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QST Articles
June 2002 Part 1
July 2002 Part 2
August 2002 Part 3

Lightning Protection for the Amateur Station

Part 1—Lightning protection can be a serious issue for amateurs. In the first of this three-part series, the author leads us through the process of developing a protection plan. Next: how to protect your equipment. The final part will cover the process of creating an effective ground system.

The Challenge

The amateur is challenged to assemble the best radio station possible, enjoy the benefits of the hobby, and have the station operable during times of need. This can be a significant challenge especially considering the awesome capabilities of Mother Nature's lightning strikes. While she may have the upper hand as far as when and how much energy she delivers, you have the ability to influence how that energy is diverted into the earth. Said another way, you can implement a lightning protection plan that will protect your Amateur Radio station, even from a direct strike!

The commercial radio folks have done this for years; many of them have critical installations located on hills or mountaintops that are great lightning strike targets. They do survive direct strikes and continue to provide important services to the communities that they serve. While this type of solution is possible for the Amateur Radio station, it does cost money and it does take a significant amount of resourcefulness, ingenuity, and effort to implement and maintain.

The plan does work; *but* you must follow all of the rules—exactly. Any violation of the rules, even just a little one, may result in a violation of the protection plan and damage to your equipment. In some cases the damage to a semi-protected radio station could be worse than if no protection plan had been implemented at all. I'll start with some background.

Lightning Characteristics

The conditions necessary for an old-fashioned summer afternoon thunderstorm are lots of moist air from ground level to a few thousand feet, cooler air above with little to no wind, and plenty of sun to heat the air mass near the ground. As the warm, moist air is heated, it rises quickly to heights where the temperature is below freezing, eventually forming a thundercloud as shown in Figure 1. Within the thundercloud, the constant collisions among ice particles driven by the rising air causes a static charge to build up. Eventually the static charge becomes sufficiently large to cause the electrical breakdown of the air—a lightning strike.

The average thunderstorm is approximately six miles wide and travels at approximately 25 mph. The anvil shape of the cloud is due to a combination of thermal layer (tropopause) and upper high velocity winds that cause the top of the cloud to mushroom and be pushed forward. The area of imminent danger is the area up to 10 miles in front of the leading edge of the cloud.

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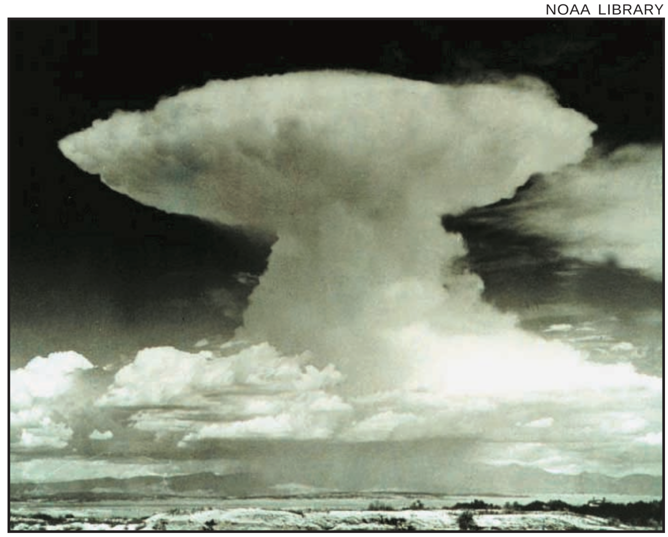

Figure 1—A typical convective thunderhead.

When a lightning strike does occur, the return stroke rapidly deposits several large pulses of energy along the leader channel. That channel is heated by the energy to above 50,000°F in only a microsecond and hence has no time to expand while it is being heated, creating extremely high pressure. The high pressure channel rapidly expands into the surrounding air and compresses it. This disturbance of the air propagates outward in all directions. For the first 10 yards or so it propagates as a shock wave (faster than the speed of sound) and after that as an ordinary sound wave—the thunder we hear.

During a lightning strike your equipment is subjected to several huge impulses of energy. The majority of the energy is pulsed dc with a substantial amount of RF energy created by the fast rise time of the pulses. A typical lightning strike rise time is 1.8 µS. That translates into a radiated RF signal at 139 kHz. Rise times can vary from a very fast 0.25 µS to a very slow 12 µS, yielding an RF range from 1 MHz down to 20 kHz. However, the attachment point for a direct lightning strike has a time as fast as 10 nS. This RF content of the strike

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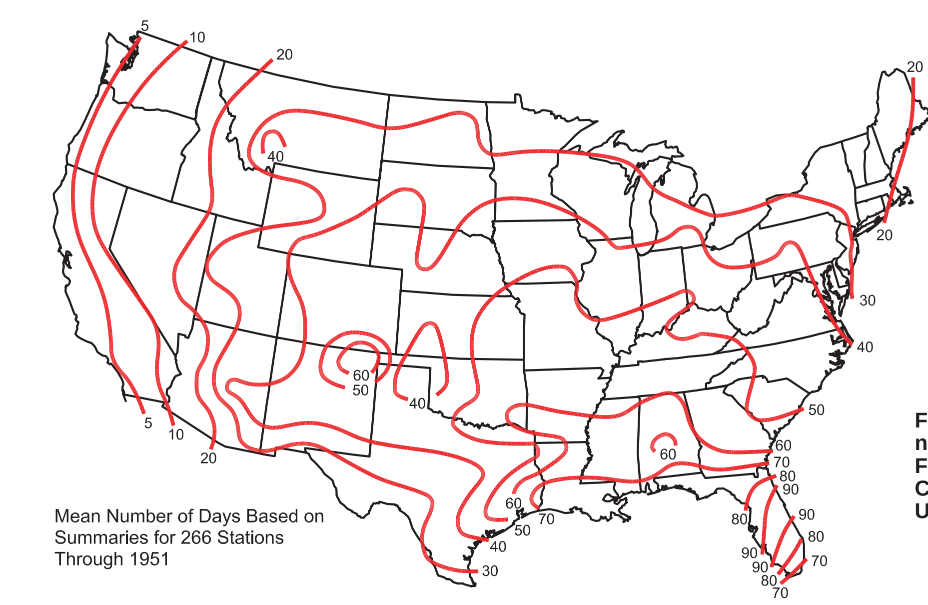

Figure 2—This map shows the average number of thunderstorm days per year. From Technical Paper No. 19, Climatological Services Division, US Weather Bureau, 1952.

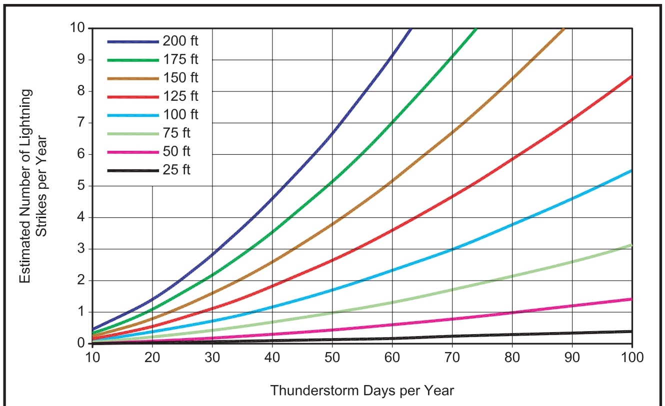

Figure 3—Estimated number of lightning strikes per year based on the number of thunderstorm days in your area and the height of your antenna. Based on information from *Living with Lightning*, Seminar Notes #ECP-826B Version F, GE Mobile Radio Technical Training, © GE 1985.

will have a major effect on the design of the protection plan. In addition to the strike pulses, the antennas and feed lines form tuned circuits that will ring when the pulses hit. This is much like striking a tuning fork in that ringing is created from the lightning's pulsed energy.

Average peak current for the first strike is approximately 18 kA (98% of the strikes fall between 3 kA to 140 kA). For the second and subsequent impulses, the current will be about half the initial peak. Yes, there is usually more than one impulse. The reason that we perceive a lightning strike to flicker is that it is composed of an average 3 to 4 impulses per lightning strike. The typical interval between impulses is approximately 50 mS.

Vulnerability

Frequently, amateurs provide an inducement for Mother Nature to find us. For good long distance communications, we put our antennas on the top of towers and place the towers so that they protrude above the surrounding buildings or countryside. While this provides for great signal coverage, it also makes it easier for Mother Nature to find a shorter, conductive path to ground.

The probability of having your tower struck by lightning is governed primarily by where you are located and the height of the tower. In 1952, The Weather Bureau compiled a contour map of the US showing the mean number of thunderstorm-days that occur in a year shown in Figure 2. The counting criterion is relatively simple—a thunderstorm-day is one in which one or more claps of thunder are heard. This gives us a reasonable view of the country with respect to our exposure to lightning.

The other significant factor that affects the probability of being struck is the height of the tower above the average ground level. As you might suspect, the higher your tower, the higher the probability of being struck. Figure 3 shows the estimated number of times per year that a tower of a given height would be struck based on the number of thunderstorm-days in your area.

Now that you can estimate your approximate exposure, you might have one of several reactions. First, you could say the predictions are all wrong—personally, I have never had my 100-foot tower struck since I put it up two years ago. Maybe you are just lucky or the law of averages has yet to catch up with you. Another reaction you could have is, "Wow! This explains what has been happening and I had better do something about this right away."

In either case, this article shows what you need to do to protect both your life and equipment, broken into straightforward steps to maximize your probability of success. Every Amateur Radio station is different and there is no "one size fits all" solution. There are, however, some well grounded (pun intended) principles that must be followed. A failure to follow the principles will result in the expenditure of both time and money with no better protection (possibly even worse damage) than if you had done nothing at all. Please follow each step carefully, thinking about the principles involved, and carefully apply the information to your specific installation.

Identify What is to be Protected

The goal of the planning process is to establish a "zone of protection" within the radio room, as opposed to the whole house or building. Additional zones may be considered separately. The first step in the process is to identify what you want to protect. The immediate answer is, well, everything. While you can come close, you may run out of money, time, or energy. So let's create a priority list and work the list from

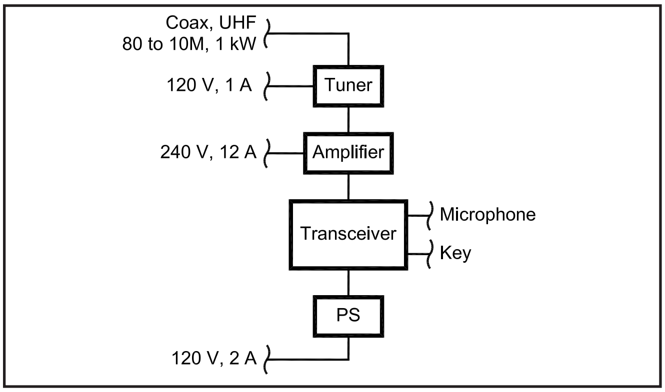

Figure 4—Block diagram of a typical simple HF radio station.

high to low priority. Probably first on the list are the more expensive items associated with your radio station, usually the transmitting and receiving equipment. Viewed another way, without these there is no radio station, so they should be very near the top of the list. What follows on the list depends on just how you enjoy the hobby—the antenna tuner, linear amplifier, terminal node controller, or computer. Further down the list might be the antenna, rotor and transmission line. Each person's list and priority ordering will be different. Pause here and mentally construct your priority list, being sure to include all the elements of your radio station. We will then work through the process of developing your protection plan.

The first step is to construct a complete block diagram of the equipment in your radio room starting with the top priority item. (You will make a separate plan for other areas needing protection.) This is usually simple and straightforward. In some installations it may be necessary to look behind the equipment to determine precisely the connections between each element. The accuracy of the diagram is important in determining the nature and effectiveness of the protection plan.

I would imagine that the list's top priority items are your transmitter and receiver (or transceiver). If you have multiples of either, then they are probably listed in order of value. These are the heart of your radio station, so make them the starting point of protection plan which will in turn examine and diagram each element of the station.

Assuming your primary item is a transceiver, represent it in the block diagram as a single rectangle. Label it with the manufacturer's name and model number. If your primary equipment is a transmitter/receiver pair, then represent them as individual single rectangles.

Next, think about the antenna connection to the primary transceiver, transmitter, or receiver. If the connection goes directly to the external antenna, simply draw a line from the rectangle to the edge of the paper. However, if the antenna is connected to the equipment via a linear amplifier, antenna tuner, or a multi-position coax switch, add this (these) as separate rectangle(s) interconnected with the primary radio equipment. The feed line going to the antenna should still go to the edge of the paper. Label the feed line's lowest and highest frequency (MHz or band name), the maximum transmit power in watts (rounded up), and the type of connector and gender (UHF/PL-259 male or N-series male, for example).

Add a rectangle to the diagram for each additional transceiver, transmitter, amplifier, and receivers in your radio room. Be sure to show all interconnections and antenna connections for each of these secondary rectangles. If any of the secondary radio equipment has a direct connection to an antenna, show the feed line going to the edge of the page. Be sure to label each rectangle with the manufacturer's name and model number and each feed line with connector type and gender, frequency range, and maximum transmit power. Figure 4 shows a block diagram for a simple station.

The block diagram should now have a rectangle representing each piece of radio equipment and accessories in the radio room. Each of the rectangles should have lines representing the interconnecting cables and feed lines. Each feed line that leaves the radio room and goes to an antenna or some tower-mounted electronics should be drawn to the edge of the page and labeled.

A Close Look

Now it is time to examine each of the rectangles, one at a time, and to add to the diagram any other electronic devices (as rectangles), complete with the electrical connections and interconnections between them. Some of these will be easy and intuitive, while others will require a little more crawling around behind the equipment. Every connection must be included—this is important to the integrity of the solution. The only exception is a non-conductive fiber-optic connection.

To complete the diagram in an orderly fashion, pick a rectangle and answer all of the following questions for that rectangle. Then, pick another rectangle and do the same until all of the rectangles have been examined.

Is there a connection between this rectangle and any other rectangle? If so, add a line between the respective rectangles and label its function.

Is there a connection between this rectangle and a device not yet included on the block diagram? This can include standalone amplifiers, power supplies, computers, terminal node controllers, modems, network routers, network hubs, and the like. If so, add the new device to the diagram as a rectangle and label it. Then add and label the connections. Repeat this step until all connections from this rectangle to new devices have been completed.

Is there an ac power connection required for this rectangle? If so, draw a line to the edge of the page and label it with the voltage and current required.

Is there a requirement to supply ac or dc power through a feed line to operate remote switches or electronics? If so, label the feed line at the edge of the page with the peak voltage and current requirements.

Are there control lines leaving the rectangle going to remote electronics, relays, or rotors? If so, draw a line to the edge of the page and label it appropriately.

Is there ac power leaving the rectangle going to the tower for safety lighting, convenience outlets, crank-up motors, or high-power rotors? If so, draw a line to the edge of the page and label it with the voltage and current required.

Is there a connection to a telephone line, ISDN telephone circuit, DSL telephone circuit, or cable connection (RF, video or data) for this rectangle? If so, draw a line to the edge of the page and label it appropriately.

Is there a connection to another antenna system such as for GPS, broadcast or cable TV, or DBS dish for this rectangle? If so, draw a line to the edge of the page and label it appropriately.

Is there a connection to other equipment elsewhere in the house or building, such or network or intercom cabling? If so, draw a line to the edge of the page and label it appropriately.

Once you have completed the process for each of the rectangles, including all of the new ones that were added, you should have an accurate block diagram of your radio station. It may be prudent to review each rectangle to verify that nothing was left out. Your block diagram should look something like Figure 5.

Now step back and physically look at the equipment in the radio room. Has every piece of equipment been reflected in

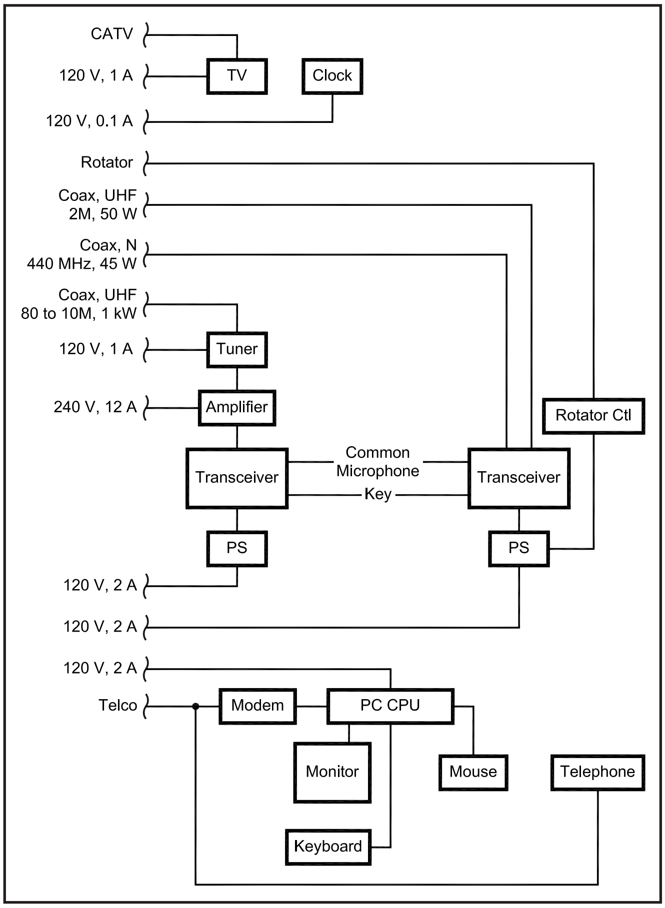

Figure 5—Block diagram of a typical more-complex radio station.

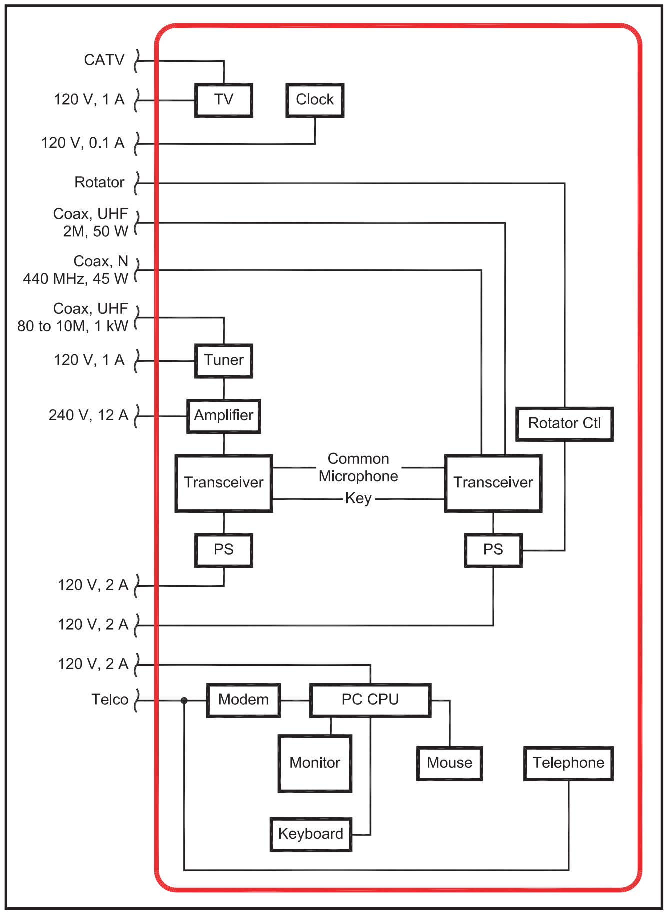

Figure 6—Lines that penetrate the circle are the radio station I/O circuits that must be protected.

the block diagram? Every metallic item within four feet (in all directions) of the radio equipment must be considered as a part of the radio equipment even if it is not electrically connected to it. If there is such an item that has not been included, we need to carefully examine it. An example of such a device could be a simple stand-alone telephone on the operating desk or a computer system (CPU, monitor, keyboard and mouse) some part of which is sitting on or near the radio desk.

Nearby devices (telephone and or computer), while electrically not a part of the radio station, are within a spark-gap of the radio station equipment and therefore considered proximally connected to the radio station and must be added to the block diagram. Follow the same procedure that you used to add equipment to the block diagram. As an example, Figure 5 also shows a computer that is included in the protection plan, but not directly connected to radio equipment.

Now that the diagram is accurate and complete, draw a circle around all of the rectangles allowing each of the lines that extend to the edge of the page to cross the circle as shown in Figure 6. The equipment represented by the rectangles within the circle is to be protected. All of the lines going from the circle to the edge of the page are called I/O (Input/Output) lines or circuits.

All or Nothing

One word of caution regarding the accuracy and attention to detail; the protection is all or nothing. If an I/O line is inadvertently missed then the protection plan is flawed and the damage could be worse than having no protection at all.

Please note: Just because equipment may survive a direct lightning strike, does not mean that you can. You *cannot* operate (touch) the equipment during a strike because *you* breach the protected equipment circle to the outside world. You are conductive, and it could hurt both you and your equipment.

Now that you have identified all of the I/O lines for the station, each must be protected and each of the I/O line protectors must be grounded and mounted in common. We will discuss how to do this in the next part of this article.

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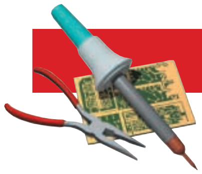
NEW PRODUCTS

TRI-BAND H-T ANTENNA FROM MALDOL

Designed to improve the performance of today's Amateur Radio hand-held transceivers that feature 220-MHz operation, Maldol's new MH-610 tri-band whip antenna covers 144, 220 and 444 MHz in a lightweight, durable package. The 14-inch whip is made from super-flex material—the stuff used in "unbreakable" eyeglass frames—and can withstand a tremendous amount of abuse.

Price: $49.95. For more information, see your favorite Amateur Radio products dealer or contact NCG at 1275 N Grove St, Anaheim, CA 92806; tel 800-962-2611, fax 714-630-7024, **www.natcommgroup.com**.



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.

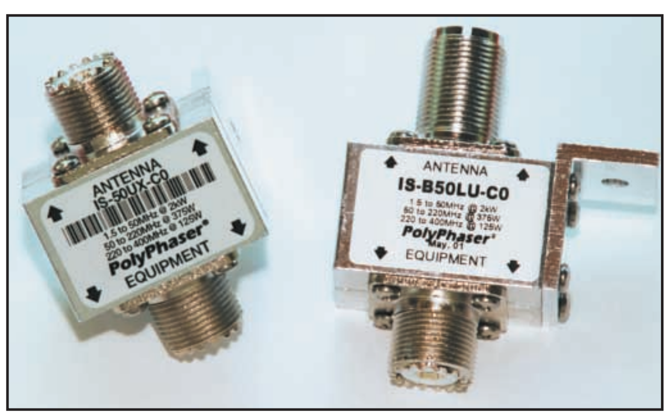


Figure 7—Typical coax protectors, the PolyPhaser IS-50UX and IS-B50LU.

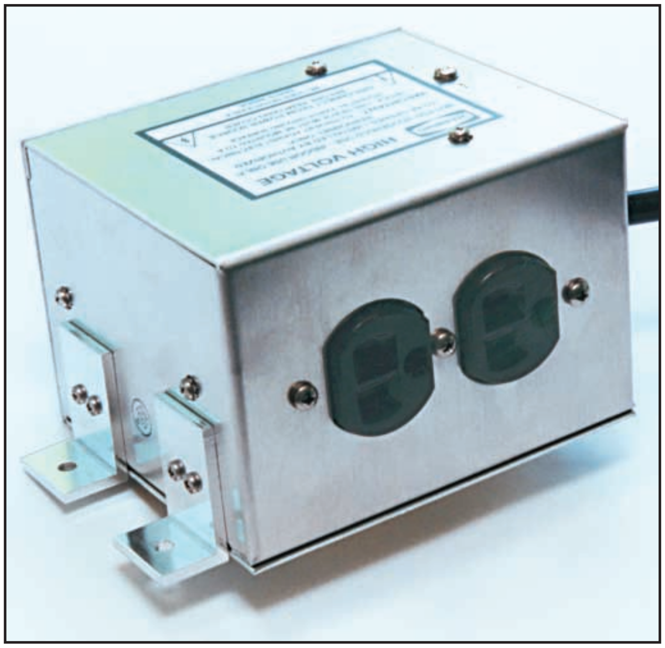


Figure 8—An in-line ac power protector.

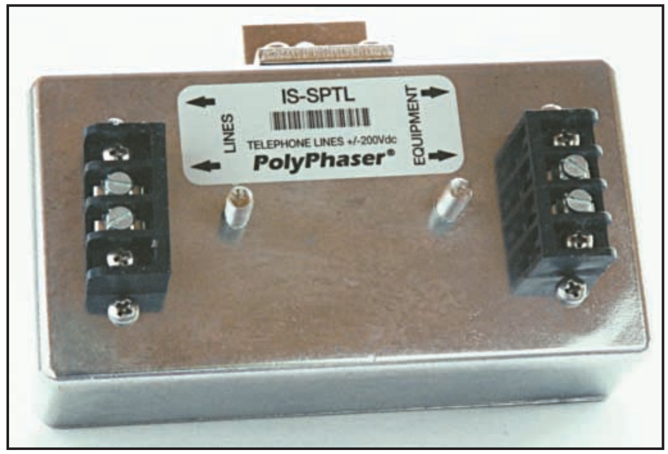


Figure 9—A telephone line protector.

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

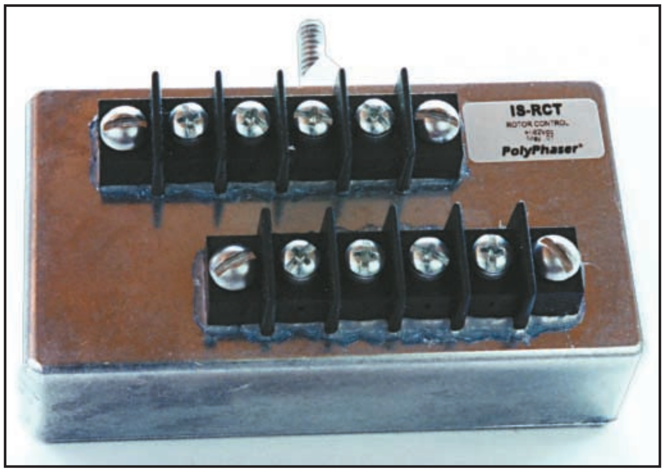


Figure 10—This shunt-type device is capable of protecting up to eight circuit lines with an operating voltage of up to 82 V dc.

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.

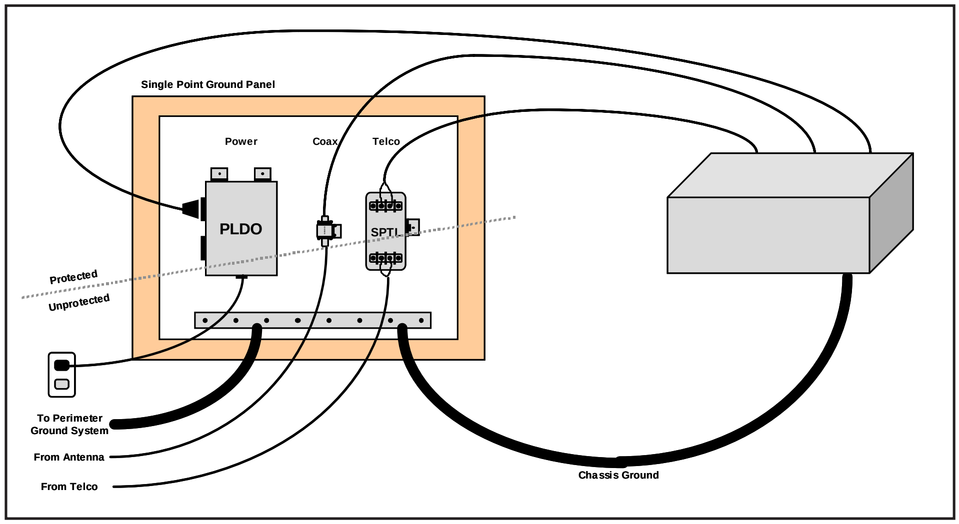


Figure 12—The SPGP showing the division of the protected and unprotected cables.

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.*

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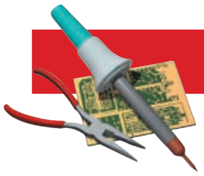

By Ron Block, KB2UYT

Lightning Protection for the Amateur Radio Station

Part 3—In this final installment, the author shows how to develop a good external ground system to complete your station's protection.

Establishing a Good Ground

Now that the SPGP (Single-Point Ground Panel) is connected through the wall to the outside world, there is still a lot of work to do. It's necessary to switch from brainpower and the challenge of getting copper strap through walls to the brute force required to establish a good ground system. The operative word here is *system*—not a ground rod, but a network of interconnected ground rods.

The primary purpose of the external ground system is to disperse as much of the lightning energy as possible into the earth before it follows the feed line into the radio station. No matter how hard one tries, some of it will follow the coax, which is why you created the protection plan for the radio equipment. The easier you make it for the strike energy to dissipate in the earth before it gets to the radio station, the less your equipment protection plan will be stressed.

With great diligence, hard work, no real estate restrictions, plenty of funds and highly conductive soil, it is possible for up to 90% of the strike energy to be dissipated in the earth, leaving just 10% heading for your equipment. This would be quite an accomplishment. In many commercial sites it doesn't work out that well and rarely, if ever, for the Amateur Radio station—there are always restrictions. Let's see what should be done and then adjust to the home environment's restrictions.

Figure 13 shows what has to be done. In the center, the concentric triangles represent the tower. Ideally, the tower is separated from the house by 20 to 50 feet. This distance provides sufficient room for the dissipation of the magnetic fields during the strike event. This distance also takes advantage of the natural inductance of the antenna feed lines to limit the amount of surge and allow more time for the tower grounding system to absorb the strike energy.

Radials and Ground Rods

Spreading out from the base of the tower is a set of eight radials. While the number of radials required for a particular installation will be dependent on the soil conditions in your location, the system shown here is a reasonable start. Each radial is a bare copper wire (preferably, strap) buried 6 to 18 inches below grade. The radials should be positioned so that the energy is dissipated away from the house.

Connected to the radials are ground rods. The ground rods are spaced approximately twice the length of a ground rod. For an 8-foot rod, the spacing would be 16 feet. During the strike, each ground rod has a cylindrically shaped region of influence centered on the ground rod. This is the region in which the ground rod disperses the strike energy. If the rods are placed closer, the regions of influence begin to overlap and the ground rod's ability to disperse energy is diminished. Although this overlapping does not harm the ground system,

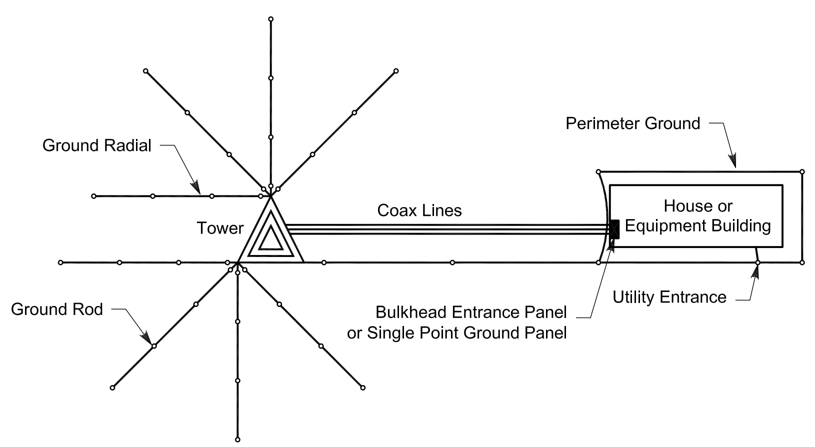

Figure 13—Aerial view of tower and equipment building showing recommended ground radials and perimeter ground. Tower and Ground Radials drawing, *The "Grounds" for Lightning and EMP Protection*, Roger R. Block, PolyPhaser Corporation, Minden, Nevada.

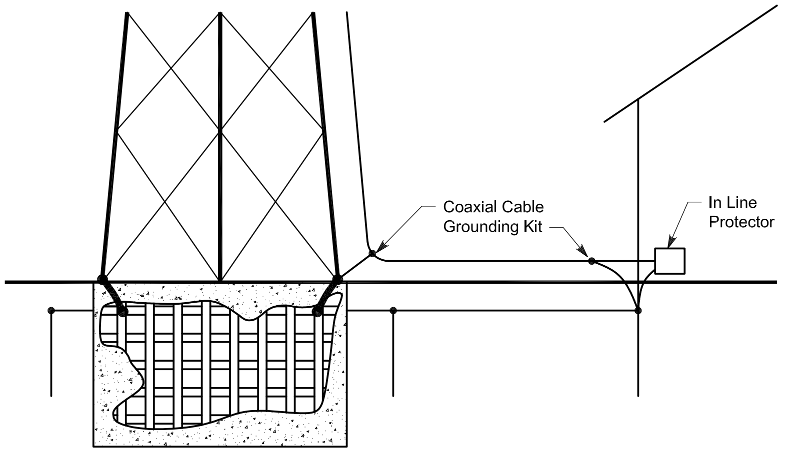

Figure 14—Grounding coaxial cables should be done at both the tower base and the entry point to the house or building. For minimum energy transfer from the tower, bring the coax all the way down the tower and apply a ground kit. Coax Take-off Point drawing, *The "Grounds" for Lightning and EMP Protection*, Roger R. Block, PolyPhaser Corporation, Minden, Nevada.

it does increase the cost since more rods are used.

Ideally, the connection between a radial and its ground rod should be made using an exothermic bonding process. This connection will most likely outlast the life expectancy of the ground system and you won't have to do annual inspections. A number of manufacturers supply the molds and fusing material for a variety of cable/strap and ground rod sizes. Two of them are Erico Incorporated (**www.erico.com**) and Alltec Corporation (**www.allteccorp.com**). If the exothermic process is not used, mechanical clamps that can be used to connect the radial to the ground rod are available. All mechanical connections must be inspected annually or more frequently to ensure the integrity of the system.

Ground rods must be mechanically driven into the ground. This is the only way to ensure that the rod achieves a reasonable "connection" to the earth. Drilling a hole and then backfilling the space around the rod is not acceptable.

While a very long radial/ground rod system is good, electrical and economic considerations come into play. Analyzing the average cost of installing an additional foot of the grounding system versus the benefit of a lower impedance system, the break-even point is somewhere around 80 feet. For practical purposes in areas with reasonably conductive soil, the maximum length of a radial should be limited to approximately 80 feet. If the impedance of the ground system needs to be lower, additional radials should be used as opposed to longer radials.

Some caution must be exercised when laying out the radials. If a radial comes within 4 feet of a metal object, it must be bonded to the metal object. The 4-foot rule applies to objects that are above, below, to the left or to the right of the radial. This includes metal fence posts, kids' swing sets, buried fuel tanks, and so on. Be sure to watch out for dissimilar metal properties when bonding to these objects.

Care must be exercised when connecting the radials to the tower. Most towers are zinc-coated steel (galvanized). Connecting a copper wire or strap directly to the tower leg will cause the zinc to erode, allowing the base steel to oxidize (rust). This in turn will increase the resistance of the connection and over time may threaten the mechanical strength of the tower segment. One solution to this problem is to use a buffer layer of stainless steel between the zinc and the copper. Several manufacturers offer tower leg clamps.

If you are constructing a new tower you can use the tower base as a "ground rod." Called a Ufer ground, it utilizes the rebar that reinforces the concrete base as an excellent ground connection. The rebar itself must be electrically interconnected so there are no spark gaps and there must be at least 4 inches of concrete between the rebar and the surrounding earth. If this is done, a wire can be brought out from the rebar and attached to the tower leg. A great big ground rod! No, you will not blow up your concrete—the other radials with ground rods will handle most of the strike energy. Since you must put rebar in the concrete anyway, use it to augment your ground system.

There are two more items that need to be highlighted in Figure 13. The first is that the SPGP (or bulkhead entrance panel) is connected to the tower ground radial system. This connection should use the same material and ground rods as is used for the radials via a buried path. If the distance between the tower and the SPGP ground point is more than approximately 100 feet, however, it may not be cost effective to interconnect the tower ground system with the SPGP ground system. In this case some portion of the tower ground system must be duplicated for the SPGP ground system.

The second item is the perimeter ground, shown in Figure 13 as going completely around the house or equipment building. This perimeter ground serves two purposes: first, it helps conduct the surge energy around the house, minimizing the ground potential differences under the house during the strike event; and second, it enhances the basic ground system by providing more connection points to the earth. The existing utility ground is also connected to the perimeter ground—this is a must!

Some Specifics

That's how it should be done; here are some general guidelines for adapting this to your specific situation.

- In general, doubling the number of radials lowers the impedance of the ground system by one half.
- Radials don't have to go in a straight line; they can follow the contour of your property or flow around obstacles. Make turns gradually (12-inch radius or larger).
- A perimeter ground that only goes three-quarters or halfway around the house is better than no perimeter ground at all. Although flowerbeds, walkways and driveways frequently present insurmountable obstacles, do your best to get most of the way around. The perimeter ground must at least connect to the utility ground.
- Short ground rods are better than none at all. Just place them closer together spaced at twice their length.
- Soil doping can improve soil conductivity. Be aware that some additives may cause ground and water pollution and can shorten the life of the grounding materials.
- Where possible when installing a new tower, place it at least 25 feet from the house; 30 feet is even better. By placing the tower at some distance from the house, you minimize the amount of magnetic energy that will couple from

it into the wiring of the house. In addition, you take advantage of the inductance of the coax line in limiting the surge energy headed toward your equipment. Don't get too carried away with the distance; the added feed line also attenuates your signals.

- If you are fortunate enough to have multiple towers, each should have its own ground system of radials and ground rods. If the towers are within 100 feet of each other, a radial should be used to interconnect the towers.

Coaxial Cable Grounding

Each coaxial cable traversing your tower needs to be properly grounded to the tower. The first point is at the top of the tower where the coax connects to the antenna. The second point is where the coax leaves the tower to go to the radio equipment. This take-off point should be as close to the base of the tower as physically possible. The third point, for towers taller than 150 feet, is every 75 feet down the tower as measured from the top.

Depending on the height of the tower (inductance) and the severity of the lightning strike (current), the tower could easily have an instantaneous voltage difference between the top and the ground that exceeds 100 kV. In simplified terms, if the tower is viewed as if it were a very long resistor with one end connected to ground and the coax take-off point as a tap point on that resistor, you can begin to appreciate the problem associated with allowing the coax to leave the tower at any point above the bottom. For a 100-foot tower with a coax take-off point at the 10-foot level, approximately 10% of the tower energy (10 kV in this example) will follow the coax to your equipment. If you lower the connection to the 1 or 2-foot level, the energy flow will be correspondingly lower.

The grounding of the coax to the tower should be accomplished using a commercial-type grounding kit followed by the application of a commercial grade waterproofing material. Be careful of dissimilar metals when connecting the grounding kit pigtail to the tower.

In addition, another grounding kit should be applied to the coax just before it enters the house. This will remove some additional energy from the shield of the coax and further minimize the stress placed on your protection system. See Figure 14.

Special Considerations

Numerous Amateur Radio stations will be in locations that make it impractical or impossible to follow some or all of the advice given so far in this article. For those stations there are some things that you can do to achieve a reasonable level of protection for your equipment.

First, establish an SPGP for your equipment by creating a box-level schematic of your radio station. Identify and procure the appropriate protectors for all of the I/O connections to the radio station. Mount them on a common conductive surface. Where your installation varies from the ideal may be that the SPGP cannot be connected to an external ground.

As a substitute for an external ground, locate an alternative conductive path. Here are some recommendations for potential sources. These are in the order of most to least desirable.

- Building steel
- Stand pipe
- Metal cold water pipe
- Metal building skin
- Electrical system safety ground

Even though many of these ground choices are highly inductive and will not function as a good RF ground, the goal is to survive a lightning strike event by ensuring no current flows on the radio equipment I/O connectors. This is achieved through SPGP grounding techniques, which maintain an equal potential between equipment chassis during the strike independently of how the SPGP is grounded. For small upper-floor radio stations, this will work just fine.

Operating Safety

No matter how good your installed lightning protection plan is, you *cannot* be in electrical contact with the radio equipment during a lightning strike event. Although there is no current flowing between the radios in your radio room, all of the equipment will be statically elevated above ground. If you are holding onto the microphone or the key during the strike event, *you* are now the path of least impedance to ground from the protected and now elevated equipment chassis. This ground path can be to the rebar in the concrete floor below your feet or to a nearby electrical wire or water pipe.

Consider getting a storm warning device capable of sounding a warning when lightning activity is within 10 miles of your radio station. (Lightning detectors are available commercially, or you can build one; see Radmore, "A Lightning Detector for the Shack," Apr 2002 *QST*, pp 59-61.) When the alarm sounds, leave the radio room. If your protection plan is installed correctly, you may leave the equipment connected and powered-on—but you must leave the room. Commercial radio operators get away with operating during lightning strikes because most of their equipment is remotely operated—just like a repeater.

More Information

After you have implemented the guidelines presented here and if you have questions (recognizing that every site is unique) feel free to contact me. Be aware, the first thing that I will ask you to share with me is your box-level schematic and some physical characteristics of your radio room and antenna farm. With this information as a reference, we can discuss your situation. Please forward a copy of the appropriate information before contacting me. Some additional information is also available on the WR Block & Associates Web site at **www.wrblock.com**.

Thanks

Many thanks go to Roger R. Block, my brother and founder of PolyPhaser Corporation, for his input in the preparation of this article.

Ron Block, KB2UYT, has been a PolyPhaser distributor and consultant 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.*

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[The resources sidebar that appears in Part 2 of this series (July 2002 *QST*, p 52) was not meant to be a complete list of manufacturers and suppliers of lightning detection equipment. To access the ARRL *TISFind* database, see **www.arrl.org/tis/tisfind.html**, and search for the key words "lightning" and "ground."—*Ed.*]

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