By Ron Block, KB2UYT

Lightning Protection for the Amateur Radio Station

Part 2—Last month, the author discussed the characteristics of lightning and the hazard it presents to the amateur, and presented a method of preparing a schematic of a protection plan. This installment shows us the type of protection to apply and how to design the protective installation.

The process described in Part 1 of identifying the equipment to be protected can be applied to any item or set of electronic equipment. With some adjustment, it can be applied to tower-top electronics such as preamps or power amplifiers, to a computer installation in another room, a TV or a stereo system. The principle is the same: identify all of the electrically and proximally connected equipment, identify all of the I/O (input/output) lines, add protectors and ground. The theory is easy; it's the implementation that can be challenging.

Protecting Each I/O Line

Let's examine each of the I/O lines identified in the box-level schematic, dividing them into broad categories for discussion. Each I/O line represents a potential source or sink (ground) for lightning strike energy, either directly from Mother Nature or indirectly via a connecting wire or arc. We must provide a protector that is physically and electrically appropriate for the type of I/O line we are protecting. The protector has a relatively simple job to do—short circuit when threatened (over voltage). While this may seem like a relatively simple thing to do, it is surprisingly difficult to accomplish without first sharing much of the strike energy with your equipment. This is especially important for receivers with sensitive FET front-end stages and electronic interfaces (RS-232, 422, and so on) where the maximum tolerable interface voltage is just a few volts above the operating voltage.

The best I/O line protectors are connected in series between the surge and the circuit they are intended to protect. Series protectors, by design, have the capability to limit the amount of lightning strike energy your equipment will receive. The "better manufacturers" will specify the maximum amount of "let-through energy" your equipment will receive during a strike. It is normally specified as a quantity of energy in the milli- or microjoule range. When choosing a protector, select the one with the least let-through energy that meets all of the requirements for the connection.

Coaxial Cable

The first category of protector we will examine is the coaxial cable line protector. Coaxial protectors are unique in that they should not add to system SWR or signal loss, and at the same time they need to operate over a very broad frequency range at both receive and transmit power levels.

Each coax line leaving the circle around the protected equipment must have an appropriate coaxial protector. As we will discuss later, the coax protector along with all of the other I/O protectors must be mounted on a common plate (or panel) and connected to an external ground system.

Two typical PolyPhaser protectors for Amateur Radio use below 1 GHz are shown in Figure 7. While both of these protectors are shown with UHF-female connectors on both the antenna and equipment sides of the protector, type N connectors are available, as are combinations of male and female connectors. Please note, however, that there are other manufacturers of quality lightning-protection products. See the "Resources" sidebar at the end of this article.

Special coaxial protectors to protect I/O lines for GPS, DBS, broadcast and cable TV are available, as well as those for tower-top amplifiers and remote antenna switches that require an ac or dc voltage fed through the feed line. All protectors come with the appropriate type of connector commonly used for these applications.

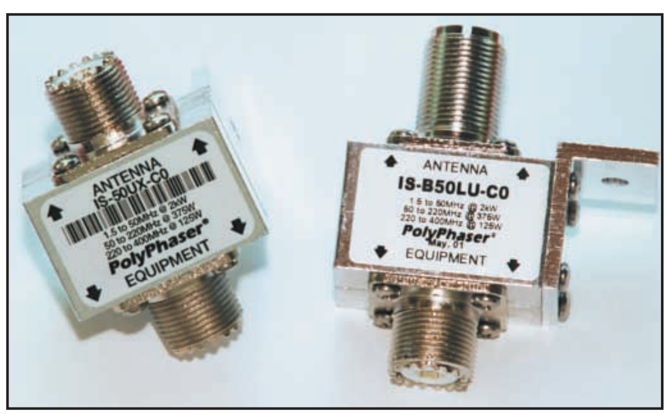

Figure 7—Typical coax protectors, the PolyPhaser IS-50UX and IS-B50LU.

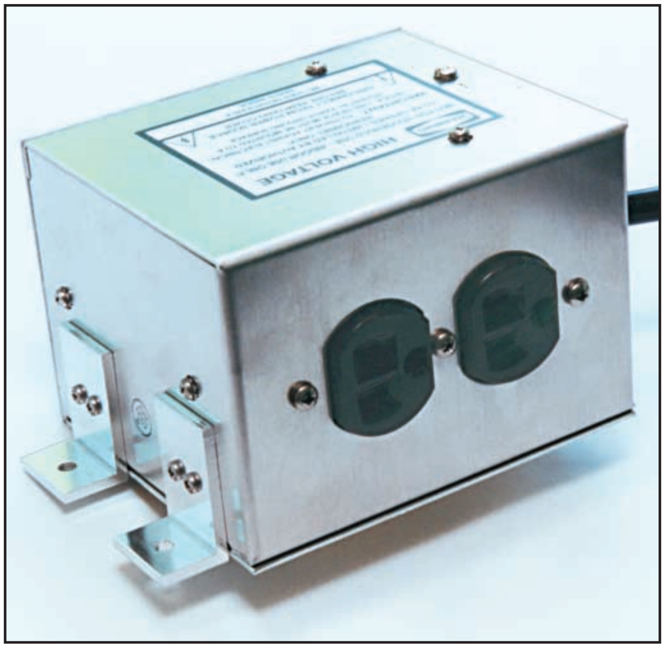

Figure 8—An in-line ac power protector.

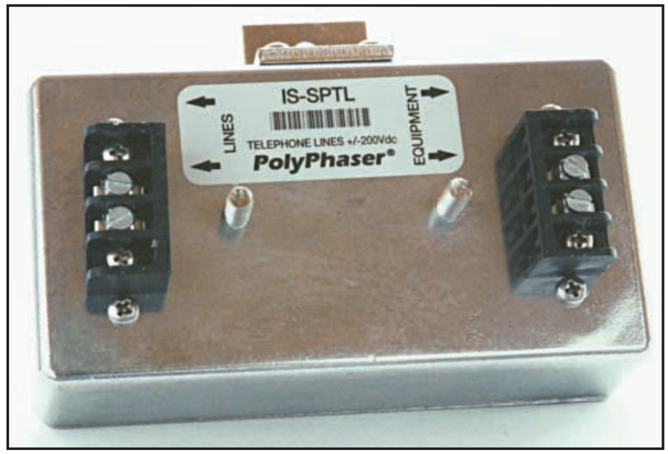

Figure 9—A telephone line protector.

Open-Wire or Ladder Line

Although protecting an open-wire or ladder line is not as convenient as with a coax line, some protection is warranted and possible. Select two identical gas tube protectors and connect them from each leg of the feed line to ground near the entrance point. Each gas tube should be specified as capable of handling an instantaneous peak current of approximately 50,000 A based on the 8/20 µS IEEE standard test waveform and have a turn-on voltage that is well above the normal transmission line operating voltage. Be sure to consider the highest SWR and the highest transmit power in your calculations. Typical turn-on voltages range from 600 to 1200 V. The voltage chosen should be about twice the calculated voltage to minimize the potential for the accidental firing of the gas tubes during tune-up or other transmitter anomalies.

Keep in mind that the application of the gas tubes to the open-wire or ladder line represents a shunt-type connection, as opposed to the coaxial protectors, which are an in-line connection. That means that the transmission line will share a significant amount of lightning strike energy with your equipment before the gas tubes begin to conduct. Unfortunately, this type of transmission line makes it difficult to achieve a high level of confidence in protecting high performance receivers.

AC Power

AC power protectors are available in many shapes, capabilities, and method of connection. Some caution should to be exercised in choosing your protector. There are many rather inexpensive power line protectors on the market that are clearly not suitable lightning protection. Many of these protectors depend on the safety ground wire to carry away the surge energy. While the safety ground may provide a dc path to ground, the #14 AWG wire commonly used is too inductive with respect to the rise time of the currents (RF energy) in the strike that it must conduct to ground. In addition, some low-end manufacturers who do provide in-line ac protectors use ferrite core inductors to maintain a small sleek physical appearance.

While this approach works well when the protection is merely handling power line noise, the inductor saturates under the massive current of a real strike and the benefit of the inductance disappears. Plastic housings and printed circuit boards should be avoided where possible since they will most likely not hold up under real strike conditions when you need it.

Since you are establishing a local zone of protection for the radio room you need to choose an in-line ac power protector, as shown in Figure 8, that matches your voltage and current requirements. For most small to medium size stations, a single 120 V ac protector with a capability of 15 or 20 A will satisfy all of our ac power needs. Each of the electronic items with an ac power line extending beyond the circle should be aggregated into a single line as long as it is comfortably within the maximum amperage of the selected protector (usually 15 or 20 A). Larger stations with high-power amplifiers or transmitter will most likely have a separate 120 V ac or 240 V ac power circuit that will require a separate ac power protector. Some high-end stations may require 100 A or 200 A in-line protectors.

If station ac is sent outside for convenience, for safety lighting, or to run motors (not the common antenna rotator), then that ac circuit must be separately protected as it leaves the radio room.

Telephone

Telephone lines come in many types, but by far the most common is the plain old telephone service (POTS). This is a balanced line with a –48 V dc battery talk circuit and up to 140 V ac ringing voltage. An in-line protector is the most effective type for POTS with different types of protectors available for different telephone line characteristics. One device for this purpose is shown in Figure 9.

A word of caution—many of the protectors on the market use modular connectors (RJ-11, -12, -45). While this is a great convenience for the installer, electrically this is a very fragile connector and common amounts of surge energy are very likely to destroy the connector by welding it or fusing it open. In addition, there are also issues of flammable plastic housings, ground wire characteristics, and printed circuit boards that allow arcs to the equipment side.

Control Circuits

Control circuits for all external devices must be protected, especially those that are tower-mounted. In the amateur station, this usually consists of an antenna rotator. Since most of the control circuitry managing the antenna rotator is relay-based (as opposed to electronic), we can use a less expensive shunt type protection device, such as that shown in Figure 10.

There are some new rotators on the market that use optical encoders and a modestly protected digital interface. These must

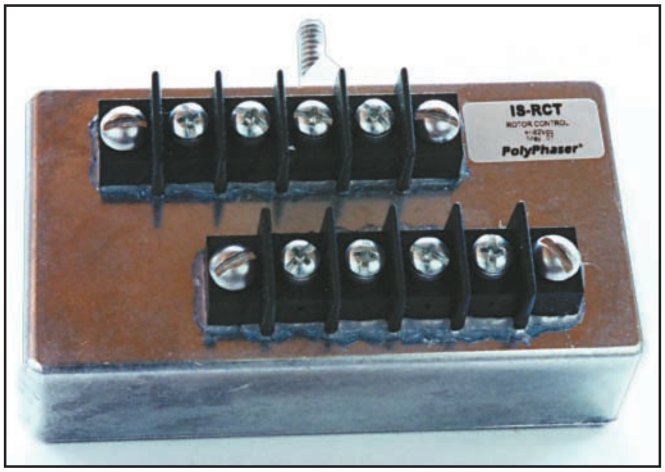

Figure 10—This shunt-type device is capable of protecting up to eight circuit lines with an operating voltage of up to 82 V dc.

also be protected. The method of protection will change, however, since the interface is electronic. Once the peak operating interface voltages are determined, it is relatively straightforward to choose the appropriate inline protector for the individual conductors.

Miscellaneous

Depending on the equipment in the radio room there may be additional I/O lines remaining to be covered. While I'll address a few of the more common ones, the others will probably require some special attention based on the physical conditions of the site.

Ethernet network cable connections linking the amateur station to the outside world or the computer in another room must also be protected as apart of the protection plan. For 10 and 100 Mbit UTP (unshielded twisted pair) networks, the use of an ITW LINX protector for Cat5-LAN (four pair) cable is recommended. This protector is wired in series with the network using 110-type punch-down blocks and grounded similarly to other protectors.

For those radio rooms that have broadcast or cable TV, protection is similar to the coaxial protectors described above with the exception that the impedance of the unit is 75 Ω and F-type connectors are used.

For single and dual-LNB DBS dishes the protector is required to have a very broad band-pass and pass dc through the coax center conductor.

GPS feed lines also are commonly required to carry a dc voltage. A high quality protector will separate the RF from the dc and protect each to its own voltage and power specification.

I/O Wrap-up

Every line that penetrates the circle and goes to the edge of the page should now have an identified protector. If you are having trouble, identify the problem area and mail the drawing to the author. The ARRL staff has compiled a list of potential sources of lightning-protection products. See the "Resources" sidebar at the end of this article.

Single Point Ground

The next step in the process will take us away from the theoretical work that we have been doing and into the real world of practical design and component layout. It's not hard, but there are a lot of things to consider as we take each step. Most of the considerations will be unique to the physical circumstances associated with your radio room.

I mentioned earlier that the primary purpose of the protector is relatively simple—to short-circuit when threatened. By shorting all of the wires associated with an interface no current can flow through the equipment between the wires of the interface. Extending this premise further, by mounting all of the protectors in common, no current will flow between the I/O interfaces. Hence, no lightning surge current will flow *through* a protected piece of electronic equipment.

To make this possible in the radio room it is necessary to establish what is known as a "Single Point Ground." This is the *one and only point* in the radio room where a ground connection is present. We need to be a little careful with the term "ground." During a strike a ground can be anything that is capable of being an energy sink. By this definition absolutely anything that is not at the same electrical potential can be a sink. Because electrical signals travel at about 1 nanosecond per foot, fast rise times may create significant potential differences for short times due to travel differences.

The creation of a single point ground will be different for every installation. It can be as simple as a couple of protectors bolted together or a through-wall entrance panel, or as complex as a copper-covered wall upon which the protectors are mounted. Whatever form your single point ground takes it must be the only ground point for all of the equipment within the circle of the box-level schematic diagram.

Figure 11 shows a single-point ground panel. This is a high-density fiberboard-backed copper panel suitable for small to medium radio rooms. It comes with a 1½ inch wide copper strap to connect the panel to the external ground system and a second 1½ inch copper strap to connect to all your operating table equipment. The panel is intended to be mounted on a wall near the radio equipment. For convenience of reference, I'll use its abbreviation—SPGP, for Single Point Ground Panel.

Now that you have a mounting surface that will become the single-point ground, a *lot* of consideration must be given to the physical placement of the protectors on the SPGP. Remember that a protector is required for each I/O line that leaves the circle of the box-level schematic. As you examine a protector, most are labeled with respect to which connector faces the surge (the outside world) and which connector faces your equipment. This is important, since the protectors are not necessarily symmetric in their design. They cannot be reversed and be expected to function properly.

A significant factor in the layout of the protectors on the SPGP is maintaining a physical separation between the incoming unprotected cables (antenna feed lines, incoming ac power, rotator lines, etc) and the protected side of the same connections. As a result of going through an in-line protector, there will be a "spark-gap level" voltage difference for a short time between

Figure 11—A typical single-point ground panel.

the input and output sides of the protector. You must take this into consideration when planning the layout of the SPGP.

A general guideline is to draw an imaginary diagonal line near the center of the panel as shown in Figure 12. Designate the area above the line as protected and the area below the line as unprotected (or vice versa). Make sure you consider how the panel will be mounted; how the (unprotected) cables will enter the unprotected area and how the (protected) cables will leave the panel. One of the nice things about a two-dimensional drawing is that the effects of gravity do not show. In Figure 12, the cables leaving the panel to the right above the dotted line must be anchored. If they are not, real world gravity will cause them to eventually bend down and come close to, and maybe even touch, the unprotected cables. If this happens, during the strike event there is the potential for a spark-gap breach of the protectors between the cables—a failure of the protection plan.

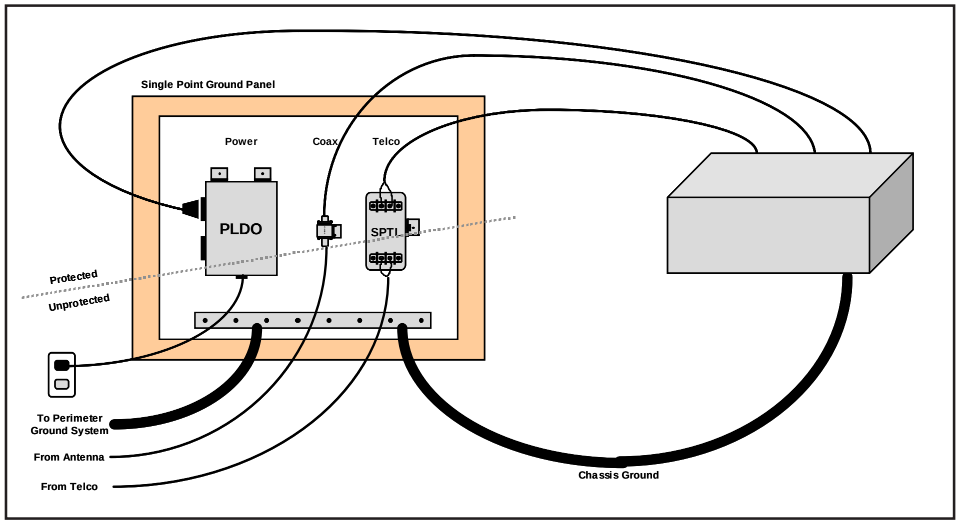

Figure 12—The SPGP showing the division of the protected and unprotected cables.

Neatness counts—cables (transmission lines, power (ac and dc), speaker, microphone, computer, control) should be cut to length and routed neatly and cleanly between boxes using the most direct practical route. The coiling of excess cable length on the protected side should be avoided since it can act as an air-wound transformer coupling magnetic energy from a nearby lightning strike back into the protected equipment.

The chassis ground for each element of radio equipment must also be connected to the SPGP. The SPGP is our reference point during the strike event and it is important that all elements of the radio station be at the same potential at the same time (nanoseconds). For small to medium size stations, where all for the equipment fits on a desk/table top, a single interconnect copper bus or strap to the SPGP is usually sufficient.

For stations with freestanding cabinets or racks in addition to an operating desk, the issue of rise time becomes more significant due to distance. This necessitates separate cabinet/rack direct ground connections to the SPGP. In addition, stations of this size have other special considerations, such as concrete floor conductivity, that are not covered here.

Don't forget to allow for future growth of your station in the SPGP layout. Typically this means leaving room for an additional feed line protector or two and maybe a rotator control protector. It is easier to plan for expansion now, rather than have to rearrange the protectors on the panel later.

If the form of SPGP you have chosen is a metal plate mounted in a window or a full-fledged through-wall entrance panel, you can ignore the remainder of this paragraph. The next major consideration is the placement of the SPGP with relation to the radio equipment. The SPGP is ideally mounted on the inside of an exterior wall with access to an earth ground and within a few feet of the radio equipment. That sounds easy, but depending on your radio room, it may be next to impossible. Let's work it through.

These real-world constraints sometimes present real challenges. One of the biggest challenges is grounding the SPGP. A #6 AWG wire to a radiator or water pipe is usually *not* acceptable! I say "usually" because if your radio room is on the top of a high-rise building, that may be all that you have. I'll discuss the real requirements and address this type of problem later.

The purpose of the ground connection is to take the energy arriving on the antenna feed line cables and control lines (and to a lesser extent on the power and telephone lines) and give it a path back to the earth, our energy sink. The impedance of the ground connection should be low so the energy prefers this path and is dispersed harmlessly. To achieve a low impedance the ground connection needs to be short (distance), straight, and wide.

Short

We all know that a conductor, no matter what size or shape, has inductance that increases with length. Connecting the SPGP to the external ground system should be done with the shortest possible wire. Did I say wire? Be sure to read about "wide."

Straight

Rarely is it possible, in the context of an Amateur Radio station (unless the structure was designed around the radio station), to go directly from the SPGP to the external ground system in a short, straight line. Most of the time we are encumbered with an existing structure that is less than ideal and further encumbered with esthetic constraints regarding just how much of a mess we can make. So, we do the best we can. Straight becomes a relative concept. Run the ground wire (there's that word again) as straight as possible. Keep in mind that every time the wire makes a turn, the inductance of the path is increased a small amount; ~0.15 µH for a 90-degree turn in less than 1 inch. The cumulative effect of several turns could be meaningful. By the nature of its current (magnetic) fields, a wide wire (strap) has lower inductance per length, compared to round conductors, and has minimal inductance for turns.

Also keep in mind that speeding electric fields don't like to change direction. The inductance in each bend or turn represents a speed bump, causing a large change in the fields over a short distance. If the change is large enough, some of the electrons are likely to leave the wire and find another path to ground; that is, an arc. This is not desirable; we have lost control.

Wide

We all know that no matter what size, wire has inductance. Larger wire sizes have less inductance than the smaller sizes. We also know that RF energy travels near the surface of a wire as opposed to within the central core of the wire (skin effect). If we put these together and extend the hypothesis a little, it would seem reasonable to use a railroad rail-sized bus bar as an excellent connector between the SPGP and the earth ground.

While the large bus bar would work well, it has lots of surface area and a massive core, the cost would be prohibitively expensive and it would be extremely cumbersome to work. We can have the benefits of the large bus at a very reasonable cost if we use multi-inch-wide copper strap instead, however.

One and a half inch wide, #26 AWG (0.0159 inch) copper strap has less inductance than #4/0 AWG wire, not to mention that it is less expensive and much easier to work. We can use thin copper strap to conduct lightning surge energy safely because the energy pulse is of very short duration and the cross-sectional area of this strap is larger than #6 AWG wire. The strap has a large surface area that makes it ideal for conducting the strike's RF energy.

The goal is to make the ground path leading away from the SPGP more desirable than any other path. In order to achieve this we need to find the total amount of coax surface area coming to the SPGP from the antennas. The circumference of a single 9913 coaxial cable represents about 1.27 inches of incoming conductor surface. To make our ground path appealing to the surge energy, we ideally need more than 1.27 inches of conductor surface leaving the SPGP. Where the use of a single 1½ inch wide conductor leaving the panel is reasonable, a strap three or more inches wide would be better. Inductance is calculated on the length of the connection between the SPGP and the ground, as well as the number and sharpness of the turns. If you had three 7/8-inch Hardlines, a minimum strap width of 9 inches would be needed and 12 would be better.

You now have determined what protective devices are needed and how to mount them for an effective barrier to lightning energy. Next month, the final part of the article will present guidelines for developing a good external ground to absorb and dissipate the lightning's energy.

Photos of various PolyPhaser products by the author.

Ron Block, KB2UYT, has been a distributor and consultant for PolyPhaser, a vendor of lightning protection systems, since 1989 and has completed The Lightning Protection Course *by PolyPhaser. He is the chairman of the* Amateur Radio Station Grounding *forum at the Dayton Hamvention and has been a guest speaker at various Amateur Radio club meetings. The author's brother, Roger, founder of PolyPhaser, reviewed this article for technical accuracy.*

327 Barbara Dr,
Clarksboro, NJ 08020
ron@wrblock.com