Flash and Crash 101

— how to weather the storm

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Lightning is one of the most common occurrences found in nature and certainly tends toward the spectacular. It is responsible for starting about 10,000 wilderness fires in this country each year and also infrequently causes deaths. Furthermore, there have been many misconceptions and superstitions invented over the years.

In spite of the losses that can be involved, the average person knows very little about this phenomenon. It would seem that hams in particular have something of a vested interest in knowing the facts so that the fate of their equipment will not be left completely up to chance. This article will deal both with how lightning occurs and the various protection methods that are available.

A lot of information has been obtained since Ben Franklin first tried to electrocute himself with his experiments about 200 years ago. Meteorological observations now have established thunderstorm activity levels on a worldwide basis. Fig. 1 shows that the annual number of these storms varies from single-digit numbers up to as high as 200 in parts of South America. Interestingly, the maximum activity occurs over land masses that are located close to the equator. This relationship to latitude mostly reflects increased evaporation and cloud formation in the hotter climates.

Similar data has been generated for thunderstorm frequencies encountered across the United States. South Florida has the distinction of having the highest annual activity—100 thunderstorm days. Fig. 2 shows the thunderstorm activity throughout our country and can be used as a partial guide for determining the typical frequency in your area.

The information presented in Figs. 1 and 2 shows the number of days that thunder was heard and does not tell whether a lightning flash goes to ground or is contained inside the cloud. Furthermore, the number of flashes to ground increases substantially with increasing distance *away* from the equator (Fig. 3). Severity of storms is not reflected by the data at all. (A more precise method might involve recording thunderstorm duration instead of just occurrence.) Consequently, these activity levels should be considered as relative information rather than absolute values.

The clouds that typically are responsible for thunderstorms and lightning are termed cumulonimbus. These so-called "thunderheads" are usually very large and reach overall heights of 35,000 feet. The temperature at the top of the cloud is a rather brisk −40° F. Such a cloud formation will spread out horizontally over several miles. Lest you think that lightning is produced only by thunderstorms, you might be interested to know that sever-

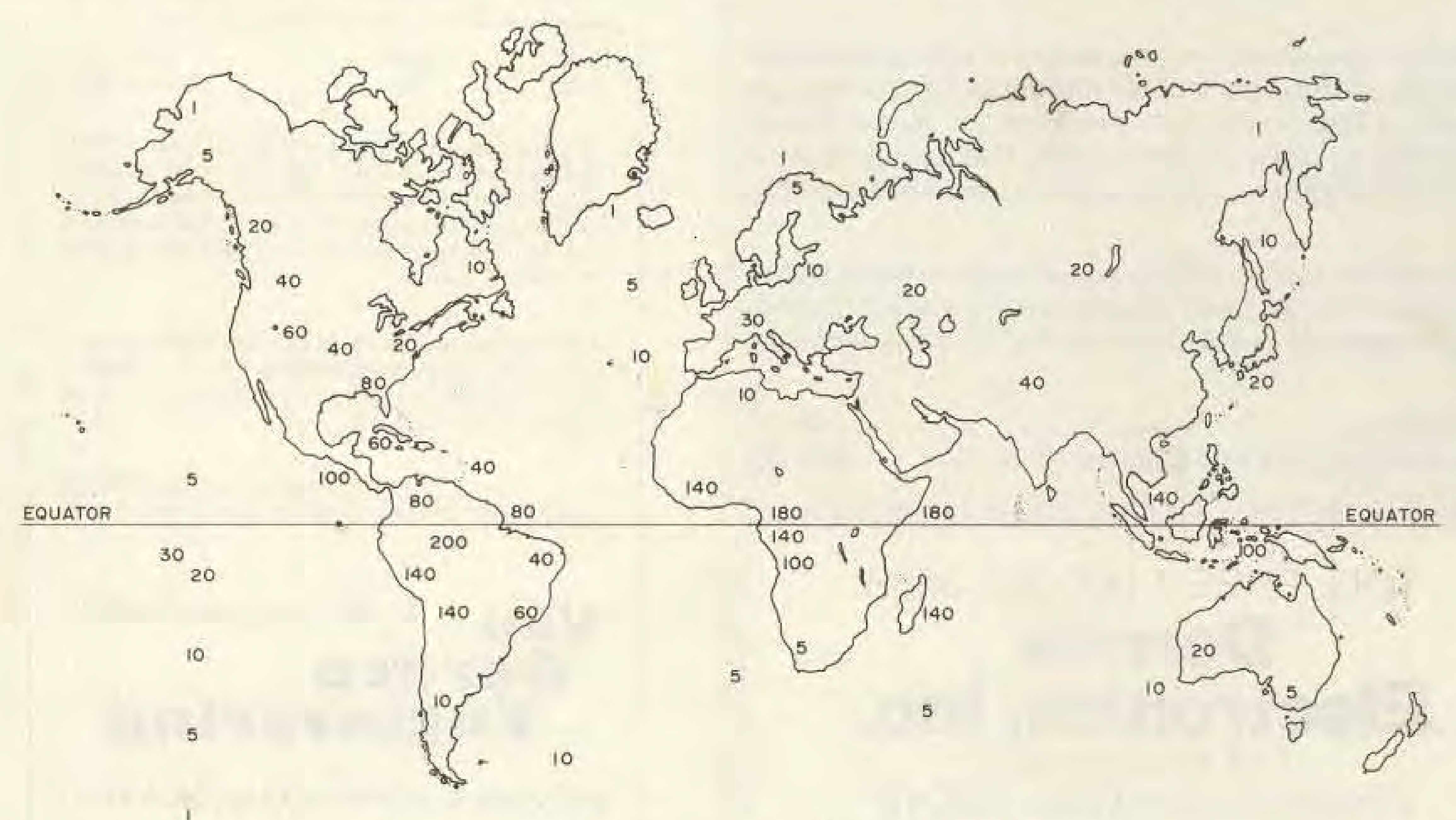

Fig. 1. Annual frequency of thunderstorm days.

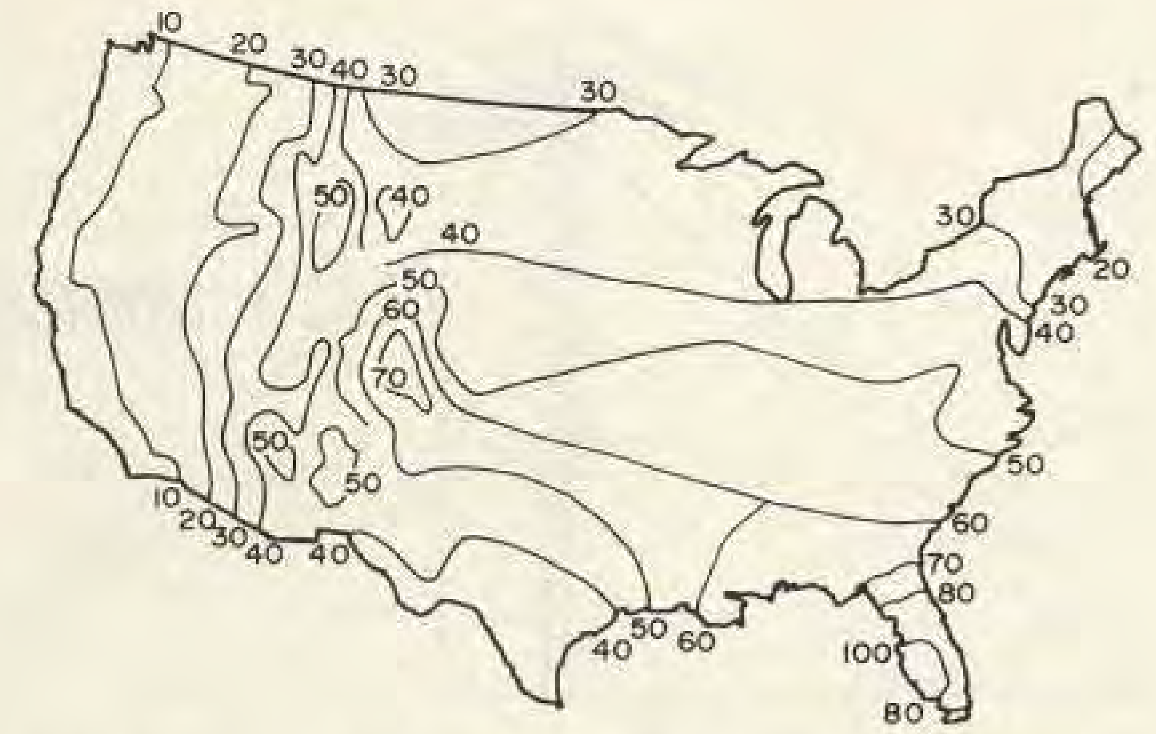

Fig. 2. Typical annual US frequency of thunderstorm days (Ref. 1).

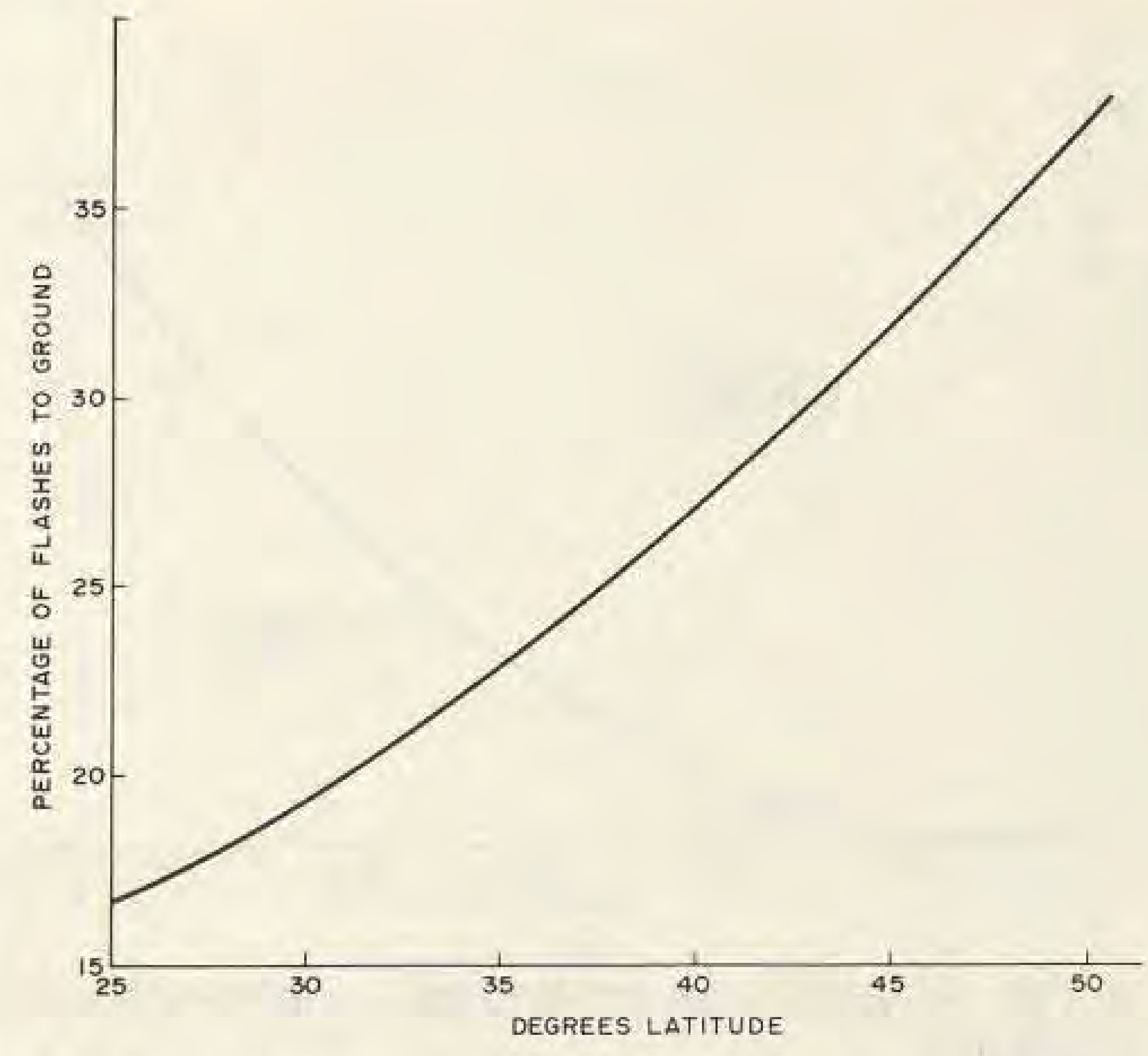

Fig. 3. Graph shows increasing probability of cloud-to-ground lightning strikes as distance from equator increases.

al other possibilities exist as well. These include: sandstorms, snowstorms, and clouds located over erupting volcanos (Reference 1). Lightning associated with snowstorms occurs often enough to be a concern to aircraft. Back on the ground, though, we will be interested in the common thunderstorms.

Contrary to widespread belief, lightning does not come instantly crashing down to the Earth whenever Zeus is angry. In fact, it does not always come *down*, but occasionally can extend up to the cloud. These items are in the folklore that we'll try to set straight. Lightning actually consists of several stages. These are: the leader, initial return stroke, residual decay current, and usually one or more restrikes (Reference 2). The high-current portion occurs in about 10-100 microseconds while the total cycle takes up to 0.25 seconds. The rate of propagation is something less than the speed of light because of inductance and capacitance effects along the path.

The source of energy that ultimately creates the discharge is presumed to be warm air rising toward the top of the cloud. The charging process in the cloud is thought to happen as a result of falling ice crystals. Portions of these crystals splinter off and become electrostatically charged. Wind currents then carry these positive charges up to the cloud's ceiling. The heavier remaining portions of the ice accumulate a negative charge at the bottom of the cloud.

Other theories also exist, but their common denominator is that the cloud contains one or more localized "cells" where the lower part of the cell is negative. Local potential differences can reach many millions of volts inside the cells. Relative to the Earth, the cell (cloud) has a net negative potential and a lifetime on the order of a half hour.

As the cloud comes overhead, the ground underneath it takes on a positive charge. Put more accurately, negative ions in the ground are repelled from the area directly under the cloud formation. When a vertical conductor (flagpole, tower, etc.) is present, an intense field concentration occurs at its tip which can exceed the breakdown (dielectric) strength of the air. This causes microampere "point-discharge" currents characterized by a bluish corona. Sailers used to call this corona St. Elmo's fire after a Mediterranean patron saint. Incidentally, this effect will cause severe local static. This is one reason why vertical antennas have a ball rather than a point at their tip. The ball's larger radius tends to reduce the possibility of corona discharges and their effects on reception.

Eventually, a column of ionized air called a pilot streamer reaches out from the cloud toward the ground. Afterwards, a more intense discharge takes place in the form of a series of incremental steps. This is referred to as the step-leader. This leader and its branches bring the negative cloud potential closer to the Earth—reduce the spark gap, if you will.

Earlier, it was noted that leaders occasionally start from the ground and nearly reach up to the cloud. Fig. 4 shows that fewer than 5% of the leaders associated with a 100-foot tower will behave like this. In all lightning discharges, however, short streamers extend upward from the object just before the discharge. This is the same phenomenon as St. Elmo's fire. When the two streamers connect, they provide a highly conducting path (filament) which allows the charge in the tip of the leader to flow to the ground.

As this current becomes higher, the filament impedance is reduced and more current flows. This reduces the charge at the leader's tip, allowing the conducting arc to reach higher up into the filament channel. Consequently, this arc propagates *up* to the cloud and is called the return stroke. The speed of this return stroke is much faster than the step-leader that was "feeling" its way down to Earth. However, the overall speed of propagation is only about one-third that of the speed of light.

Generally, people are not aware of this return stroke. However, this is what actually produces the bright lightning flash as well as the thunder. The light involved is simply a result of the arc itself, while the high currents result in rapid expansion of the surrounding air. This causes the thunderclap. An old rule of thumb says that your distance from the spot where the lightning struck, measured in miles, is equal to the number of seconds between the flash and the thunder.

The currents flowing during the return stroke average about 25,000 Amperes. Currents above 150k Amps have been recorded, but those over 80,000 Amps are rare. By comparison, the step-leader currents typically are in the tens or hundreds of Amperes. The high-current values are measured indirectly as you

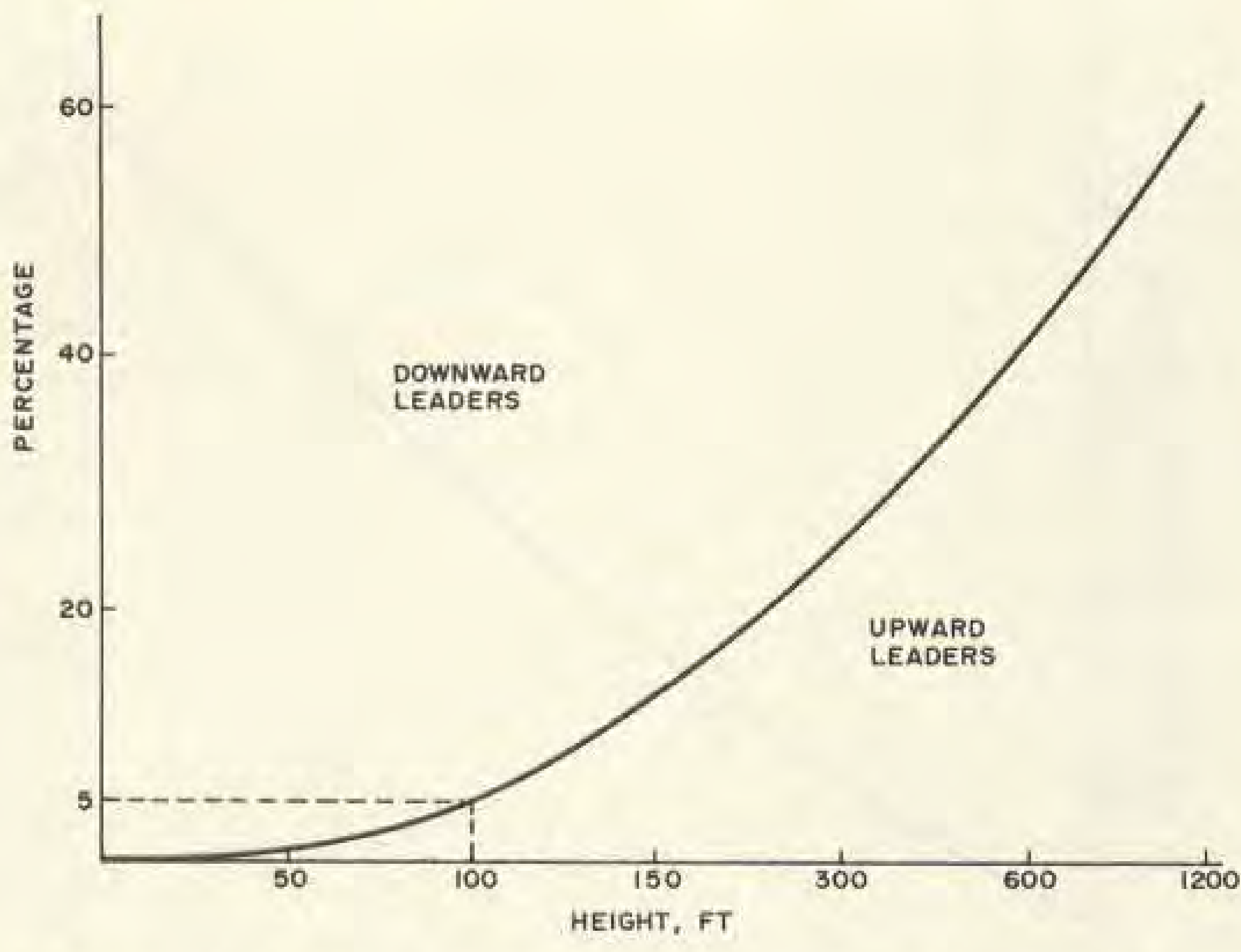

Fig. 4. Percentage of upward leaders is slight without very tall structures.

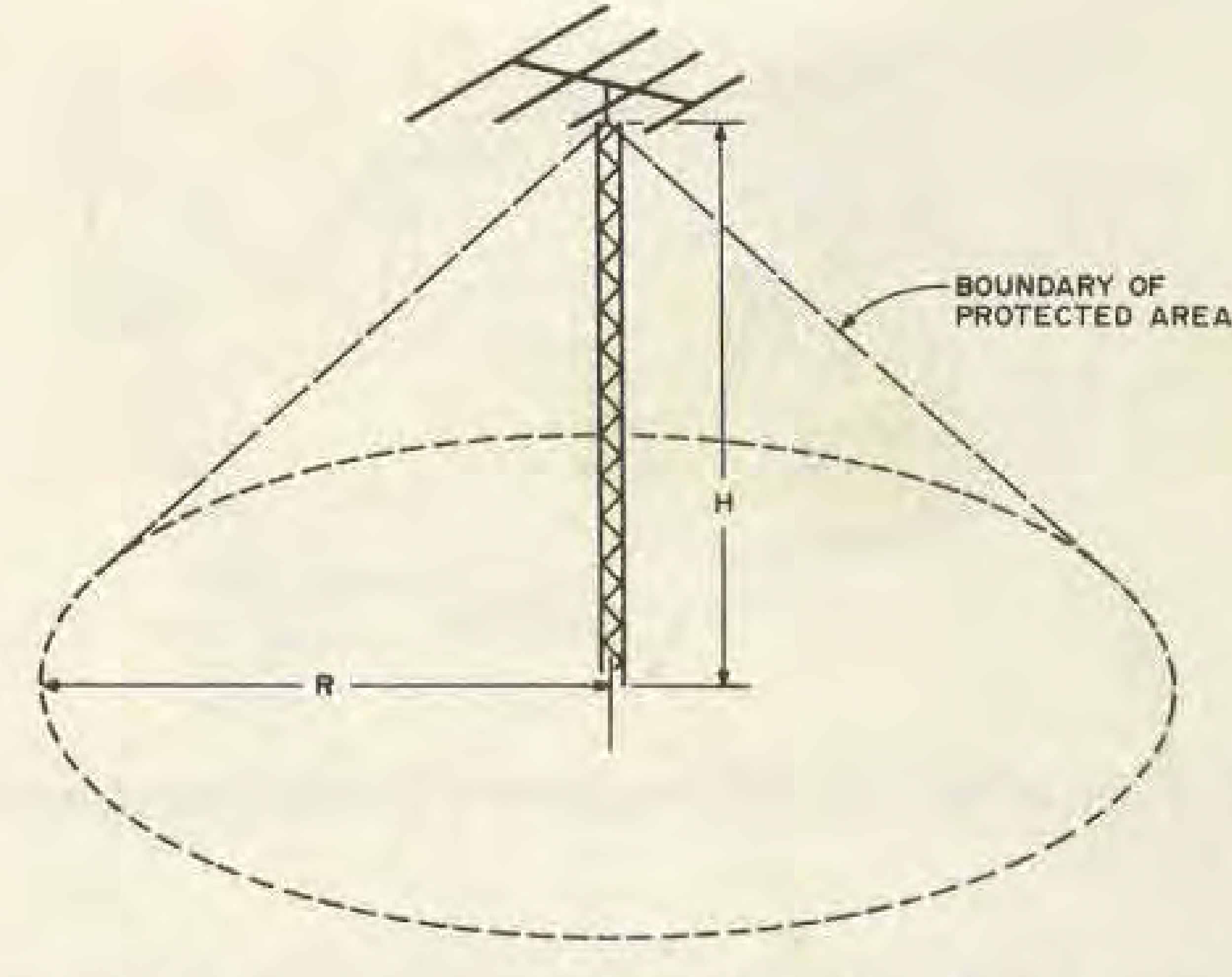

Fig. 5. Sketch showing principle of protective cone where the radius (R) at protective area (dotted) is equal to the tower height (H).

might imagine. Originally, small bundles of steel strips called magnetic links were placed perpendicularly near whatever was expected to be hit. Any eventual lightning current would magnetize the links, and the amount and direction of the current flow could be deduced. Recently, similar methods have used magnetic recording tape where the strike partially erases a pre-recorded signal of known strength. Again, the current would then be calculated.

The final phase in the overall lightning process consists of a low-level continuing current which provides the opportunity for at least one more immediate restrike. This usually happens about 200 millseconds (0.200 sec.) after the initial strike. This additional discharge invariably hits the same point on the Earth as its predecessors. This fact alone indicates that lightning can strike the same spot more than once.

Several factors can increase the probability of a building, tower, or whatever being struck. Geographic effects were mentioned earlier. Most of the others are not surprising. The type of terrain is important, with the valleys being struck less often than higher elevations. For a given location, the possibilities increase as the square of the height of objects above ground.

Grounding a tower will help reduce the amount of electrostatic charge present. This can help avoid a strike since the field strength at the top of the tower will be considerably lower, and upward streamers will find it that much harder to form. More important, though, the good ground will allow the current to be safely discharged into the ground.

Another factor is that the tower (or highest object) creates a so-called cone-of-protection which protects other structures inside this cone. An example of this could be your house. The actual area protected is not well established, although a conservative figure seems to be that the radius of the cone is equal to the tower height (Fig. 5).

There are quite a number of ways to increase the protection of your equipment during a thunderstorm without going broke in the process. However, you should realize that there is no absolute protection short of tossing all transmission lines, rotor cables, etc., out of the window and unplugging the radio. (Even this assumes that you thought to take action well ahead of the storm and were at home to do so. Do not disconnect these cables just before the storm or when it is in progress.) Fortunately, there are some things that can be done that don't require you to be a recluse in the house.

The first major step is to provide all of the station equipment with a good earth ground. This means that all equipment in the house should be attached (bonded) to an outside ground rod using as short a length of heavy wire as possible. The standard rod is a 0.5-inch copper bar driven eight feet into the ground. This provides a low-impedance path. Experiments have shown that larger diameters or greater depths do not provide better performance. These rods can be bought from local electrical supply houses.

You should avoid copper-plated steel bars because the plating will wear or corrode off leaving a rusty ground rod. There goes any low impedance! Simply check your ground rod to make sure it is not magnetic. If it is really necessary to ground to a water pipe in the house, use a cold water pipe since corrosion can break the electrical continuity of the hot water ones. Also, check to see that the water meter has been bridged with a heavy wire.

At least two of the tower legs should be attached to individual ground rods. These should be driven into the ground rather than through the concrete and into the ground. The same store that carries the rods usually also will stock brass clamps to secure the wires to the tower and the ground stakes. Remember to similarly treat any guy wires. Copper is best for the ground wires, but if aluminum is used, it should be about a #2 size. Don't run aluminum through the concrete since corrosion will ruin the wire in short order.

The wires to each rod should be short and as direct as possible with no kinks or sharp bends. Lightning does not want to turn corners! No ground wire should be placed through a metal conduit. This setup would act as an rf choke and encourage the lightning to find an alternate route. If you are compelled to be neat, use porcelain or some other non-metallic material for the pass-through.

Methods also are available to reduce the risks of strikes to antennas. Again, bleeding off electrostatic-charge buildups caused by rain and snow is helpful. Some antennas such as ground-mounted verticals and beta-matched beams

are already at ground potential and require no further attention in this regard. If this is not the case and coaxial feedlines are used, a device such as Cushcraft's Blitz-Bug can be inserted in the coax near ground level where its case can be grounded. This device contains a built-in spark gap that will bleed off excess charges to ground.

There are other tricks that can be used with coax, also. I made several one-foot diameter turns in the coax at the base of the tower. This took up excess cable lengths and also provided an rf choke to help discourage the lightning from entering the house. A right-angle turn right after the choke arrangement performs similarly. Compared to your transceiver, the price of new coax is cheap!

When the station is not being used, the antenna switch should be turned to its ground position. Since extended inactivity periods occur with vacations, etc., it is convenient to homebrew a coax grounding box which is mounted to the tower or to a ground stake. Such a device is shown in Fig. 6.

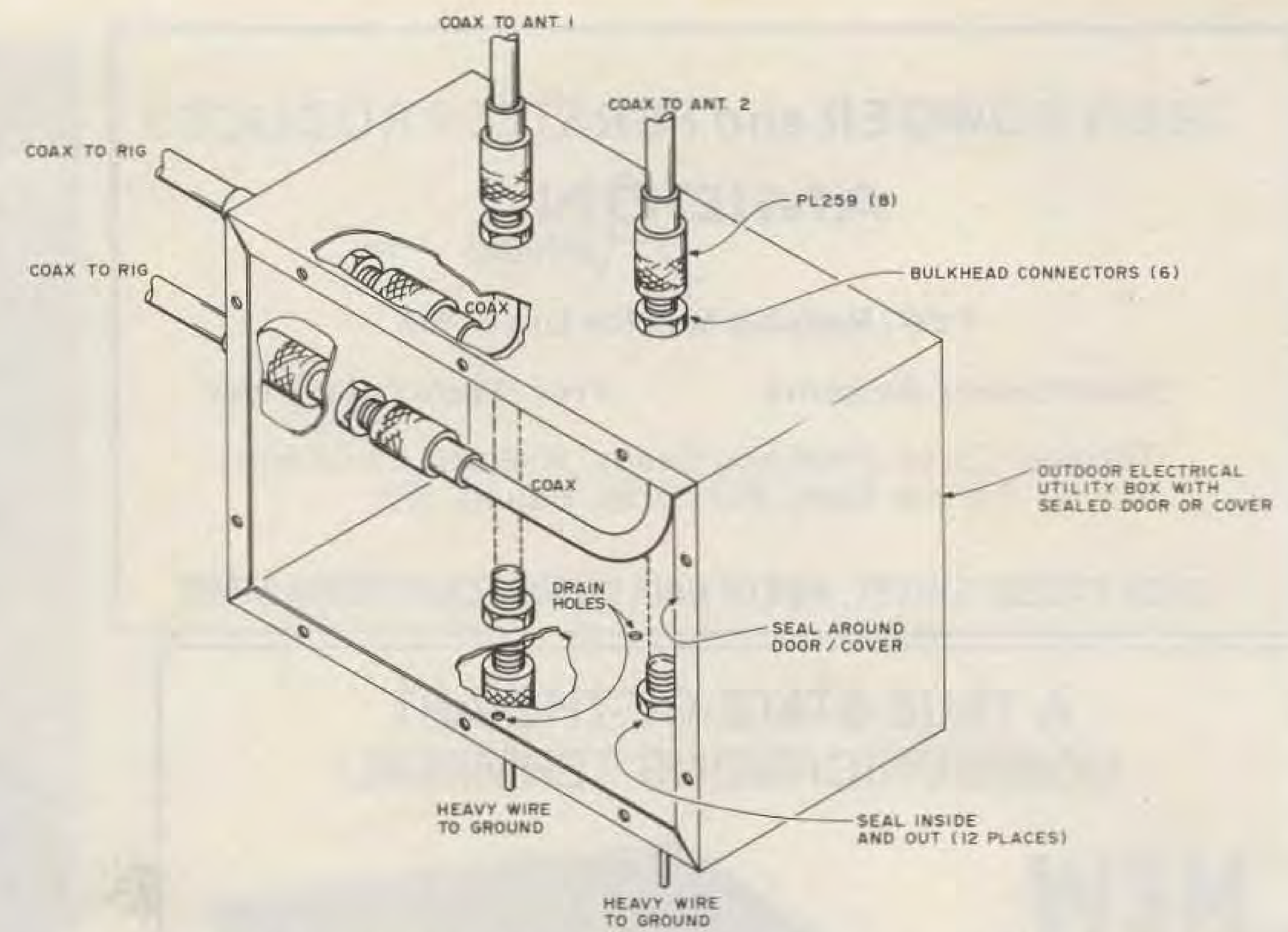

Fig. 6. Sketch showing grounding box configuration for coaxially-fed antennas.

An outdoor utility box with a hinged or removable cover and a good weather-tight seal forms the basis of the unit. Three male-male coaxial feedthrough connectors (UG363) are needed for each coaxially-fed antenna. Inside the box there is a short length of coax with PL-259 connectors attached to each end. One of the groups of three feedthough (bulkhead) connectors is located in the bottom of the box and its center conductor is grounded.

During normal use, a patch cord is connected directly from the antenna to the coax running to the radio. However, before the vacation, this patch cord is changed over to the grounded connector. This grounds the antenna directly and essentially eliminates the chance of a direct hit from entering the house via the coax lines. Remember to be sure to seal the holes around each connector mounted on the box. Silicone rubber, RV, or other compounds can be used effectively for this purpose. It is a good idea to drill one or two small holes (1/16-1/8 inch) in the bottom of the box to allow for condensate drainage.

If your station uses an open-wire transmission line, the above suggestions are not appropriate without some modification. However, this situation was covered long before we started using coax. The time-proven method of protecting gear in this case is to use an air gap (Fig. 7). The gap distance is chosen to be too large for the signal to bridge but small enough to allow lightning to jump across it and continue on to ground. Various handbooks deal with these air gaps in detail, and various things including spark plugs have been used.

In the potpourri department, a comment or two come to mind regarding roof-mounted VHF/UHF antennas and even the TV ones as well. Most people are aware that the mast that supports these antennas should be grounded. A typical installation involves bringing the transmission line, rotor cable, and the ground wire down the side of the house in a neat parallel manner. Electrically, though, it is not so pleasing. In the event of an actual strike, the lightning has a choice of paths to ground. Side flashes from the ground wire to one of the other cables is also possible. This problem can be overcome by making sure that the ground wire is the shortest and placing the other wires away from it. Again, we see the rule of thumb regarding short, direct ground wires coming into play.

One should realize that damage to electronic equipment does not necessarily require a direct lightning strike. Relatively large voltages (spikes) can be in-

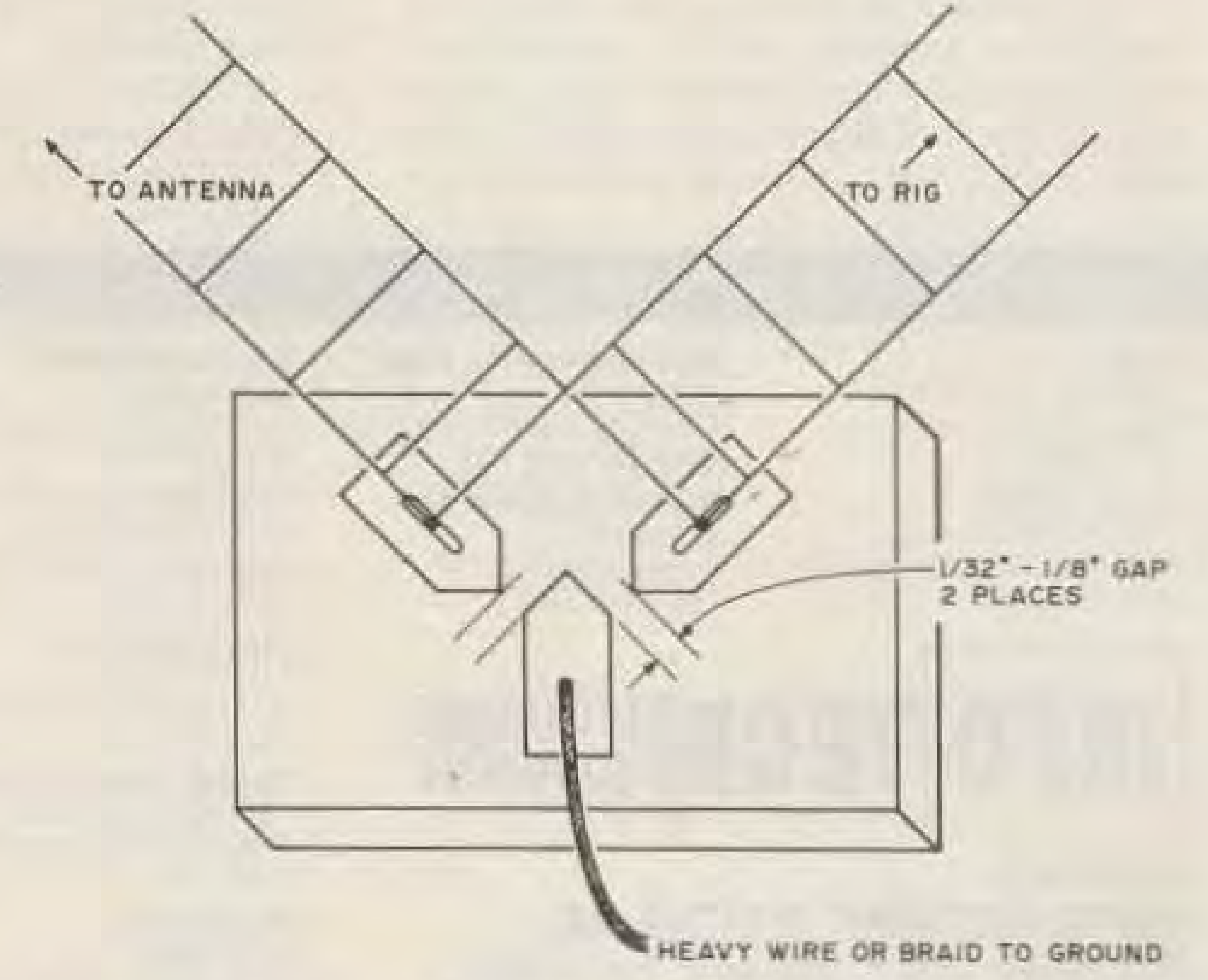

Fig. 7. One of several spark-gap methods used to protect open-wire-fed equipment.

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duced into the ac distribution system when a neighborhood utility pole is hit. The voltage transients produced can travel into equipment via the house wiring. An obvious solution is to pull the plug, but this is not always convenient and can be forgotten. Protection against these spikes is especially important with solid-state rigs since they do not have the overvoltage capabilities of their tube predecessors. Fortunately, help is available in the form of a voltage-spike-protector device. This unit can be attached to essentially any transformer-type ac equipment. The device is a metal-oxide varistor sold by General Electric (Model GE-MOV) and others. The varistor is a two-lead unit that is attached across the transformer primary winding and breaks down to a low resistance in the presence of a large-surge voltage. The action happens very quickly (several microseconds) and shunts the spike across the transformer primary and prevents damage from occuring.

A Closing Note

Well, there you have the basics of how lightning develops and what can be done to minimize its occurrence and effects. Total protection cannot be ensured unless each piece of equipment is isolated from the antenna and the ac mains. Unfortunately, this is not always possible. However, the techniques presented in this article are simple to apply and will provide a significant measure of protection for your equipment. ■

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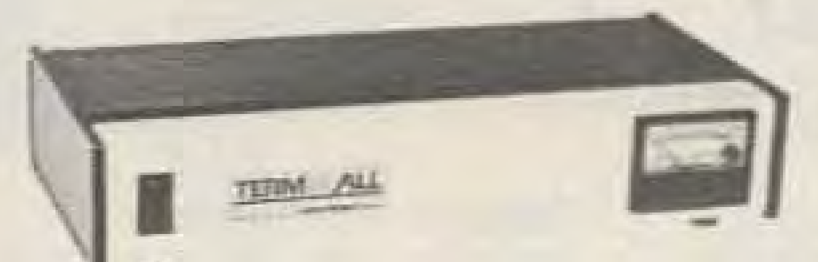

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