A Basic Primer in Lightning Effects and Protection

Lightning Parameters

A lightning strike is essentially a high amplitude direct-current pulse with a well-defined waveform. While there are several types of lightning, the type that concerns us is **cloud to ground** lightning. Understanding of the waveform of cloud to ground lightning is useful to the designer in formulating a protection system, so we will discuss this phenomena. Precisely how lightning is generated and how it is propagated to earth does not impact design greatly, therefore it is not within the scope of this report. The lightning pulse is divided into four parts, components A to D. Figure 1 illustrates a lightning waveform. Component A is the high-current pulse. It is a direct current transient that has been recorded to reach up to 260,000 amperes and last for a duration of up to 200 microseconds. Typical rate of current rise with respect to time is 3 X 10^{10} A/s, but could reach 2 X 10^{11} A/s. On the average, it will reach 20,000 amperes for a 50 microsecond duration. Strikes above 200,000 amperes are considered rare. Component B is a transition phase on the order of several thousand amperes. Component C is a continuing current of approximately 300-500 amperes that lasts up to .75 second. The last component, D (not shown), is a restrike surge that is typically half that of component A in a given strike. It has generally the same duration as component A. Typically 3 or 4 restrikes will occur in one lightning event but the maximum observed is 26 restrikes in **one** lightning event. Sources differ on the magnitude of 'D'; some state all restrikes are one-half the magnitude of the A component and some sources imply that the D component continually decreases by one-half (e.g., 1/2A, 1/4A, 1/8A, etc.). In the context of MIL-STD-464 (Electromagnetic Environmental Effects) a widely used standard for lightning effects, 20 restrikes are specified at a value of 50 kA, which is ¼ of the maximum of the A-component. A summary of MIL-STD-464 lightning parameters is presented for review.

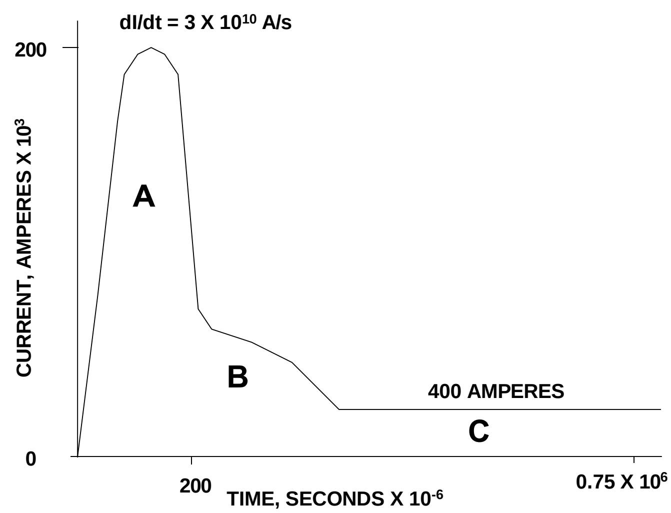
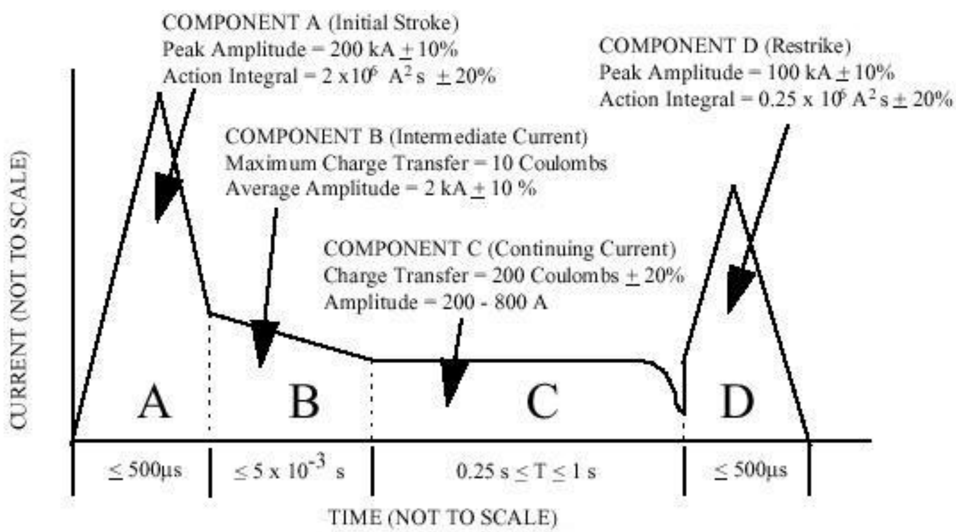
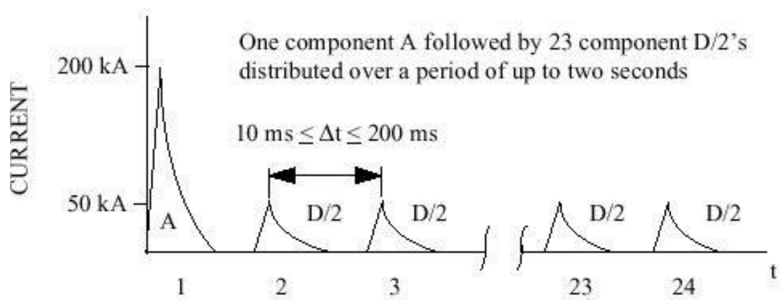


Figure 1 Representative lightning event.

- Summary of Lightning Parameters from MIL-STD-464, Electromagnetic Environmental Effects.

Current Component	Description	$i(t) = I_o(\varepsilon^{-\alpha t} - \varepsilon^{-\beta t})$ t is time in seconds (s)		
		I_o (Amperes)	α (s^{-1})	β (s^{-1})
A	Severe stroke	218,810	11,354	647,265
B	Intermediate current	11,300	700	2,000
C	Continuing current	400 for 0.5 s	Not applicable	Not applicable
D	Restrike	109,405	22,708	1,294,530
D/2	Multiple stroke	54,703	22,708	1,294,530
H	Multiple burst	10,572	187,191	19,105,100





- Lightning Magnitude Percentiles

Although MIL-STD-464 tends to use the extreme cases of lightning, the peak current associated with a lightning event can be categorized by percentile[1]. We will plot a best-fit curve to take advantage of a number of empirical studies performed to categorize peak current magnitude.

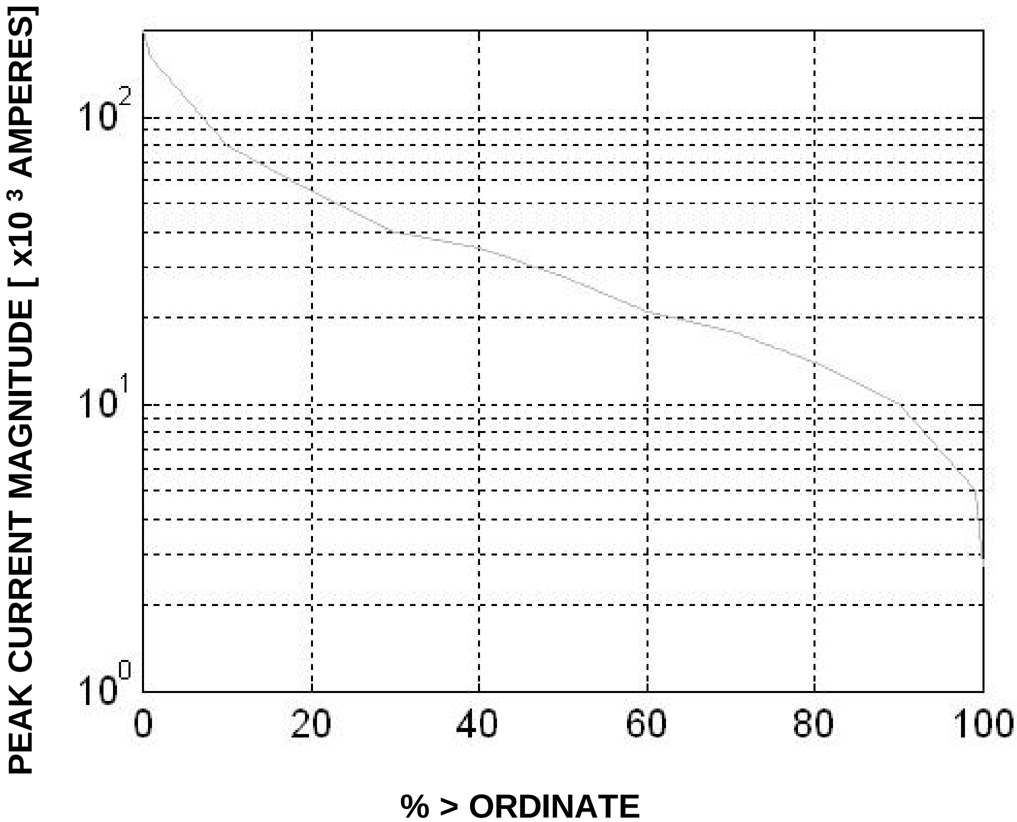


Figure 2 Lightning peak current magnitude percentiles.

In figure 2, the y-axis is the peak current magnitude in kiloamperes (kA) and the x-axis is the percentile ordinate. Examining this data, we find only 0.1% of all lightning strikes exceeding 200 kA while 99.9% exceed 5 kA. The 50th percentile of peak current magnitude is 28 kA.

[1] Hart, W.C., Malone, E.W., *Lightning and Lightning Protection*, Interference Control Technologies, Gainesville, 1988, p 3-9.

Lightning Attachment Process

Most lightning that reaches the ground (75% to 90%) is negatively charged. It begins to intercept the ground by lowering a stepped leader - a precursor to the actual lightning discharge. This leader progresses in steps toward the ground and is comprised of electric charge. It completes this process in a length of time measured in tens of milliseconds. Below the leader is a region of very high electric field. As the leader approaches the earth, the high electric field induces objects on the ground to emit leaders of opposite polarity charge. Since opposite charges attract, the path of the downward leader is influenced by an upward leader of opposite polarity. Upon connection, the actual current discharge associated with lightning begins as shown in figure 3.

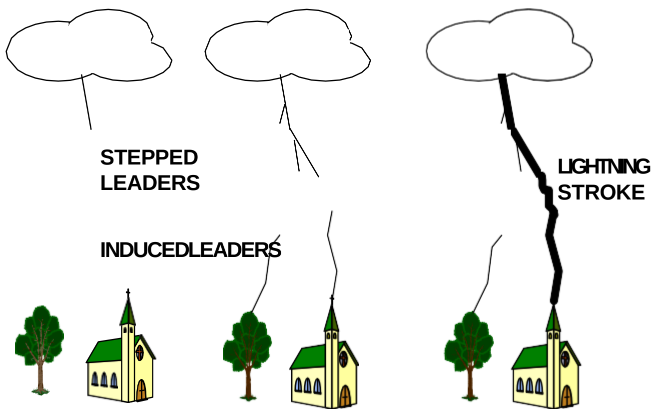


Figure 3 - Illustration of Lightning Attachment.

Rolling Sphere Model of Lightning

The final step in the lightning attachment process occurs at a point during the downward leader progression, when the leader "decides" toward which upward leader it will travel. The prevalent model of lightning propagation used today to represent this final step is the rolling sphere model as illustrated in figure 4. As the downward leader approaches the objects on the ground, it is attracted to upward emitted leaders.

Once the downward leader is within a certain radius, known as the striking distance, the upward and downward leader attract and connect. The striking distance is defined in the NFPA 780, Standard for the Installation of Lightning Protection Systems, as the distance over which the final breakdown of the initial lightning stroke occurs. This distance is specified as 150 feet for standard structures or 100 feet for structures containing flammables [2]. Examining the model, we see that the sphere will eventually intersect an object on the earth's surface. This object can be a tree, structure or person. At that time,

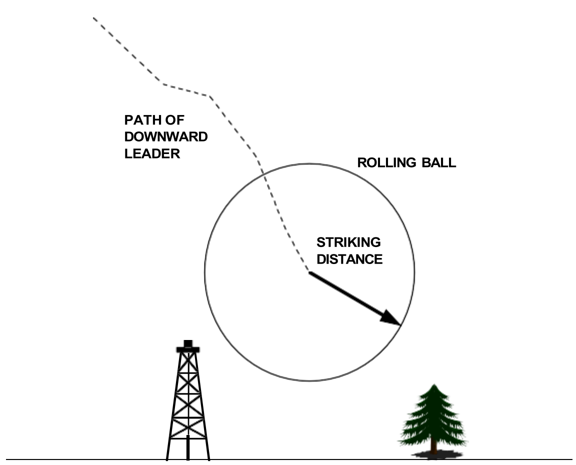


Figure 4 - Rolling Sphere Model of Final Lightning Attachment Step.

2. Standard for the Installation of Lightning Protection Systems, NFPA 780, 1995 Edition, National Fire Protection Association, Quincy, MA, 1995.

we expect that the tip of the leader located at the center progresses rapidly toward the object intersecting the sphere. Note that it is entirely possible for the final striking distance to be in an upward direction. In fact, on very tall structures, strikes are often received in an upward direction.

We note that metallic objects electrically connected to the ground that are comparatively sharp emit the leader better than other objects such as trees and people. Taller objects generally have an advantage since they are closer to the stepped leader and begin to emit their own leader sooner.

Damaging Effects of Lightning

- Direct strike

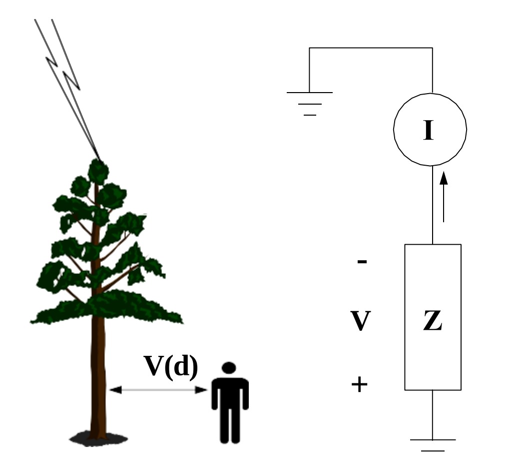
A direct lightning attachment to an unprotected structure usually causes fire and electrical damage. Occasionally, explosive damage will occur if lightning attaches to a chimney or other porous structural component. Typically, an attachment will be to a roof or protrusion, and arcing within the structure will cause ignition of structural materials. Since lightning prefers the path of least impedance once it attaches to a structure, it will often flow to the electrical system and thence to earth, causing severe damage to the wiring.

- Indirect Electrical Effects

Several damaging effects can occur from lightning other than the effects from the direct strike.

Flashover occurs when lightning attaches to something that has a relatively high impedance path to ground. A good example of such an event is lightning striking a tree. The tree presents a path to ground, but the path has a high impedance compared to that of a properly installed, well grounded lightning protection system. If we model the lightning as a current (I) source and the object through which it is passing as a general impedance (Z) we see that a significant voltage can develop on the object. If this voltage exceeds the air breakdown value (approximately 10^6 volts/meter) the lightning current may jump from that object to another grounded object in the vicinity.

In figure 5, we illustrate the flashover effect. If lightning were to attach to a tree current would flow through the tree to ground. This usually causes significant



Physical System Equivalent Circuit

Figure 5 - Flashover Model.

damage to the tree from the rapid heating and expansion of moisture within the tree. Note we are modeling the current flow as upward, since we have mentioned that most cloud to ground lightning is negatively charged. By Ohm's law, V = IZ, as current flows through the tree, a voltage is developed. If this voltage exceeds the air breakdown value to a nearby object (or person), the lightning current will likely seek a path through the air to the nearby object or person. If a person is touching the tree to begin with then the breakdown value is governed by the skin impedance (which would be quite low in comparison) and the person would find themselves as part of the circuit. A typical lightning strike might produce 20,000 amperes of current and a typical tree might have a 100 ohm impedance. In this case, the voltage developed would be 2 million volts, enough to flashover to objects 2 meters away. Many lightning injuries occur from the flashover hazard. Most common is from being in the vicinity of trees during lightning storms or near electrical conductors that are subject to lightning current. Common sources of this injury occur when a person is near a residential telephone line and it is energized by a distant lightning strike[3]. This effect can occur between wires or structural components in a building and is the most common source of ignition and fire damage in lightning accidents.

- Induced Currents/Voltage

Often lightning damage can cause electronic damage. In fact, some sources report that most insurance claims from lightning damage are for damaged electronics.

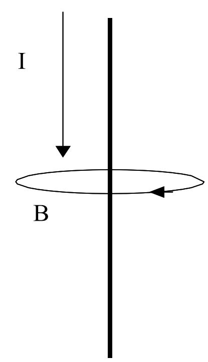


Figure 6 - Magnetic field from a current path.

A lightning strike, or flow of a high current pulse in a wire results in a magnetic field pulse that encircles it. In figure 6, the current path is illustrated, with the current direction of I, and a resulting magnetic field, B. If this magnetic field encompasses other conductors, a voltage pulse will be induced on the termination of other conductors. Although this voltage pulse is quite short in duration, it can be of very high voltage. When this high-voltage pulse is presented to the power supply or signal input of electronics, it causes a high current flow through the device to electrical ground, usually resulting in damage.

Operating Principles of Lightning Protection Systems

The premise of lightning protection systems is to intercept the lightning event by providing it a preferential attachment point on a structure and guiding it safely to earth through a preferred path. A typical lightning protection system has five major subsystems: strike termination, down conductor, grounding, ground reference and surge suppression subsystems.

[3] Golde, R.H., "A Plain Man's Guide to Lightning Protection," *Electronics & Power*, March 1969, p. 84.

- Strike Termination

Strike terminations are objects that intercept the lightning event. Commonly, pointed metal rods are used for this purpose and are termed air terminals and are also called "lightning rods." Strike terminations can come in other forms such as overhead wires or structural components of buildings. Specifications for strike terminations are given in NFPA 780. A common question often asked about strike terminations is "Don't lightning rods increase the chance my building will get hit by lightning?" The answer is NO. Strike terminations only influence the path of lightning through the air at very close ranges – perhaps twenty feet or so. If lightning attaches to a strike termination on your building, it probably would have connected to the building anyway if no strike terminations were present.

For this reason, you see several air terminals installed on buildings, usually around the periphery of the roof. Beware of ANY vendor that claims that a strike termination has some increased range of effect!

- Down Conductors

This is an electrical path of low impedance that connects the strike termination subsystem to the grounding subsystem. Commonly, they are wires but with the advent of steel-frame construction, building structural components are often used (and, in fact, pose several advantages).

- Grounding

The grounding subsystem sinks the lightning current into the earth. Commonly, the grounding subsystem consists of ground rods, copper or steel rods driven deeply into the earth, but it can have other forms. The key parameter for the grounding system is low impedance. The impedance of the grounding system is inclusive in the overall impedance of the lightning protection system, so a high impedance grounding system can increase the chance of flashover and other damaging effects.

- Ground Reference (including bonding)

The ground reference subsystem and electrical bonding is often the most elusive portion of a lightning protection system. This subsystem electrically bonds the other electrical grounds and dead metal parts that may provide a ground path in a structure to the lightning protection system. From reading about the flashover effect in previous sections, we know that lightning may flashover to other conductors. Within a building, this can cause catastrophic damage and ignition of building materials. Many instances of lightning damage are noted where lightning arcs to or from wiring to another path to ground that could be a structural component of the building or even other wires. Despite the need for bonding, designers have to be careful not to install bonding that provides an incidental ground path through sensitive electronics - a common oversight.

- Surge Suppression

Once the building has physical lightning protection, as described above, protection from indirect effects is essential, especially if sensitive electronics are involved. Without surge suppression, the job is only half done. Surge suppression is installed as "defense in depth." A good installation will install suppressors on the main data and power entries and several devices will be installed in line to protect the more sensitive electronics. Surge suppression devices installed in the plug-in power strips are almost always ineffective against any significant lightning event.

For more information concerning lightning protection systems and their components, please refer to the documents cited in the references.

Summary

We hope that this primer is useful in explaining lightning effects and the basic premise of protection systems. Please contact us to discuss your protection needs and concerns!

Email us at: info@ElectroQuest-LLC.com.

Key References

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