Minimizing Lightning and Static Discharge in Broadcasting

Lightning and static discharge represent two of the most damaging and unpredictable events faced by broadcasters. Together or separately they are responsible for hundreds of outages per year along with countless equipment failures.

In order to reduce the effects of either, it is important to understand how they occur and, as importantly, how they make their way into the broadcast system.

Static discharge occurs when there is a buildup (surplus) of electrons on a surface and a depletion of electrons on another nearby surface. As the differential increases, the potential difference, or voltage, between the two increases. Eventually, the voltage differential is great enough that the dielectric which separates the two surfaces – air or plastic or whatever medium is between them – breaks down and the electrons flow from the surplus area to the depleted area, equalizing the charge.

In many cases, this flow is harmless…if the charge is small enough or if the flow of electrons from one surface to the other is slow enough. However, should the charge be too large or the discharge too rapid, serious damage can be rendered to either of the surfaces and to any other elements which may lie in the path of the discharge.

As an example, dry air has an approximate breakdown voltage of 30,000 volts per inch. That means that should the voltage between two surfaces an inch apart exceed 30,000 volts, there is a high likelihood that an arc will occur from one surface to the other. When the arc occurs, the air ionizes around it, lowering its breakdown voltage and keeping the arc "alive" until the voltage on the two surfaces is nearly equalized.

If the two surfaces are small, there are very few electrons which actually flow from one surface to the other. However, imagine two metal plates 10 feet square, about an inch apart. The voltage differential may include many – many – more electrons before the 30,000 volt arc-over limit is reached. At that point, the sudden rush of these many electrons causes instantaneous and significant heating – enough to do damage to both surfaces.

Taking the example one step further, if one of the surfaces is above the earth's potential, by virtue of being insulated – either intentionally or unintentionally, and the other surface is near ground potential, the breakdown may occur as the electrons which have built up on the insulated surface try to reach earth potential. The path may include the second, near-ground, surface. But because this surface is only near earth ground, the path continues to true earth, heating and damaging everything in the path.

Lightning is most easily explained as an extremely high static discharge. Whether cloud and vapor movement cause a surplus or depletion of electrons in the air, equalization occurs when the breakover voltage – sometimes many hundreds of thousands of volts – is reached. Lightning's discharge is extremely fast – on the order of 20 to 50 microseconds.* As a consequence, many electrons are moved very quickly from one surface to another and the heating effect is pronounced, often with serious damage attached.

Further, lightning need not be a "direct hit" in order to cause damage. Inductive and capacitive coupling between the point of the strike and a radio tower, even a significant distance away, can cause high currents to flow in the tower even though the discharge actually occurred elsewhere.

Minimizing lightning and static discharge damage:

The first step in minimizing damage is to reduce the buildup of static charge. If there is no charge, there can be no discharge.

The key to this reduction is by providing an "easy" or low resistance path to earth ground from all equipment and towers. The first order of business is to find a reliable earth ground reference point. This may be the earth near the surface around the station or that some number of feet down. Current practice includes the formation of a "ground halo" whereby copper strap at least two inches (4 is better) wide is buried around the entire building. In addition, ten foot ground rods are driven into the soil next to the strap at the building corners and at a minimum of 20 feet between. The copper strap is bonded to each ground rod and *one* copper strap, at least 4 inches wide, is brought from the ground to the common AC electrical ground, normally an additional ground rod or, better, three ground rods arranged triangularly, approximately 5 to 10 feet apart.

In some areas, this may not establish an adequate ground and it may be necessary to rely on chemistry to aid in grounding with the addition of compounds which reduce the ohmic resistance of the ground around the strap and ground rod. Note that in many cases, such chemistry means the copper is eventually eroded and needs replacement in order to maintain the initial low resistance to ground.

Once an acceptable ground is achieved it is necessary to provide a path from equipment to ground. For towers this normally means heavily clamped or welded connectors on each leg with a low resistance path to the established earth ground. For reduction of static buildup, since the flow is primarily a DC current, a conductor which exhibits low resistance at DC is required. This can be heavy copper wire or copper strap. The goal is to maintain resistance between the equipment and the established ground at less than 0.01 ohm. As an example, a 100 foot run of a ground cable would require #0 copper to meet the requirement.

With such grounding, towers "bleed off" much of the charge which builds up on them from wind and atmospheric changes. However, any residual charge which is greater than the surrounding area can act as a launch point for the tracer(s) which are the beginning of a lightning strike.

When such discharge begins, the current flow is no longer relatively slow flowing direct current but a sudden pulse as the current almost instantaneously rises to a high value, sometimes reverses itself to a degree then falls to zero. The fact that there is a sudden change in current flow means that the current is now "alternating" and behaves as such. In fact, because the current flow occurs in approximately 20 to 50 microseconds, we can define the frequency as 1/.00002 (50,000) to 1/.00005 (20,000)Hz. More importantly, because of their steep leading and trailing edges, the pulse generates a large number of harmonics, well into the tens of megahertz. At these frequencies, the current acts as radio frequency energy. This is observable when listening to an AM radio where the harmonics of the frequency of the strike are heard interfering with the desired station.

Because these currents are radio frequency it is important to observe good radio frequency practices in guiding them to ground. This includes:

- Understanding that the "skin effect" begins to influence current flow. With RF energy, the higher the frequency, the more the current flows only on the surface of the conductor. This is good news from the standpoint of being able to use hollow conductors, saving weight and cost. However, it also means that a much larger surface area is needed to carry the same amount of current compared to the same conductor carrying an equivalent amount of direct current. For example, 3mm copper wire is capable of carrying 50 amperes of DC but is rated at about 6 amperes for a 30 mHz signal. This is the primary reason for using strap rather than cable for lightning protection. Certainly, cable can be employed but it must be of higher capacity than anticipated in DC circuits.
- There are both resistive and reactive components to the current. When keeping the resistive (real) losses to a minimum through large cable or strap, it is important to minimize the irrational (imaginary) losses by proper routing. This means minimizing the number of bends in the cable, eliminating any loops, and either routing the strap/cable very close to surrounding surfaces or isolating it (reducing capacitance) by putting great distance between the ground strap and surrounding surfaces.
- Resistance must be minimized as outlined above. As an example: During static draining, current may be measured in milliamperes. Ohm's law would dictate that 1 ampere flowing to ground through 0.01 ohm would produce a voltage drop of (E=IxR) .01 volt. However, when dissipating a

lightning strike of 50,000 amperes, the voltage across the ground wire/strap would rise to 500 volts. In a similar manner, using ground wire/strap with a resistance of 0.1 ohm would create a drop of 5000 volts across the ground wire/strap.

Further reducing "visibility" of broadcast towers: In many cases, it is possible to reduce the static charge buildup on a tower to nearly zero. When this happens, the tower virtually disappears to lightning in that its potential is not different from that of the air around it. The first requisite is the low impedance path to ground for the tower. The second is a system to bleed off charges into the surrounding air. There are two major companies manufacturing such devices. They consist of a collection of metallic fine points – usually many hundreds of sharp stainless steel "pins" – which form a type of tree. These are bonded to the top of the tower so that they are the highest point.

Courtesy, Ron Nott, Inc.

The points gradually bleed off charges resulting in a significantly reduced potential between the tower and surrounding environment. In direct before/after comparisons, these units significantly reduce discharge and strike damage. Note: It is not possible to create a true A/B test since there are many other variables which can affect frequency of discharge damage. However, any number of sites cited in the links below have experienced fewer or zero strikes since installation of the discharge devices.

Further protection of equipment:

It has been found that, should a strike or discharge occur, the least damage is incurred if equipment is kept at the same potential. That is, if two equipment racks and a transmitter cabinet are kept at the *same* potential, current will not flow between individual elements of the system. Achieving this means properly bonding each piece of equipment to a central or "star" ground. Copper strap or low resistance cable is used; paint is removed where the connections are made to cabinets or cases and a single bond is then run to ground. In the event of a sudden increase in current flow, it will not be between pieces of equipment but through all equipment together to ground. Any rise in voltage above ground is equal in all elements of the system and no current flows between them.

Use of ferrites can reduce equipment damage. Equipment connections can be routed through ferrite rings (toroids) of the proper type – those exhibiting highest reactance at the desired frequencies. These rings will reduce the flow of RF energy, including lightning, on the outer conductor or surface of interconnects. These must be used judiciously since, in some circumstances, the rings will cause voltage differentials between pieces of equipment, counteracting the very "common voltage" that is sought. Example: All transmitters, processors and racks are bonded. A ferrite ring is used over the AC connection of the audio processor. A surge enters through the AC line and all other AC connections suddenly rise to 1000 Volts. The ferrite on the processor AC line successfully limits the surge voltage to the processor to under 100 volts. The voltage *differential* between the processor and the rest of the system is 900 Volts, capable of causing significant damage.

Insertion of inductance into connecting lines can reduce the effects of discharge. A single turn loop in a coaxial cable before connecting to equipment will provide a level of inductive reactance that can reduce the flow of a lightning hit into the equipment but *only if* the outer conductor is properly grounded *before* the loop (the side opposite the equipment).

Summary:

Lightning damage can be reduced by reducing static discharge opportunities. Static discharge can be reduced by maintaining the system as close to earth ground potential as possible and by providing a low resistance and reactance path to ground from the system.

Specific techniques include

- Ensuring the shortest, straightest path to a good earth ground
- Establishing halo and star ground systems
- Using low impedance cabling or strap between equipment and ground
- Employing static reducing devices
- Incorporation of inductive loops in equipment connections
- Judicious inclusion of ferrite beads, rods and rings (toroids)

*In actuality, a lightning strike is a complex series of discharges. The strike may extend from ground to the atmosphere or the converse. Currents can exceed 300,000 amperes.

References:

http://www.lbagroup.com/international/tower-lightning-protection.php

http://www.nottltd.com/lightning.html

http://www.indelec.com/foudre/Glossaire/Glossaire.aspx

http://lists.contesting.com/pipermail/amps/2005-April/044414.html

http://www.lightningsafety.com/nlsi_lhm/rtaf3.html

National Lightning Safety Institute (see below)

Revised: January 16, 2012

Recommended Grounding Guidelines

Prominent lightning engineers and major technical codes and standards agree as to proper grounding guidelines. We present summaries of those generally accepted designs.

1. From *Golde, Lightning, Academic Press, NY, 1977, vol. 2, chapter 19 by H. Baatz, Stuttgart, Germany, p. 611:*

"Equalization of potentials should be effected for all metallic installations. For lightning protection of a structure it is of greater importance than the earthing resistance...

The best way for equalization of potentials utilizes a suitable earthing system in the form of a ring or foundation earth. The downconductors are bonded to such a ring earth; additional earth electrodes may be unnecessary..."

2. From *Sunde, Earth Conduction Effects in Transmission Systems, Van Nostrand, NY, 1949, p. 66:*

"Adequate grounding generally requires that the resistance of the ground , at the frequency in question, be small compared to the impedance of the circuit in which it is connected. By this criterion, it may be permissible in some instances to have a ground of high resistance, several thousand ohms, as in the case of "electrostatic" apparatus ground, the impedance to ground of insulated apparatus cases being ordinarily quite high. In other [situations], however, a resistance of only a few ohms may be required for effective grounding."

3. From *Horvath, Computation of Lightning Protection, Research Studies Press, London, 1991, p. 20:*

"The earthing of the lightning protection system distributes the lightning current in the soil without causing dangerous potential differences. For this purpose the most effective earthing encloses the object to be protected. The potential increases on the earthing and on all earthed metal parts of the object relative to the zero potential at a distant point. It may reach a very high value but it does not cause any danger if the potential differences inside the object to be protected are limited. Potential equalization is realized by the bonding of all extended metal objects."

4. From *Hasse, Overvoltage Protection of Low Voltage Systems, Peter Peregrinus Press, London, 1992, p. 56.*

''Complete lightning protection potential equalization is the fundamental basis for the realization of internal lightning protection; that is the lightning overvoltage protection for the electrical and also the electronic data transmission facilities and devices in buildings. In the event of a lightning stroke, the potential of all installations in the affected building (including live conductors in the electrical systems with arrestors) will be increased to a value equivalent to that arising in the earthing system -- no dangerous overvoltages will be generated in the system…

Nowadays lightning protection potential equalization is considered indispensable. It ensures the connection of all metal supply lines entering a building, including power and communication cables, to the lightning protection and earthing system by direct junctions across disconnection spark gaps, or arrestors in the case of live conductors."

5. From *IEEE Emerald Book, Powering and Grounding Sensitive Electronic Equipment, IEEE Std 1100-1992, IEEE, NY, 1995, p. 216:*

"It is important to ensure that low-impedance grounding and bonding connections exist among the telephone and data equipment, the ac power system's electrical safety-grounding system, and the building grounding electrode system. This recommendation is in addition to any made grounding electrodes, such as the lightning ground ring. Failure to observe any part of this grounding requirement may result in hazardous potential being developed between the telephone (data) equipment and other grounded items that personnel may be near or might simultaneously contact."

6. From *International Standard IEC 1024-1, Protection of Structures Against Lightning, International ElectroTechnical Commission, Geneva, 1991, p. 23:*

"In order to disperse the lightning current into the earth without causing dangerous overvoltages, the shape and dimensions of the earth-termination system are more important than a specific value of the resistance of the earth electrode. However, in general, a low earth resistance is recommended.

From the viewpoint of lightning protection, a single integrated structure earth termination is preferable and is suitable for all purposes (i.e. lightning protection, low voltage power systems, telecommunication systems).

Earth termination systems which must be separated for other reasons should be connected to the integrated one by equipotential bonding…"

7. From *FAA-STD-019b, Lightning Protection, Grounding, Bonding, and Shielding Requirements for Facilities, Federal Aviation Administration, Washington DC, 1990, p. 20:*

"The protection of electronic equipment against potential differences and static charge build up shall be provided by interconnecting all non-current carrying metal objects to an electronic multi-point ground system that is effectively connected to the earth electrode system."

8. From *MIL-STD-188-124B, Grounding, Bonding and Shielding, Department of Defense, Washington*

DC, 1992, p. 6 and p. 8:

"The facility ground system forms a direct path of known low voltage impedance between earth and the various power and communications equipments. This effectively minimizes voltage differentials on the ground plane which exceed a value that will produce noise or interference to communications circuits." (p.6)

"The resistance to earth of the earth electrode subsystem should not exceed 10 ohms at fixed permanent facilities." (p. 8)

9. From *MIL-STD-1542B (USAF), Electromagnetic Compatibility and Grounding Requirements for Space Systems Facilities, Department of Defense, Washington DC, 1991, p. 19:*

"This Standard, MIL-HDBK-419, and MIL-STD-188-124 do not recommend the use of deep wells for the achievement of lower impedance to earth. Deep wells achieve low dc resistance, but have very small benefit in reducing ac impedance. The objective of the earth electrode subsystem is to reduce ac and dc potentials between and within equipment. If deep wells are utilized as a part of the earth electrode subsystem grounding net, the other portion of the facility ground network shall be connected to them."

10. From *National Electrical Code, NEC-70-1996, National Fire Protection Association, Quincy MA, 1996, Article 250 - Grounding, p. 120 & p. 144:*

"Systems and circuit conductors are grounded to limit voltages due to lightning, line surges, or unintentional contact with high voltage lines, and to stabilize the voltage to ground during normal operation. Equipment grounding conductors are bonded to the system grounded conductor to provide a low impedance path for fault current that will facilitate the operation of overcurrent devices under ground-fault conditions." (p. 120)

"Metal Underground Water Pipe. A metal underground water pipe in direct contact with the earth for 10 ft. (3.05 m) or more (including any metal well casing effectively bonded to the pipe) and electrically continuous (or made electrically continuous by bonding around insulating joints or sections or insulating pipe) to the points of connection of the grounding electrode conductor and the bonding conductors. Continuity of the grounding path or the bonding connection to interior piping shall not rely on water meters or filtering devices and similar equipment. A metal underground water pipe shall be supplemented by an additional electrode of a type specified in Section 250-81 or in Section 250-83. The supplemental electrode shall be permitted to be bonded to the grounding electrode conductor, the grounded service-entrance conductor, the grounded service raceway, or any grounded service enclosure." (p. 145)

11. From *MIL-HDBK-419A, Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, Department of Defense, Washington DC, 1987, p. 1-2, p. 1-6, p.1-102 and p. 1-173:*

"The value of 10 ohms earth electrode resistance recommended in Section 1.2.3.1a represents a carefully considered compromise between overall fault and lightning protection requirements and the estimated relative cost of achieving the resistance in typical situations." (p. 1-2)

"At fixed C-E facilities, the earth electrode subsystem should exhibit a resistance to earth of 10 ohms or less." (p.1-6)

"All metallic pipes and tubes (and conduits) and their supports should be electrically continuous and are to be bonded to the facility ground system at least at one point." (p. 1-102)

"Water pipes and conduit should be connected to the earth electrode subsystem to prevent ground currents from entering the structure." (p. 1-173)

National Lightning Safety Institute

Providing expert training and consulting for lightning problems