34

Lightning Protection for Broadcast Stations

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Lightning strikes to broadcast transmitter facilities are of course created by atmospheric electricity, and have been responsible for significant losses of both equipment and revenue time. These losses have at times been extensive and resulted in the demise of the operating firm. Within the range of the writer's experience, equipment losses alone have ranged to over $40,000 in one strike.

Atmospheric electricity also creates other forms of hazard to radio stations. The strong electrostatic field, which can reach 5 kv per centimeter, charges the isolated guy wires and tower, much like a capacitor. A subsequent stroke to a nearby target, or a cloud-to-cloud discharge, changes this electrostatic field drastically. The antenna elements compensate by dumping the charge, across insulators and into the earth. The results of this phenomenon known as "guy snapping" are twofold: large reflected waves are sent over the transmission line into the transmitter and the insulators eventually breakdown due to the "tracking" effect. They also have been known to explode as the result of absorbed water vaporizing rapidly.

Damage from atmospheric electricity is also manifested by its influence on the primary power to the station. Most stations in high lightning incident areas suffer as much equipment damage and downtime from primary power surges induced by lightning, as they do from direct strikes to the incoming phase conductors, nearby or at some distance away from the station; or by induced transients resulting from large field changes in areas where these power lines pass through. Either form can be deleterious to solid state electronics in particular. Present day surge protection is designed to deal with this phenomenon; however, they often do not respond fast enough for some of these transients or they allow too high an overvoltage, and when used alone, may prove to be only partially effective.

Transients induced on the remote signal and/or control lines will also damage equipment. The causes are the same as the power line surges and transients. The treatment is usually much more difficult.

To understand the reason for these forms of lightning-induced damages, it may be well to review some of the more significant physical characteristics of atmospheric electricity. The following is a composite data taken from many sources:[1]

1. Stroke charge content is from 2 to 200 coulombs.
2. The peak currents achieve values between 2,000 and 400,000 amperes.
3. The stroke current flow durations vary from about 1 to 100 milliseconds.
4. The current rise times vary from less than one microsecond to over 10.
5. The relaxation or recharge time requires more than 40 sec., and can take many minutes.
6. The average field strength under a storm is between 10 and 30 kv per meter; it rises to between 3 and 5 kv per centimeter just before a strike.
7. The cloud-to-earth potential can exceed 10^8 volts within an active storm area.

One of the more significant of these factors is the shape and rise time characteristic of the impulsive type lightning stroke. While the non-impulsive or so-called "hot" stroke rises slowly to its peak, taking 100 milliseconds or more to abate its energy, it is not so with the impulsive stroke. It can rise to peaks averaging 20,000 amperes within *less than one μ sec.* This factor is the cause of most lightning damage to broadcast stations. This is particularly different when considered in conjunction with stations having high resistance grounds; or the AM station without any path to ground for these high frequency, high energy levels. As an example, consider a FM or TV station with a five-ohm ground; the average 20,000 ampere stroke will develop about 100,000

[1] *Atmospheric Electricity*, J. Alan Chalmers, Pergamon Press, 2nd Edition, 1967.

volts between equipment ground and true ground. Equipment not prepared to accept these kinds of transients will be damaged.

Philosophically, protection as a subject can be based on either remedial principals or preventive principals. A remedial form of protection is based on the assumption that lightning must occur in the area of concern and the protective system must be designed to deal with all of its manifestations, within the systems. Of course, the effectiveness of such an approach depends on the engineers' ability to identify all manifestations and provide adequate means of protection. Conversely, the preventive scheme only deals with the source of the problem, the atmospheric electricity. Although the specific designs must of necessity be prepared by specifically trained engineering consultants, this chapter delineates typical configuration and application criteria.

PROTECTION AGAINST STRIKES TO TRANSMITTER FACILITIES

The protection of transmitter systems against direct lightning strikes involves dealing with the tower. Because of its height above earth, and its metallic nature, it makes an ideal lightning collector (or Lightning Rod). Conventional remedial forms of protection amounted to the use of lightning rods on the top of the tower with Ball or Horn Gaps at the base of the tower and good grounding to carry away the high currents. Design details may be found in Lightning Protection.[2] Over the years these concepts have proved to be useful in reducing the deleterious effects of the strikes but were never 100 percent effective. As an example, reference is made to the case history of Radio CKLW recorded in Lightning Prevention.[3]

To prevent damage with any degree of assurance, it is necessary to prevent strikes to the antenna towers and the feed lines. A recent development by a California company has made this possible through the development of a system called the Dissipation Array.[4] Since 1971, this system has proven successful in preventing lightning strikes for innumerable installations throughout the world.

The Dissipation Array System is applicable to AM or FM Broadcast Stations, as well as TV. It consists of three subsystems; the Dissipator, the Ground Current Collector, and Service Wiring. The installation must be designed specifically for each station to be protected by a competent consultant, with experience in the Dissipation Array System.

The system operational concept is based on the "Point Discharge" phenomenon; where a sharp point in a strong electrostatic field is found to leak off the charge by ionizing adjacent air molecules. Where a difference of potential in excess of 10 kv exists between the point and its surroundings, a current will continue to flow. Since the atmospheric electricity generated by charged clouds can exceed 10^8 volts prior to discharge and the ion current flow is proportioned to the square of the difference in potential, the charged clouds provide all the motivating force required. The overall concept is illustrated by Fig. 1, using one possible array design.

The Dissipators are the primary component of the Dissipation Array System. They must be designed to take advantage of the large gradient formed over the towers by the electrostatic field. There must be a sufficient number of points, properly oriented, located, and separated, to create the required ion current flow and an associated space charge to shield the area of concern. These Dissipators take various shapes and forms, usually mounted on top of each tower.

Several forms of the Array are illustrated by Fig. 2, 3, and 4. Their static weight varies from 60 to 250 pounds. The effective wind loading area varies from ¾ to 3½ sq. ft., acting at the top of each tower; variations in these parameters are the direct result of design tailoring to fit specific requirements and constraints.

Antenna loading effects are a prime consideration for the AM Broadcaster. The potential design variations for the Dissipators are such that the antenna top loading effect can be varied over a wide range, starting from less than 0.1 percent to over the equivalent of a 40-ft. tower

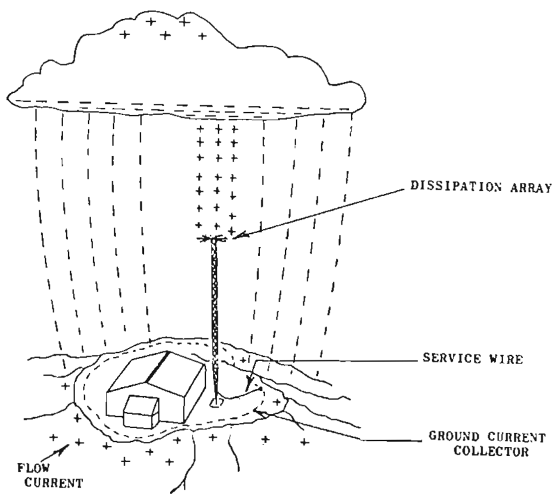

Fig. 1. Typical dissipation array installation, FM broadcast station.

[2]*Lightning Protection*, J.L. Marshall, Wiley, 1973.

[3]Lightning Prevention: A Year's Trial, Staff of CKLW, *Broadcast Management Engineering*, April 1974.

[4]A proprietary system produced by Lightning Elimination Associates, Inc., of Downey, California.

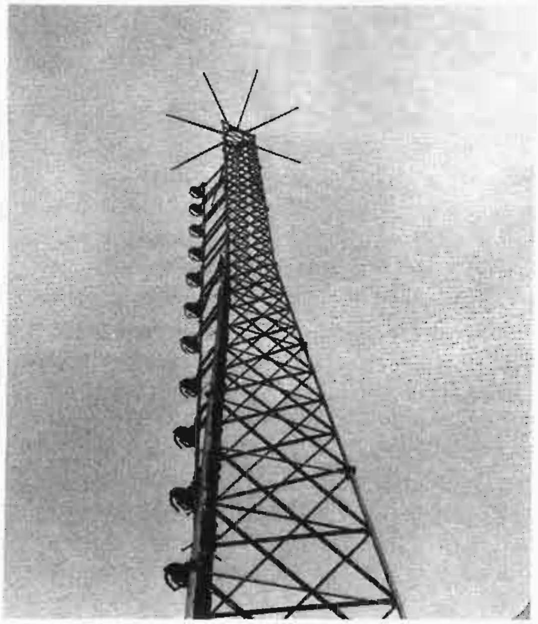

Fig. 2. Umbrella array, FM broadcast station.

section. The array/tower design can be integrated such that the cost of one or two tower section can be saved. As a result, the Dissipation Array System may actually cost less than the antenna alone. These kinds of data must be obtained from the supplier. (See Footnote 4.) Fig. 2 illustrates a typical Umbrella Array, used for the protection of FM stations; a form of this may be used for AM stations desiring some top loading. Fig. 3 illustrates another possible configuration used for the protection of AM where minimum top loading is required. Fig. 4 illustrates one possible configuration for the protection of TV stations and some FM stations where the tower top is not available for use. Note that a Dissipation Array System does not have to be the highest

Fig. 3. Panel array, AM broadcast station.

Fig. 4. Spreader array, TV station.

element on the tower. It can be several hundred feet below the top, if properly installed.

The Ground Current Collector is designed to collect the surface charge induced by the atmospheric electricity, and provide a preferred path from the earth to the dissipating medium. Since this charge is on the earth's surface, so also must the collector be deployed there. Applications for the different kinds of broadcast stations are somewhat different, more because of economics than the technical requirements.

For Broadcast Stations in the LF to 1,500 Hz range, the collector requirement can be satisfied by the usual ground mat or counterpoid radials, as long as they are spaced at no more than 5°. This may also be true of other stations using similar counterpoids.

For FM and TV stations, a Ground Current Collector must be installed, approximately as illustrated in Fig. 5. It may also serve as the station electrical ground. In contrast to the conventional lightning rod grounding system, this system need make only good ground contact. It is buried at about 12 in. in depth, surrounding the tower and buildings, and tied into tower and building with at least three radials. The wire may be a six or eight gauge copperweld, with short ground rods of about four ft., driven at about 50-ft. intervals. Proper operation of this subsystem is totally dependent on a well-integrated *system* design.

The Service Wiring is important in that it is the means whereby the charge is conducted from

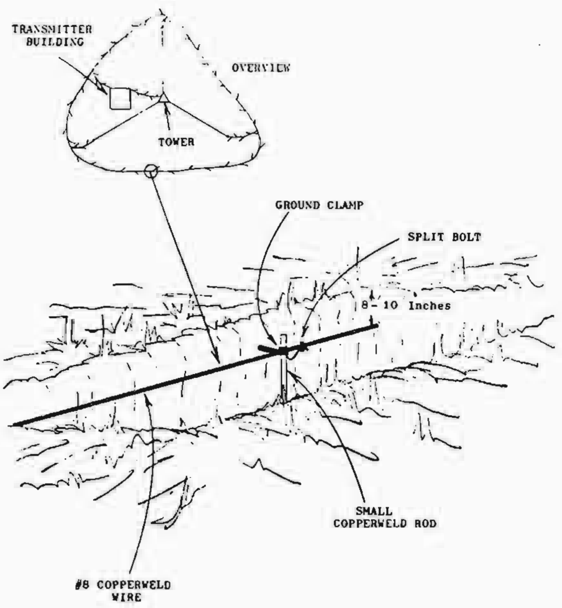

Fig. 5. Typical ground current collector installation.

the Ground Current Collector to the Dissipator. The design objective is to assure a low resistance, multiredundant path for the dissipation current. For FM and TV stations this presents very little difficulty since the tower itself is grounded and usually of low resistance. However, at least one single conductor is recommended to run the full length of the tower, to assure no loss of continuity.

For AM stations with base insulated towers, some form of dc path is required from the tower to earth. A Static Drain Choke or grounded ¼ wave stub will usually satisfy this requirement. If this does not exist, some form of choke feed must be devised. The remainder of the subsystem can be as for the FM station and illustrated by Fig. 1.

PROTECTION AGAINST GUY WIRE INSULATOR ARKING

Since the electrostatic fields under charged clouds can achieve a potential of 3 kv per centimeter of height above the earth, an insulated guy wire suspended at an average height of 100 meters can take on a potential of 30 million volts just prior to a local discharge. Even if a stroke does not hit the antenna system. the collapsing field around the tower and its guys will leave a bound charge on the guy wire. The results are so-called "Secondary Arking," where the charge jumps the insulator in a cascading effect, on a path toward earth. There are two ways of eliminating, or reducing this phenomenon to a tolerable level. This may be accomplished by providing some form of a leakage path for the bound charge, and/or by reducing the field in the antenna farm area.

One option involves the use of Dissipating Guy Wires, either with or without resistive type insulators. This concept provides a means for leaking the charge off slowly through a form of corona. This charge, being no longer bound to the wire by its "smooth" round surface, will leak off at an exponentially decaying rate, under the right conditions.

A second option involves the use of a larger Dissipation Array System for the transmitter area protection. With this concept, the Dissipators in particular are "oversized" to provide a much greater dissipation capability—the design objective being to minimize the field excursions within the antenna or antenna farm area. This can require up to a factor of ten greater dissipation capability than for lightning stroke prevention alone.

The use of resistive insulators alone has improved the situation; however, inherently slow response time limits their potential effectiveness. Whereas their usefulness was limited because of the destructive effects of a lightning strike; use in conjunction with a Dissipation Array System would eliminate that hazard.

Another option involves the use of tunned chokes in place of the insulators. To implement this concept, each insulator would be replaced with a specially designed broad band choke, which would exert maximum impedance to the operating frequency; and yet pass the slowly varying dissipation current and/or the induced charges created by atmospheric electricity. The drawback is related to the fact that it must be tuned to or near the operating frequency. (See Footnote 4.)

PROTECTION AGAINST TRANSIENTS INDUCED INTO THE ANTENNA FEED SYSTEM

Open wire Transmission Lines are particularly vulnerable to induced transients created by the rapid field changes associated with atmospheric electricity, even though there are no direct strikes to the transmitter area. Local cloud-to-cloud discharges can change the field strength by over 30 kv per meter. As a result, transmission lines set 3 meters above earth could easily experience transients of up to 90-kv peaks. Protection against this form of transients can take several forms. These may be classified as remedial or preventative.

Typical of the remedial forms is the Magniphase Solid State Line Protector sold by Continental Electronics,[5] or its counterparts, the Line Protection Unit sold by RCA,[6] separately or as part of their transmitter package. These subsystems are designed to protect the transmission lines, antennas, and antenna tuning units from damage due to line faults, arks and overloads, particularly those created by large variations in the atmospheric electricity. These units are designed to sense the Transmission Line impedance and temporarily interrupt the transmitter output when significant changes from the norm occur. Design data and/or installation instructions are available from the suppliers. (See Footnotes 5 and 6.) The major disadvantage with this form of protection has to do with its impact on station performance. Continuous interruptions and complete shutdown are not infrequent, particularly under heavy lightning conditions.

A preventative concept, based on a Dissipation Array derivative can also eliminate this hazard or reduce its influence to acceptable levels. This is accomplished by generating an ion screen that effectively shields the transmission line from the atmospheric electrical activity. A Dissipator of some form is required to protect the full length of the line, in this case, elevated well above it. The Ground Current Collector must run parallel with the line, just below the surface of the earth, and connected to the transmission line grounded wires at each support. One such installation is illustrated by Fig. 6.

A second option would involve use of many ground wires surrounding the center conductor, such that a Faraday Shield effect is achieved, spacings of not more than 10 cm. may be required to satisfy this requirement.

A Buried Coaxial Feed will normally eliminate the transients induced by changing fields created by atmospheric electricity. However, if the runs are of significant length, and/or proceed through an area where lightning strikes to the towers are possible, several forms of induced transients are very probable. These forms come about as the result of movements of the charge induced in the earth due to the presence of a charged cloud. If the coax is in the presence of this charge and a local strike occurs to one of the towers, that charge will take the most conductive path to that tower, and very often the coax shield will provide that path. The resulting transient induced on the center conductor can be of greater magnitude than that induced on elevated/open transmission lines. These lines are also subject to direct strikes and in poor soil can "collect" strikes from as far as 100 ft. on either side of the line.

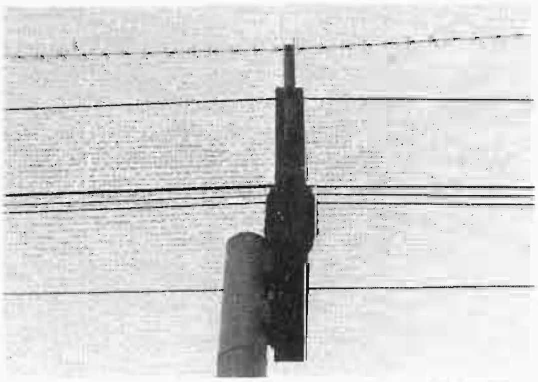

Fig. 6. Typical dissipator installation for an open-wire transmission line.

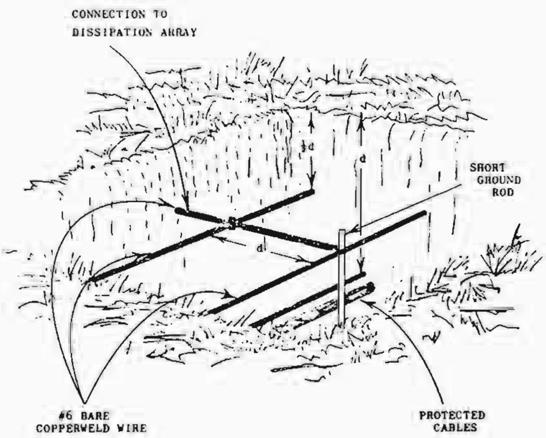

Fig. 7. Recommended coaxial feed installation.

Protection against these phenomena can take two forms. In most cases, protection of the tower area with a Dissipation Array System will eliminate the direct strike and perhaps much of the induced transients as well.

A second option involves the use of two shield wires, buried in the same trench, at one-half the distance from the surface of the earth to the coax, on 45° angles from the centerline, as illustrated by Fig. 7. About a 6 gauge (5 or 6 mm) copper wire should be used, with short ground rods of about 1 meter length, spaced about 16-meter intervals. Where a Dissipation Array is used, these shield wires should be connected directly to the Dissipator.

PROTECTION AGAINST POWER LINE SURGES

With the advent of solid state electronics, broadcast facilities have become more susceptible to variations in the primary line voltage. Electrical storms create several forms of transients which appear on the primary power lines, as a significant variation in the voltage. These

[5]Continental Electronic Mfg. Co., Dallas, Texas.

[6]RCA, Broadcast Transmitter, Division, Camden, New Jersey.

variations or transients are created by two related but different phenomena; i.e., by direct strikes to the lines, close-in or at some distance, and induced transients. They are related in that they are created by atmospheric electricity; they are different in both magnitude and immediate cause.

A Direct Strike to a power line serving the station will dump between 2 and 200 coulombs of charge on the line, within 1,000 msec. If it is an impulsive stroke, it can reach a peak of 20,000 amperes in less than 1 μsec. If it strikes the line within one or two miles of the station, much of the high frequency energy will pass through the conventional surge protection. The result will be a loss of many solid components.

Induced Transients are created by the same mechanism that causes "guy snapping" or insulator ark-over; i.e., the large excursions in field strength under the storm system. However, the major difference is in the Q of the lines. Since they have a much greater storage capacity, much larger charges can be induced into the power lines. The results on the broadcast station are similar to the direct strike. Deleterious transients are coupled into the station.

Protection can be provided against both situations. One option involves protecting the sensitive portion of the incoming distribution lines with a Dissipation Array concept similar to that suggested for the Transmission Line. Since there may be many miles of line involved, this may not be economically feasible. A second option involves use of a specially designed low-pass filter, in conjunction with one of several forms of conventional surge protectors, that are commercially available. Because of the variation in primary voltages, phases and frequencies, each of these must be designed individually. For a specific requirement a variation of this concept is to design the station's electrical power feed such that the incoming lines are passed through about 50 ft. of well-grounded metal conduit before entering the transmitter building. At the point of entry a high speed surge protection such as those commercially available from several suppliers[7] can be reasonably effective. However, some of these surge protectors have to be changed periodically, in areas of high lightning activity.

In cases where the foregoing is not practical and/or where a higher degree of protection is required, the specially designed low-pass filter concept is more attractive. A proprietary system, based on this concept is available through Lightning Elimination Associates, Inc., of California. A more conventional but less effective form of protection can be obtained through use of any one of the commercially available surge protection devices by itself.[8] These devices are designed to divert the surplus charge to ground by ionizing a conducting gas when the voltage exceeds a preselected voltage. However, when used alone, they often do not ionize in time to prevent the passage of some high frequency energy resulting from nearby strikes. Further, their successful use depends on the availability of a "good" ground; where good ground may be defined as one ohm or less. Greater resistances will permit in excess of 20,000 volts to develop, for short instants, between equipment and/or equipment and true ground.

CONCLUSIONS AND RECOMMENDATIONS

Modern technology has tamed the rigors of atmospheric electricity. However, as in all scientific disciplines, the solution to this problem has been removed from the realm of the novices. Lightning strikes to broadcast stations can be prevented, damage from transients can be eliminated; however, a qualified consultant is required. To be sure of the results, check the guarantee. Guarantees against lightning strikes and lightning damage are available.

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[7]Typical of this kind of protection is surge Eliminator, Model LEA-SE-220 marketed by Lightning Eliminator Associate or the ACR-1000 marketed by Transector Systems.

[8]The Model 1235-01 Surgitron marketed by Joslyn Electronics Systems Division.