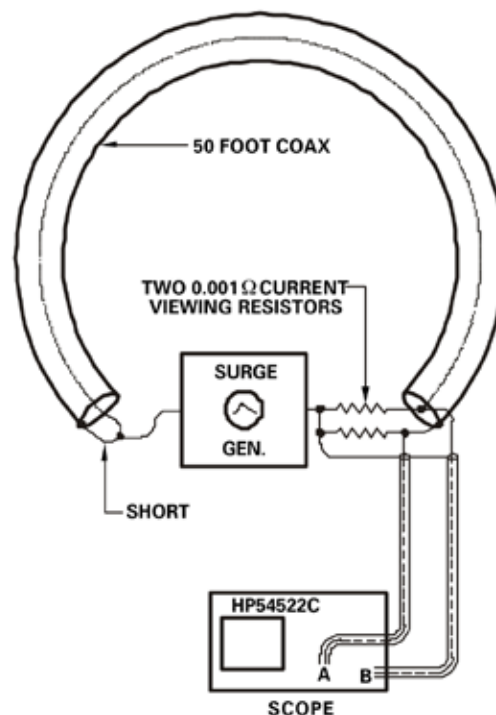
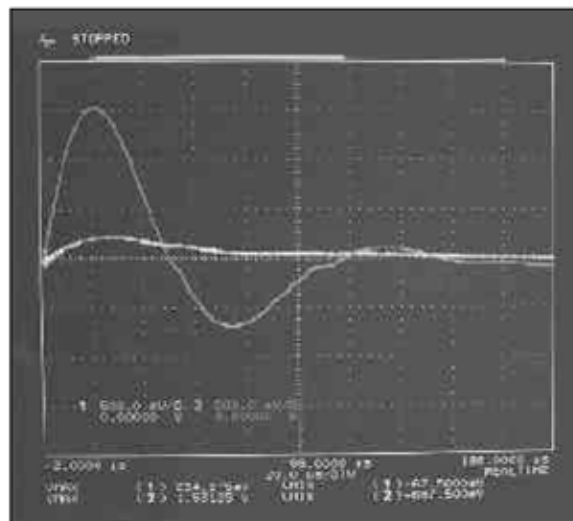


Figure 1



The above pulse was used on a 50' long, 7/8" coax feeder. One end was shorted to simulate a shunt-fed antenna, while the other end went to separate 0.001 Ohm current viewing resistors.

We should not be surprised by the above results. After all, even the manufacturer calls coax “unbalanced cable!” The current rise time at the top of a feeder coax attached to a tower would be much faster, perhaps 1 or 2 μ s during a lightning strike. The differentials between shield and center conductor with a faster pulse rise time would be much higher. Since lightning frequency pulses travel through both the different impedances of shield and center conductor, the larger circumference shield will have lower inductance, therefore a faster current rise time than the center conductor. Since the pulses arrive through different impedances, a differential voltage would occur across the shield and exterminated center conductor.

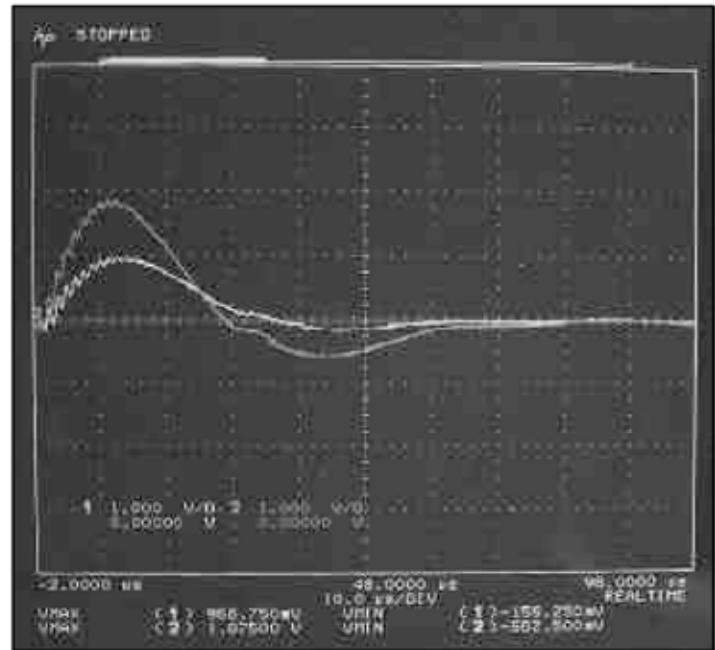
In the first example, using a 50-foot length of feeder coaxial cable, the positive peak differential between the center conductor and shield currents was 1297 Amperes, and the negative peak differential was 625 Amperes. If terminated to a capacitively coupled circuit (high impedance at lightning frequencies), the center conductor voltage would quickly rise and “arc through” the equipment input back to shield potential. If terminated in an inductively coupled circuit (low impedance at lightning frequencies), current flow on the center conductor would continue through the inductive coupling “loop” back to shield potential. High peak current flow through the input circuit could destroy the input connector, the coupling “loop,” and continue through to the next stage(s). Obviously, this pulse differential must be equalized and prevented from entering the equipment!

A coax cable center pin protector could be considered a very fast voltage sensitive (gas tube) or frequency discriminate (filter) switch. When a given threshold voltage is exceeded for a gas tube type protector, the protector “switches” the energy from the center conductor to the shield (ground). When a filter type protector sees the lower lightning frequencies (out of its pass band), it directs them to the shield (ground). In both cases equalization occurs between the center conductor and the shield.

DC Continuity Arrestors Share Lightning Surge With Equipment

Lightning arrestors with dc continuity, such as an air gap, simple gas tubes, and 1/4 wave shorted stubs, cannot divert this strike voltage differential without sharing some of it with the equipment. This “sharing” for dc continuity coaxial gas tube arrestors occurs during the time period between zero volts and when the threshold for turn-on has been achieved. Expect a short, high-voltage “spike” to occur at the output before the gas in the tube has time to ionize and become conductive (a short duration 700 to 1kV peak occurs with a 3kA, 8/20 μ s waveform test pulse, and the arrestor output connected to a 50 ohm load. See Figure 3). This high peak voltage goes to the equipment causing arcing, degrading capacitive inputs, or creating damaging current flow in shunted inputs.

Figure 2



A six-foot-long 1/2-inch coaxial jumper cable with the same pulse applied as in Figure 1.

For 1/4 wave shorted stubs, from 2GHz and down, the inductance of the stub will still allow considerable voltage to be presented to the equipment input. (+6Vpeak, -2Vpeak ringing for the entire test pulse waveform measured for a 1900MHz 1/4 wave stub with a 3kA 8/20 s test waveform and the stub output terminated to a 50 Ohm load. See Figure 4.) This is due to its inherent $L di/dt$ inductive voltage drop, along with perhaps making the on-frequency antenna ringing voltages greater, because of its own high Q ringing. A higher peak voltage will be present if the equipment has internal capacitive coupling to the center conductor of the coax line. If it doesn't, (e.g., a shunt-fed repeater duplexer) the lower frequency voltages are immediately converted to a current. In this case, dc continuity type arrestors would be relatively useless in stopping the surge current since the gas tube arrestor would not turn on in time and the 1/4 wave stub would share surge current with the equipment.

DC Blocking Is The Answer

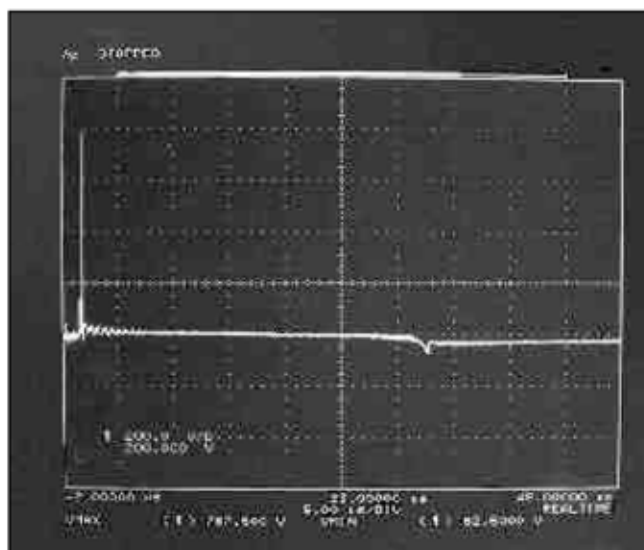
PolyPhaser's dc blocked filter type arrestors (see Figure 5), when tested with the same pulse in the same configuration as described above, will typically let through less than 500 milli-volts peak for less than 10 nanoseconds!

Insert photo 53.

Surges Damage Duplexers And Isolators

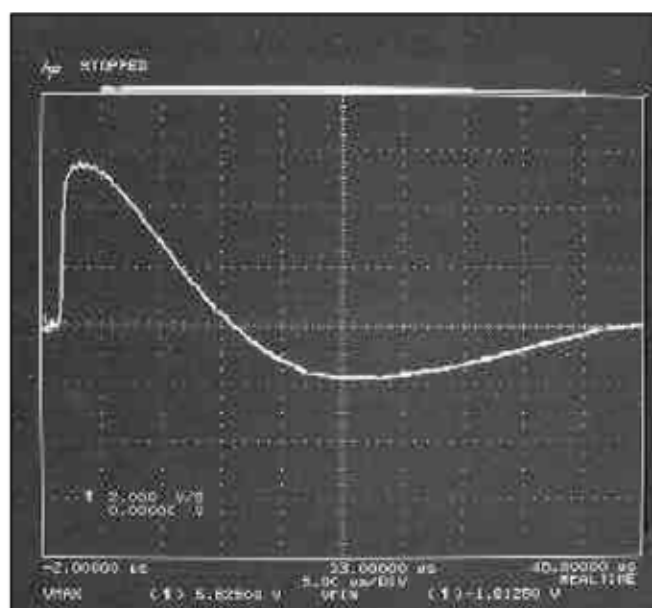
Not all duplexers have shunt feeds, but those that do can handle some of the lower frequency lightning surge current if properly grounded. It depends on the length of the cavity (frequency band), the size of the shunt-fed loop and its rigidity. (It is really best to prevent the lightning energy from ever entering the equipment building, let alone the equipment itself.) Large magnetic fields can be generated in the duplexer that can bend the loop, de-tune the cavity, and allow even stronger magnetic fields to exist in subsequent strikes. The strike can also weld the cavity input connectors together so the coax line cannot be removed. The "on-frequency" antenna ringing can create large voltages inside the cavities and

Figure 3



Non dc blocked gas tube protector. Observe 788 Volt peak pulse before gas can ionize and become conductive. This voltage could be applied directly to the equipment input.

Figure 4



Quarter wave stub. Much lower peak to peak voltage than gas tube (8 Volts peak to peak), but much longer duration. Total energy delivered to equipment input dependent on strike event duration.

cause internal arcing. If the first piece of equipment seen by the incoming low-frequency coax surge is an isolator, with each strike (if it survives) a gradual increase in insertion loss will occur due to the surge current's magnetic field re-orienting the isolator's magnetic field, and/or changing the magnet's flux density.

The Best Protector

The most effective type of lightning arrester is "dc blocked." There is no center conductor continuity from connector pin to pin. This internal capacitive coupling prevents the sharing of low-frequency surge current with equipment and limits the throughput energy to an amount that can be coupled only by the electrostatic field in the capacitor. This allows the dc blocked gas tube type "Impulse Suppressor" to fire as the voltage reaches the turn-on threshold.

PolyPhaser has given considerable attention to the gas tube design to insure that, when transmitting, the RF power will not keep alive the gas in the tube after a strike. Many other protectors, even those licensed by our patent, use a type of gas tube that will not extinguish properly. The transmitted energy continues to excite the tube which becomes a broadband noise generator and will burn up unless transmit power ceases.

Some arrestors use an internal grounding coil designed to drain any coax voltage build-up. (There would not be any, if a dc grounded antenna were used.) The coil is in parallel with the gas tube and does not help filter higher frequency components like antenna ringing, etc. This type of design uses a simple gas tube and has the gas tube extinguishing problem.

An additional problem of this design is the coil, which has added insertion losses, resonances and is wound on a ferrite torrodial core. When a hit occurs, the coil's magnetic field orients the domains of the ferrite core and degrades the inductance value of the coil, causing further RF losses with each successive hit. (Over 90% of the strikes are of the same polarity, so the effects of repeated hits are cumulative to the ferrite core.) PolyPhaser uses only air core coils where they are required. The coils carry a very small inductance and create a low L di/dt voltage drop.

If a grounded antenna can't be used and voltage does build up, it will not get to the equipment. As the protector reaches threshold for turn-on in a dc blocked circuit, it will go into a momentary soft turn-on as the gas barely ionizes and bleeds the static charge to ground. This does not create noise since it will not get to the arc mode and lasts only a short time.

Have it both ways! A dc blocked rf path, with isolated and protected low-voltage injector, pick-off, or pass-through ac/dc for tower top powered devices. A series of protectors designed for receive only from 50 MHz up and power handling transmit/ receive protectors from 800 MHz up are available. This could be a "bias T" replacement that includes rf and dc protection.

Filter Type Protectors. A laser-cut spiral inductor on the surge side effectively grounds the dc and low-frequency lightning components, while allowing the desired frequency range to pass through a flat plate series capacitor to the equipment side (dc blocked, low "Q", wide band pass). Product frequency ranges (at this writing) are from 800 MHz to 6 GHz, with ranges and bandwidths designated by model number.

Intermediation. Careful attention should be paid to intermodulation distortion specifications on all coaxial products due to increased equipment densities and closer frequency assignments at Cellular and PCS sites. Peak power requirements are considered to assure adequate "headroom" for digital modulation techniques.

Intermodulation problems due to non-linearity have always been a problem. With increasing demand for mobile communications, the need for greater channel capacity and more sensitive receivers has made Passive Intermodulation Distortion (PIM) more of a problem than ever. There are many causes of PIM in a communications system. One that directly affects coaxial protector products are connectors and connections to them. The following list was compiled from several articles on PIM:

- Restrict connector materials to copper and copper alloys.
- Connector body plating of silver or white bronze with a minimum plating thickness of 6m m (0.0002”).
- Avoid use of stainless, nickel, or ferrite in signal path. Use gold center pins.
- Quality machining - minimum finish of .4mm.
- Properly designed interface at connection 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.

Lightning Surge Current Ratings. Surge current ratings on coax lightning protectors are like horsepower ratings for cars. Is more better? Some manufacturers point to a 50kA rating and say the protector will take 50+ strikes at 50 kA before failure. Although this is interesting, you might also ask how much energy (with a 50 kA strike) does the protector let through to your equipment? The standard test for any coax protector is a 3kA 8/20 microsecond waveform pulse (other standard pulses are being introduced such as a 10/350 or 10/1000), with the output connector terminated in to a 50 Ohm resistive load. The let through energy is calculated from the integrated peak voltage and pulse width.

Since the purpose of any coax protector is to equalize the center conductor potential with the shield potential minimizing current flow through the equipment input, how much lightning current will actually be on the center conductor of your coax line? To answer this often-asked question, we need to determine two things:

- How much current is available?
- Into how many paths will the current divide as it travels toward earth ground?

The total current available from a direct strike is a given amount. Typically, the current will be below 65kA, a 50% occurrence strike will have 18kA, and only 10% will have more than 65kA. We will use the 65kA figure for this discussion.

For a tower with one antenna and coax line, the amount of current delivered to the master ground bar (MGB) or bulkhead is a function of where the line leaves the tower and the length of the run to the MGB. The higher the grounding kit is on the tower and the closer the MGB and cable entrance is to the tower, the more current will travel toward the equipment. It is all a matter of inductance. If more than one coax line is on the tower, the inductance path between the tower and the equipment will be less (inductances in parallel divide) and therefore, the strike current to the equipment will increase. Even though the total strike current to all the equipment is increased, the amount on each coax line will be less (divided). In general:

- The more coax lines there are, the more the current is divided and the less there will be on any given line.
- The lower the coax is grounded to the tower, the less shield current there will be on each coax line.
- The lower the inductance path to ground from the MGB or bulkhead, the less shield current will enter the building.
- The farther the tower is spaced from the MGB/ building entrance, the more inductance the coax line(s) will have, and the less current will be on the line(s). We do not recommend adding loops to increase inductance. They can couple more energy like a transformer (depending on orientation to the tower) instead of reducing it.

The total strike current will first be divided between tower (lowest inductance) and all coax cables. Current on each coax will be divided between the shield and the center conductor. The shield has a much larger surface area, therefore less inductance, so the higher frequency components of the strike will easily travel on it. This means the shield will have a higher peak current with a shorter duration while the smaller and more inductive center conductor will have less current but longer duration.

Typically, the center conductor will have less than half the total peak current. This means that when calculated, the typical center conductor surge on a coax cable is not 40kA, not 20kA, and not even 10kA. For only one coax cable and a 65kA strike (10% occurrence hit), a worst-case center conductor peak current value would be less than 7.5kA. For a cell site with nine (9) same-size coax cables, the center conductor peak current would be less than 850A each! The amount of strike current on the center conductor will have a slower rise time and lower peak current. This is important to know since 1/4 wave stubs or other dc coupled protectors, with a dc path on the center pin, will share this strike current with the equipment input.

A throughput energy rating, in Joules with a standard wave shape, is a much better way of evaluating the performance of a lightning arrester than knowing how many tens of thousands of amps is required to blow it up!

High Frequency Ringing

Antenna and 1/4 Wave Stub. If your antenna is hit or if a strike is close to the tower, the voltage rise times at the strike attachment point can be on the order of 20 to 50ns. This can cause antenna “ringing” since the antenna is a tuned circuit. Once this happens, the ringing will propagate down the coax line on top of the low-frequency energy going toward the protector.

A 1/4 wave stub will not reduce this on-frequency ringing and could increase the voltage since it too is a narrow band tuned circuit. In order to see this ringing, one needs a scope with a bandwidth large enough to cover the operating frequency. Many 1/4 wave stub manufacturers use 100 mega sample/ second scopes while looking at a 900MHz device and don't show the whole picture. Observations made, using

a 4 gigasample/second scope, with a 1.1GHz bandwidth, show the ringing effects of cellular antennas when they are hit and have produced the same ringing effects in 1/4 wave stubs.

The PolyPhaser filter series protectors are a low Q wide band pass tuned circuit and not as likely to ring as filters with a narrow band pass high Q tuned circuit.

Secondary Effects. Since the shield also has a dc path to your equipment, the farther away the coaxial protector is from the equipment, the more likely it is to re-introduce the differential on the coax line. The coupling of the shield and center pin is what caused the differential initially. If the distance from the protector (on your single point ground) and the input on the equipment rack exceeds approximately 20 feet, another center pin protector should be mounted to the single point ground connection at the equipment rack.

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

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