2-Way Technical Refresher Course

Learning to Live With Lightning

The same conditions which make a structure or site desirable for two-way radio make it a target for lightning. The highest spot in the area is guaranteed to get "hit." Here are some pointers on how to protect valuable radio facilities.

By A.K. "Kenny" Guthrie
Manager, Product Information and Training
General Electric Mobile Radio Department

I've been in land mobile communications — the two-way radio business — for almost all of my working career. I was enthusiastic about it in the beginning, and after 30 years in two-way, I'm still enthusiastic.

So, as we approach the broad subject of lightning, you won't be surprised that I reflect the interests and viewpoints of a specialist in the *mobile radio* field.

Lightning is a fascinating subject — one which can be discussed and studied from many angles. My orientation leads me to address lightning in terms of two-way radio, and my experience causes me to focus upon lightning damage to land-based two-way radio facilities.

We'll talk a little about what lightning is, and the nature and magnitude of the stresses which it exerts upon our equipment. Unfortunately, I have no magic umbrella which will immunize your facilities from this unwelcome visitor. Instead, my main thrust is upon some of the things you can do to improve your chances of surviving a lightning event without catastrophic damage.

Lightning is a transient electrical current which equalizes a difference of potential, and creates a lot of fireworks in the process.

A.K. "Kenny" Guthrie, manager of product information and training for GE, is a 23-year veteran of the company. He served seven years as a radioman with the Indiana State Police. Previous to that he served with radio station KHMO in Hannibal, Missouri, and with the U.S. Army. Guthrie joined GE as district service manager in Indianapolis in 1953.

Wind works on moisture, the moisture in clouds, and the moisture falling as precipitation. The wind tears the droplets apart physically, ionizing them, or, separating them into positive and negative ions. The force of the wind drives the relatively light negative ions back into the cloud. The positive ions, which are comparatively heavy, fall to earth.

As the process continues, the cloud becomes increasingly negative and the earth below becomes increasingly positive. The positive area on earth is real, with charges held in concentration by attraction of the cloud overhead.

Not only is this area positive with respect to the cloud, it is also positive with respect to distant earth. The positive area on earth tracks the movements of the cloud above, just like a shadow. (See Figure 1.)

When the potential difference between cloud and earth exceeds the breakdown voltage of the atmosphere, there is a discharge to earth. We call this vertical lightning.

The stroke current heats the ionized path to incandescence and produces a visible flash. The air surrounding the discharge path is heated and expands outward at supersonic speed. The air then cools and moves back to cancel the partial vacuum. The return trip is slower — it's at an audible rate. We hear the sound of thunder.

Take two clouds, fairly close together. Wind works on both of them. Both become negatively charged, but one more so than the other. Each has a positively charged area tracking it on earth, but, again, one more so than the other. There is a potential difference between each cloud and earth. There is also a potential difference between the two clouds. If the atmosphere *between* clouds breaks down first, the discharge will be overhead, and we have horizontal lightning.

Lightning has a regional flavor. A weather bureau map summarizes 30 years of history. The unit plotted is "thunderstorm days per year." If thunder is heard even once, that day is recorded as a "thunderstorm day" for that location. The gradient is from southeast to northwest, and activity peaks up in coastal areas. The southeastern part of the United States is singled out for special attention.

Considering individual thunderstorms, instead of thunderstorm days, the spread is even more dramatic. (See Figure 2.) During these same 30 years, Tampa recorded more than 3800 separate thunderstorms, while Seattle recorded fewer than 100. If repairing lightning damage appeals to you as a career, now you know where the action is.

Spots More Likely to be Hit

Not all spots within a general area have an equal probability of collecting a lightning stroke. An elevated structure or natural elevation collects lightning which would otherwise strike the surrounding earth. Anything which rises above prevailing terrain protects a circle of earth with radius about three times the height of the projection. It protects its surroundings by taking the strokes itself.

And, when terrain isn't flat, it is effective height which counts. When a hill rises from flat terrain, the effective height is that of the structure *plus* the elevation of the hilltop.

Height makes a big difference. Take for example a square mile of real estate in an area which typically experiences four strokes per square mile per year.

One specific square foot could be marked off in that area. If my Sears-Roebuck calculator hasn't let me down, you can look for a hit to this exact spot about once every seven million years!

Put a 200-foot tower on that spot and the odds change. The stick gathers in a million square feet worth of lightning. One event per six years is now a reasonable estimate. Set the same tower on a 400-foot rise, and you can expect action every seven or eight months.

The higher the structure, the more often you get hit. The same conditions which make a structure or site desirable for two-way radio, make it an attractive target for lightning. Your facilities are protected if they're in the shadow of something taller. Get the highest spot in the area, and you'll get the lightning — just as sure as death and taxes.

Two Kinds of Current

The realities of lightning cause us to consider two kinds of current. Vertical lightning involves a stroke current at a point on earth, and, it's pretty obvious that the current which is concentrated in the stroke must be distributed outward in earth from the stroke point. Although horizontal lightning confines its stroke current to the heavens, it, too, produces distributed ground currents.

Stroke current equalizes the potential of the clouds. The attraction of each cloud to positive charges on earth is modified. The charges on earth then re-arrange themselves according to the new situation. Positive charges move. Moving charges constitute a current. There *is* a current in earth, coincident with the discharge overhead.

Stroke current to earth can enter our equipment directly through connected facilities. A hit to the antenna system, the power feed, or connected telephone lines, can bring stroke current into the cabinet. Once in, it's going out — hopefully through the cabinet grounding; if not through the intended path, it will exit through a path of its own choosing.

Ground currents enter our equipment indirectly. When a structure takes a stroke, there is a corresponding current into the earth, but the actual current is distributed.

On the left, in Figure 4, note the voltage drop which results from current through the resistivity of the earth. When there is current through intervening earth, a voltage drop can be measured between two "grounded" points. On the right, we symbolize the magnetic field which encircles any current path, be it in a physical conductor, or part of a distributed current. This magnetic field exists in earth, and it extends above the earth. A voltage is induced into any conductor which is cut by this magnetic field.

The magnetic field from distributed ground current cuts both conductors of a pair. The field cuts both conductors

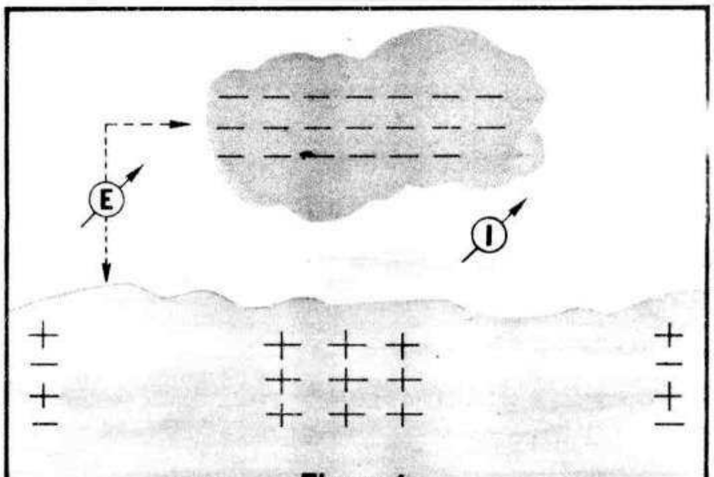
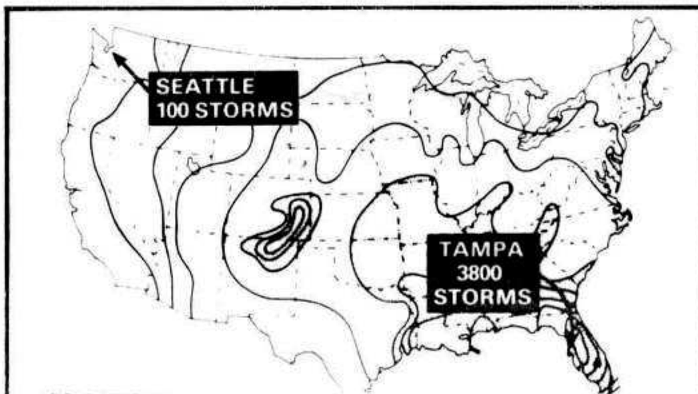


Figure 1.



30-YEAR TOTAL THUNDERSTORMS

Figure 2.

EXPERIENCE: 4 STROKES/YEAR/MI²

EFFECTIVE HEIGHT	EXPECTED FREQUENCY OF LIGHTNING HIT
0	EACH 7,000,000 YEARS
200 FT.	EACH 6 YEARS
600 FT.	EACH .68 YEARS

Figure 3.

at the same instant and to an equal extent. Thus, identical voltages — identical in both magnitude and phase — are induced into each wire.

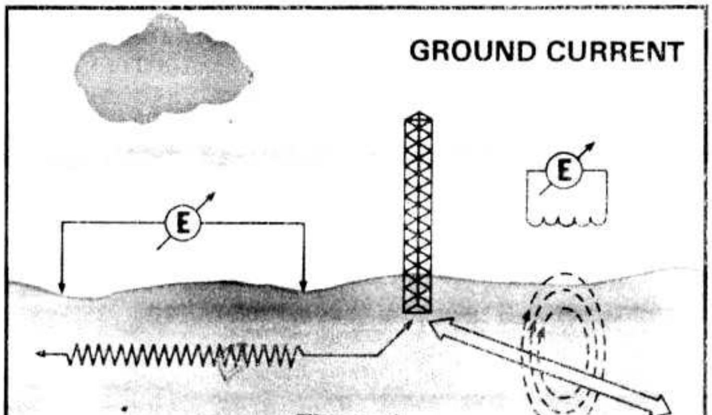


Figure 4.

This is a longitudinal effect. Although both wires may rise hundreds or thousands of volts above ground, there is no difference of potential across the pair. A remote control unit, across this line, does not register so much as a click, unless something breaks down.

Stroke currents enter equipment through direct metallic connections.

Ground currents make themselves felt indirectly, through longitudinal rise of power and telephone lines, overhead or buried.

The stroke current is where it all starts. What the observer considers a single display of lightning is called a "flash" by the specialists. The flash is made up of individual strokes — as few as one, and typically two or three. Starting with zero current, there is a rapid rise to crest and a slower decay down to zero. Successive strokes are of declining peak amplitude. The duration of the entire sequence is in the range one-third to one-half second.

Rise time is typically two microseconds, implying that major energy content is well below the standard broadcast band. Decay is slower, typically 40 microseconds to 50 percent of peak amplitude. The rise time isn't particularly impressive, but the current is brutal.

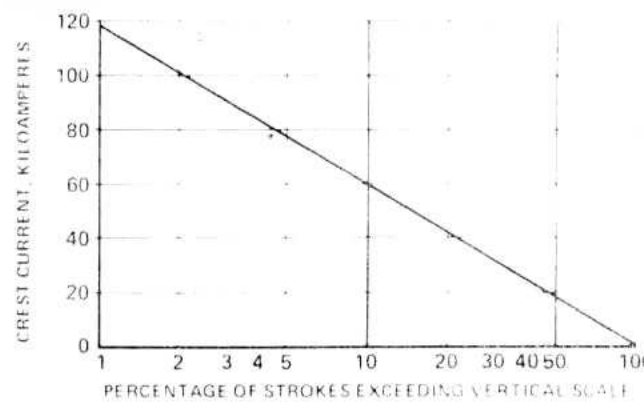


Figure 5.

All lightning strokes are not created equal. Figure 5 summarizes a series of stroke current measurements taken on the Empire State Building. Lightning is lightning, and the Empire State Building is a handy place to work.

It is tall enough to minimize waiting time between incidents.

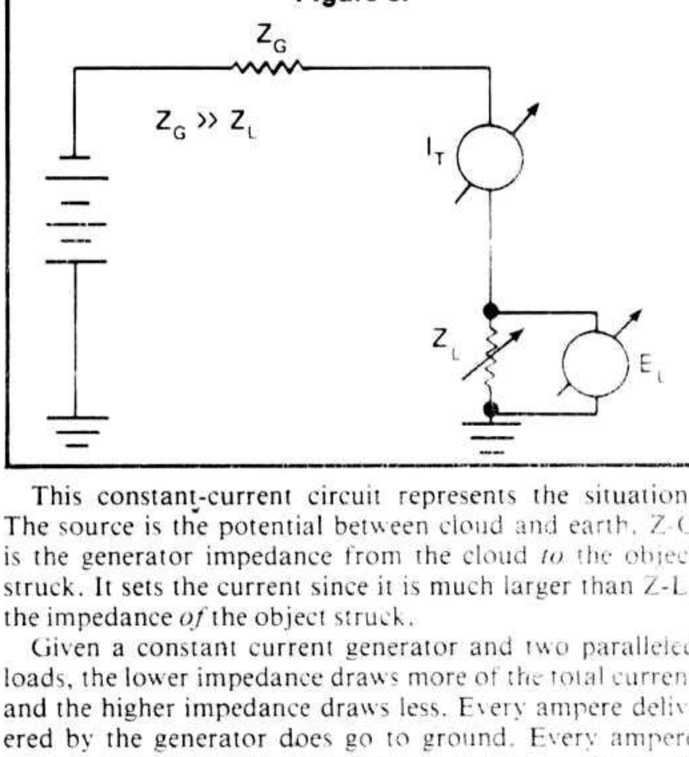
The unit is kilo-amperes, thousands of amps. The chart is a cumulative percentage distribution.

One-hundred percent of the discharges measure zero amps or more. (I trust this information is not a complete surprise.) The surprise comes when you observe that half the strokes measure more than 18,000 amps at crest. Ten percent exceed 60,000 amperes. One-percent are off-scale at more than 120,000 amps. With these magnitudes, it's indeed fortunate that the duration is as short as it is.

Constant-Current Circuit Represents Situation

Stroke current is delivered from a constant current generator. It's a long way from the cloud to a point near the earth. The impedance is high — high enough to set the current for the entire circuit. Series impedance at the point struck is small by comparison. Whether the last few feet is through the legs of a tower or the legs of a cow, you can expect about the same current. (See Figure 6.)

Figure 6.



This constant-current circuit represents the situation. The source is the potential between cloud and earth. Z-G is the generator impedance from the cloud *to* the object struck. It sets the current since it is much larger than Z-L, the impedance *of* the object struck.

Given a constant current generator and two paralleled loads, the lower impedance draws more of the total current and the higher impedance draws less. Every ampere delivered by the generator does go to ground. Every ampere accepted by the lower impedance is one amp which will never enter the higher impedance. This fundamental becomes our key principle. To find a way to "live with" lightning, we will build upon this idea of "current division according to impedance ratio."

Shunt, then isolate. We protect Z-2 (see Figure 7) by lowering the impedance of Z-1. An ampere taken through Z-1 to ground is one we can forget about in Z-2.

We can further protect Z-2 by adding an isolating impedance, Z-P. As the impedance of the vulnerable branch is built-out, current is diverted from Z-2 and pushed back to ground via Z-1. Isolation, alone, can't do the job. If Z-1 isn't there, 100 percent of the current will flow through Z-2, the build-out impedance notwithstanding. If a shunt path is provided, an isolating impedance will make it more effective. Without a shunt path — not a chance

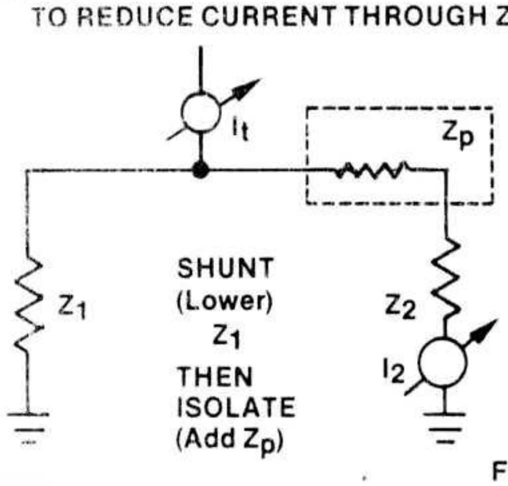


Figure 7.

The top of a base station antenna is usually the highest and most vulnerable spot in an entire radio system. Stroke current collected by the antenna can flow right down the coaxial cable, with the bulk of it traveling down the outer conductor. The top of the antenna is the first opportunity to shunt current away from the equipment you want to protect. All other factors being equal, choose an antenna with elements directly grounded to the tower structure. And, make sure you have a solid bond between the grounded elements of the antenna and the tower. The tower is a good path toward ground. Make use of it.

Keep tower grounding resistance as low as you can. The stroke current belongs in the structure, not on the transmission line. My advice is: "Ground until you run out of gas or run out of money!" Every amp which goes through the tower to ground is one amp which cannot enter the equipment. If one ground rod is good, two are better and three are still better. Not much better, perhaps, but . . . better. The magic number seems to be six feet. If you can separate paralleled ground rods by at least six feet, it pays to double them up.

At the spot where the coax leaves the tower, you can shunt and isolate, applying both of our protection principles. Make a solid bond between tower and coax sheath at the point of takeoff. Given jacketed cable and a bond at the top only, the entire voltage drop of stroke current through the tower is available to drive current down the coax. When the sheath is bonded at the bottom, the driving voltage is only five to 10 percent of the total voltage drop across the tower. The manufacturers of coaxial transmission line offer grounding kits, even for jacketed cable. It's unfortunate they sell so few of them.

Introduce Change of Direction

By bringing the line off the tower with the sharpest bend permitted by the cable construction, we introduce the first isolating impedance. It results from the spot impedance of an abrupt change of direction to an extremely high current. Check the minimum bending radius of the cable, and use it — no more and no less. This impedance isolates — it keeps current out of the line — and that's what we want.

Continuing down the transmission line run, introduce a change of direction at the minimum permissible cable bending radius at every reasonable opportunity. And, provide an additional grounding to sheath whenever possible.

As a minimum, make it a point to ground at points where the line is supported on poles and where it enters a building.

It's wise to take at least part of the transmission line run through conduit. The conduit appears as a continuous shorted turn to the magnetic field created by transient stroke current. The conduit itself serves as a very effective build-out (or isolating) impedance.

Going from hard line to RG8 or RG58 at the equipment end, wind the surplus semi-flexible line into a coil. This is your last chance to introduce inductance where it will do some good. At this point, inductance ceases being a friend, and becomes your enemy.

"One Point" Grounding Is Preferable Approach

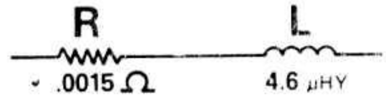
Whatever you do, don't bring the transmission line into the cabinet at a point removed from cabinet ground, assuming the stroke current which enters the cabinet does exit through cabinet ground, the only route is through the very equipment you want to protect.

And, note that you can get a voltage drop across the impedance of the cabinet. This puts unnecessary stress between equipment bolted to the top of the rack and that bolted to the bottom.

The preferable approach is "one point" grounding. Bring the coax into the cabinet adjacent to the grounding conductor where you can make a good, low-impedance, bond. This keeps the current outside the cabinet, where it does no harm, or, at least, harms something other than your equipment. This gets us to the subject of cabinet grounding. (See Figure 8.)

Figure 8.

10 FEET, #12 AWG



ALMOST PURE INDUCTANCE

Consider 10 feet of number 12 wire, resistance is small, inductance is substantial. Even at frequencies below the standard broadcast band, the impedance is almost pure inductance. To the lightning stroke current waveform, this wire isn't a *conductor*. . .it's an *inductor*. Four-point-six microhenries doesn't sound like much, does it? Look what happens when we introduce lightning-style transient currents. (See Figure 9.)

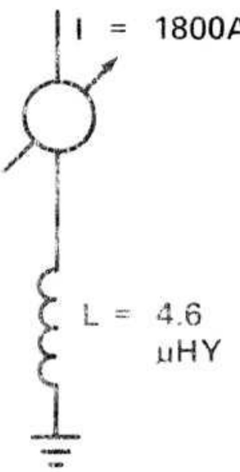
Voltage drop across an inductor is L times D-I over D-T. D-I is current at crest. We've assumed 1800 amperes, 10 percent of a median lightning stroke. D-T is the rise time, two micro-seconds from zero to crest. The drop across 10 feet of wire is 4100 volts.

This can happen in practice, and it does!

This antenna collects a median lightning stroke 18,000 amps at crest. Half of the strokes are even more potent. There are two paths to ground. We assume a good shunt path through the tower to ground. It takes 90 percent of the current, leaving 10 percent, 1800 amps, to ride down the transmission line.

Eighteen hundred amps flow into the cabinet, and 1800 amps are going out! There's only one intended exit — 10 feet of number 12 wire — almost pure inductance to the lightning transient. The voltage drop across that wire is more than 4,000 volts. The cabinet, and everything in it, is suddenly 4,000 volts above its own ground reference.

Figure 9.



$$E_L = \frac{di}{dt} L = \frac{1800 \times 4.6 \times 10^{-6}}{2 \times 10^{-6}} = 4140\ V$$

The power transformer core and, perhaps, the secondary also, rises along with the cabinet. One side of the primary is connected to AC-neutral, a remote ground, usually of respectable quality. Four-thousand volts tries to break down the insulation of the transformer and the wiring on the primary side. If the insulation isn't good for 4,000 volts, you just lost a transformer, or something else.

The same stress tries to break down the series combination of control panel and telephone line protector. The protector is designed to break down — it does so at about 1,000 volts at this waveform. Unless the control panel can survive longitudinal stress at around 3,000 volts, it just bit the dust.

We expect the telephone and power facilities to carry metallic and longitudinal stresses into our equipment, and we make provision in design to protect the equipment from them. You can now see the situation working in reverse. Because of less-than-ideal grounding of the cabinet, we're in a position to exert stress back into the power and telephone facilities.

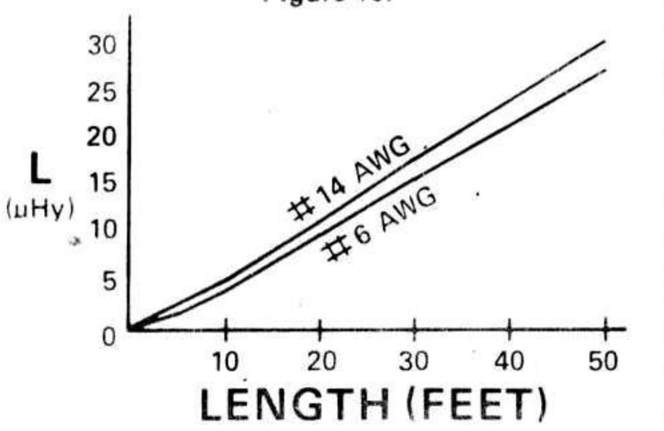
Controlled Gap Relieves Stress On Power Transformer

You can relieve the stress on the power transformer and primary wiring with a controlled gap — a gas tube, for example — between cabinet and AC-neutral. The gap breaks down before the goodies, brings AC-neutral to near cabinet potential, and passes the transient to the power company. (If you *are* the power company, it passes to another department). Codes and other rules permitting, a solid metallic bond from AC-neutral to cabinet does even more, and it does it with less.

The same approach works to protect the control panel. Two single-element gas tubes or one three-element gas tube relieve the stress on the control panel. Stroke current bypasses the panel as it does its thing with the telephone protector.

Besides protecting ourselves from the consequences of

Figure 10.



voltage stress, we should attempt to reduce the magnitude of the stress. (See Figure 10.)

Since voltage drop varies directly with inductance, it behooves us to reduce the inductance of the cabinet grounding. Inductance varies directly with length and inversely with diameter, but length has the most leverage, by far.

Half-length drops inductance by 55 percent. Double-diameter, which means four times the copper and four times the money, drops inductance only nine percent. It follows, that ground wires should be short and ground wires should be fat, but it is much more critical that they be short.

It is important, too, that ground wires be straight. High current resist a change in direction. A right angle bend constitutes a spot impedance. When you must change direction with a ground run, make the most sweeping arc which the circumstances will allow.

Keep grounding runs in the clear. Mutual inductance to other conductors will increase the apparent inductance of your own ground lead.

Double up on ground wires when possible. Two wires are always better than one. Two wires are much better than one when they are separated by at least six inches to minimize mutual inductance.

In running ground wires, avoid sharp bends like the plague. Never bundle or cable a ground wire with anything. Most especially, do not cable a grounding wire with your own power or telephone facilities. You don't want to couple stroke discharges back into your equipment by another route.

Can you think of a worse cabinet ground than the third wire of an AC power cord? It's not short, fat or straight. It is tightly coupled to the AC feed to the station. The third wire is justified for personnel safety, but it should be paralleled with a decent lightning-quality ground.

A ground wire run along metal may as well be clipped for all the good it will do. Mutual inductance from the metallic wall raises the impedance to lightning discharge currents. Ditto for a ground wire run inside conduit. A ground wire through conduit is like a ground wire through a low-pass filter. The conduit, itself, is a much better grounding for lightning protection than is a wire contained within the conduit.

While I can't offer immunity from lightning and its effects, I have given you some simple preventative approaches: ground cabinets adequately, shunt, and then isolate. These tips will help you "live with lightning."

JULY 77

Letters

Lightning Comments

Mr. Guthrie's article, "Learning to Live With Lightning", in the May issue was informative and useful.

I do think, however, that he should have pointed out the advantage of flat copper strap for grounding instead of round wire. The self inductance can be reduced from 35 to 45 percent for the same weight of copper.

Taking the standard medium-frequency self inductance formulas (Terman, *Radio Engineering Handbook*, 1st Ed. p. 49 Eq. [16], and p. 51 Eq. [26]), the self inductance for a No. 6 wire of 0.02062 sq. in. cross section and for a 2" wide copper strap 0.01031" thick, 0.02062 sq. in. cross section works out for various lengths as indicated in the chart below.

Length Ft.	L_W uH	L_S uH	Reduction in L, Round to Flat, %
10	5.67	3.22	43
20	12.18	7.29	40
30	19.01	11.67	38.6
40	26.05	16.27	37.5
50	33.25	21.01	36.8

Copper flashing used for roofing is good for this purpose, and we have found this works very well using several wide strips as short as possible on the tower base and equipment cabinets and, as Mr. Guthrie advises, avoiding sharp bends.

One of the common horror stories we see often are cases where masts have been mounted on roof tops in some cases without even a pretense of grounding except accidentally through conduits or guy wires.

R.W. Johnson, P.E.
Consulting Engineer
Ben Lomond, Calif. 95005

Mr. Guthrie replies:

The "name of the game" is to reduce the self inductance of grounding conductors. In general, one should make the choices which tend toward making them short, fat, straight, and isolated from other conductors and conducting surfaces.

And, as Mr. Johnson points out, geometry does make a difference. Flat strap does give you better grounding per pound of copper than does round wire. Although copper strap isn't readily available from the sources which supply most radiomen, the suggestion to go to the "friendly neighborhood" roofer is a good one.

I would add the suggestion that the distributors which serve the (building) lightning protection industry are an excellent source of conductors, hardware and tools.

Yes, indeed. The sight of antenna support structures which are completely devoid of intentional grounding can give you a bad case of the "shakes." I'm almost as shaken upon seeing a station which is grounded only by the third wire in an AC cord.

Dealers' Conference

Dear Judy:

I would like to thank you for the opportunity of serving as a guest panelist at the National Business Radio Dealers' Conference. I have had several phone calls and letters from others attending the meetings and all agree it was one of the most informative, well organized conferences held in a long time.

I look forward to such a conference becoming an annual event. You certainly made everyone feel comfortable; the meetings provided a good time as well as a learning experience. Thanks again.

Jerry D. Miller
Miller Communications Inc.
Fisk, Missouri 63940

Our next Dealers' Conference will be held March 20-22, 1978 at the Regency Inn in Denver, in conjunction with the IEEE Vehicular Technology Group meeting. These two groups will form the nucleus of activities for an industry-wide Land Mobile Radio Week. — Editor.

LESSENING LIGHTNING'S EFFECTS

By A. K. "Kenny" GUTHRIE
COMMUNICATIONS EDITOR

To paraphrase our founding fathers in this bicentennial season, "All lightning strokes are not created equal!" Just how unequal they are is indicated by this data taken during extensive observations on the Empire State Building:

100% of the strokes exceed 0 amps at crest
50% of the strokes exceed 18,000 amps
10% of the strokes exceed 58,000 amps
1% of the strokes exceed 120,000 amps

Although the fact that all strokes exceed zero amperes shouldn't come as a complete shock, we start reasoning from this point. If you have an installation which is a real "dog" and can survive no more than zero amps, you can look forward to a wipeout EVERY TIME your site is visited by lightning. But, if you "beef up" the installation so that it can survive an 18,000 ampere stroke (which is no big deal), HALF of the strokes will go to ground without doing damage. Get to the point that the installation can survive a 58,000 amp discharge, and NINE OUT OF TEN of the lightning strokes which come your way can be ignored.

There are a whole lot more "little" strokes than big ones! Every action which pushes the survival point up the ampere scale, even if slightly, gives a LEVERAGED improvement in the interval between damaging strokes. You will never know the exact crest current which your installation can survive, and you will never know the exact magnitude of the current which finally creams it. But, you do know that every constructive action which you take improves the probability of survival (or increases the interval of peace between the incidents of trouble).

Though the crest current is massive, its duration is brief. The typical stroke reaches crest in 2 microseconds; it decays to 50 percent of crest value in about 40 microseconds.

You can look at the lightning source as a constant current generator. The driving voltage is the potential developed between cloud and earth--nothing you can do about that! The source impedance is the loss through the atmosphere between cloud and a point near earth--that's beyond your control also. The impedance of the object struck is a miniscule part of the total and has little effect upon the current.

The stroke current, at whatever value it is, can enter your equipment directly via a "hit" to the antenna system or to connected power or telephone facilities. Once "in" it's going out, hopefully through the grounding provided. We hope, too, that the current will choose a non-damaging path between point of entry and point of exit.

Stroke current can affect your apparatus indirectly as distributed currents couple inductively to overhead or buried telephone or power facilities. The consequence of this coupling is longitudinal voltage stress between circuits connected to these facilities and the grounded portions of the gear.

It adopting a "survival" philosophy, the most critical point is the antenna system. If it is at a good VHF site, it's the highest thing around. The same factors which make it attractive for communication make it an attractive target for lightning. To make matters worse, this attractive target is directly connected to the equipment by a rather solid conductor--the coaxial cable shield.

You're faced with a filtering job. There is a constant-current generator, poised to deliver a brief but brutal shot to the antenna system. There is a heavy conductor, waiting to move this current, or a portion of it, into the equipment. Briefly stated, our objective is to keep this current out of the goodies! Equally brief, our approach is common to 'most any filtering task: SHUNT, THEN ISOLATE.

Every ampere taken to ground through a shunt path is one ampere which doesn't have to be dealt with inside the vulnerable equipment.

Since the shunt current is inversely proportional to the shunt impedance, we try for the lowest impedance we can reasonably get, on every shunt path to ground.

Having provided shunt paths--a predetermined preferred route for the stroke current--we multiply their effectiveness by adding isolation in series with the undesired paths. We deliberately increase the impedance of the path we want the stroke current to avoid--the path which leads to our equipment.

Inductance is the prime element of these impedances. Inductance can be friend or foe. We want low inductance in the shunt (grounding) conductors. We want high inductance in the path which leads toward vulnerable gear. There is a paradox here. We may recommend techniques in some cases which we avoid like the plague in others! The inductance used or avoided (as the case may be) may be lumped as, for example, a few turns wound in semi-flex coax cable. It may be distributed, as we run conductors in conduit. If may be the spot effect afforded by an abrupt change in direction of a conductor which carries high current.

Here's how to apply the "SHUNT, THEN ISOLATE" technique, starting from the antenna and working down:

SHUNT TECHNIQUES

- Use an antenna with directly grounded elements
- Solidly bond the grounded portion of the antenna to the grounded support structure (special attention to outriggers)
- Optimize tower grounding--ground until you run out of ideas or run out of money
- Ground coax cable shield to the tower at point of takeoff (essential when jacketed cable is used)
- Add auxiliary grounds to transmission line as convenient (especially at supports and building entries)

ISOLATION TECHNIQUES

- Bring coax cable off tower with minimum bending radius permitted by cable spec's
- Introduce as many right angle bends in the cable run as you can
- Route cable through conduit
- Wind semi-flexible cable into a coil of several turns and any convenient diameter near entry into equipment cabinet

If you apply these techniques, you'll have fewer amperes to dispose of in the equipment and you'll enjoy longer intervals between disasters. But...some strokes will still deliver current, and this current is going to go somewhere.

Once admitted to the cabinet, this residue of stroke current can choose (or divide) between three possible sinks:

- AC Neutral, after breaking down a power transformer or the primary wiring;
- Telephone Line Protector Ground, after breaking down your control panel and a line protection gap; or
- A cabinet grounding conductor.

Given a choice, I recommend the last one!

Every cabinet which has an antenna connected should have an effective ground. To be effective, it must be able to handle the current (#6 AWG Solid is reasonable), and its inductance should be minimized. GROUND WIRES SHOULD BE:

- SHORT. Inductance increases with length.
- FAT. Inductance decreases with diameter (but the major leverage is in length)
- STRAIGHT. Avoid bends which approach a right angle. When you must change direction, make the most sweeping arc which the realities of the installation will permit.
- IN THE CLEAR. Avoid mutual inductance effects. Keep grounding wires out of conduit, away from metal surfaces, and away from other wiring.

Above all, DON'T bundle grounding conductors with power or telephone conductors. The last thing you want is a path which couples the effect of stroke current back into your gear.

Try as you will, your grounding will have some inductance and there will be a voltage drop ($E = diL/dt$) across it. Under stroke conditions, the cabinet voltage will rise above its own ground reference, and certainly above the remote AC neutral ground and the remote telephone protector ground. This puts longitudinal stress from the cabinet toward these remote grounds, again putting stress across AC wiring in the station (including transformers) and the control panel.

A quick and effective way to remove stress on the AC side is to tie AC Neutral directly to the chassis. This transfers the stress to the AC supply wiring. You may blow a meter ring off the pole, but the station survives! If a solid connection doesn't appeal to you, a gas tube between AC neutral and chassis is also effective.

Control panel protection calls for a pair of single-element gas tubes (or a three-terminal gas tube) connected between each side of the telephone line and chassis. A stress between chassis and the telephone line protector will break down the gas tube, instead of wrecking the control panel.

This leave us with only one major stress mechanism--the effect inside the cabinet as stroke current moves from point of entrance to point of exit. There is a chance of burning a conductor open; there is a possibility of developing damaging voltage drops within the cabinet. The easy way to "solve" this problem is to avoid it. Keep the current out of the cabinet. Bring the coaxial cable into the cabinet adjacent to the ground wire (usually at the bottom). Then, bond the coax shield to the ground wire at the cabinet entry.

The major stresses in most installations are those which result from disposing of the current collected by the antenna system. Much of our damage arises as we deliver these currents to our power company and our telephone company. The techniques discussed will minimize both the current magnitude and our own internal damage.

Of course, it isn't wise to ignore the transients which come the other way--from the power and telephone networks into our boxes. Whole families of protective devices of proven efficacy are available--space doesn't permit a survey of them in this article. For now, we merely point out that a little series inductance in the power and telephone lines can have a very beneficial effect.

There's no point in wiring telephone connections like one was wiring a substation! Small-diameter twisted jacketed pair is somewhat inductive, and is the thing to use. It helps to run it in conduit.

On the power side, running the feed through conduit for at least 20 feet will multiply the effectiveness of a quick-response transient protector on the load side, and will tend to protect it from catastrophic damage. You can introduce inductance by tieing several hard knots in a power cord (for an interesting exercise, try calculating the flux linkages). A voltage regulating transformer provides transient protection in addition to its other significant benefits.

There's no one "magic wand" of overwhelming significance in this writeup. It's just a bunch of "little things." But, "Every little thing helps."