LIGHTNING

Sources of Lightning

Since the time of Benjamin Franklin (1750), lightning has been recognized as being a gigantic spark occurring between an accumulation of electric charge in a cloud and the earth or another charged cloud. The most common source of such charged cloud centers is the thunderstorm, of which there are two main classes: (a) local convectional thunderstorms and (b) frontal storms. The former are the result of local heating of the air adjacent to the ground in summer, whereas the latter are the result of the overrunning of warm moist air by a mass of colder air, giving rise to turbulence as a result of relative motion of the air masses. In either case, there results an unstable condition that causes the warm moist air to rise at an accelerating rate and by the condensation of its moisture to form a tall cumulo-nimbus cloud. In such a thunderstorm cell, there is at first a violent updraft, followed later by strong down drafts. The little understood processes that lead to the separation of large amounts of positive and negative electricity are doubtless related to these vigorous air movements. The usual thunderstorm involves several such circulation "cells," and in the case of a frontal storm these may extend in a row for many miles. Usually negative electric charges accumulate in the lower portion of the cloud whereas positive charges are carried to the upper portions, with the result that enormous differences of electric potential are developed between the top and bottom of the cloud and between the latter and the earth.

Lightning has also been observed in the dust, steam and gas clouds arising from volcanoes in eruption in dense smoke clouds over large fires, in the dust clouds of deserts, and in clear skies probably from charged bodies of air that drifted near each other or near the earth. In addition, there are apparently silent luminous discharges within cloud layers and haze that have been observed at all times of the year, especially in regions where thunderstorms are scarce.

General Lightning Theory

Due to certain atmospheric processes during thunderstorms, charges are collected in clouds; equal and opposite charges are induced on the ground. As the charges build up, the potential gradient [volt/m] in the air increases. When the gradient exceeds the dielectric strength of the air between cloud and ground the air breaks down. A streamer starts from cloud to earth. The gradient needed to start a streamer is about 5-10 KV/cm. Lightning strokes may be started with potentials from 5-20 megavolts between cloud and earth. Lightning currents from cloud to earth are 85% negative varying in crest magnitudes from less than 1,000 A to more than 160,000A.

Lightning behaves in terms of a complete electrical circuit. The charge in a thundercloud wants to reach and distribute itself through the ground and tends to use tall objects. Good conductors such as metal mast and towers often carry the lightning current without being damaged. Nonmetallic objects, such as trees, etc. are poor conductors but are still better conductors than air. The danger with nonmetallic objects lies in the fact that the lightning currents will heat them ($H = i2Rt$) to the point they will explode.

The lightning charge tends to distribute itself when it reaches ground. Since electrical currents travel more easily in wet ground than in dry ground, there is more danger from hazardous ground voltages in high resistance soil than in low resistance soil. A secondary danger occurs through induced voltages in long metal objects adjacent to a lightning strike. There is no evidence that any form of protection can prevent a lightning discharge. Damage comes from electromagnetic fields caused by the lightning stroke, voltage drops in the ground system, structural damage from burning heat and mechanical forces. The goal of protection, therefore, is to provide a path by which a discharge can be conducted to earth without entering a vulnerable part of the equipment.

Lightning as a Source of RF Interference

To better understand the cause of radio interference resulting from lightning discharge, Figure 1 should be studied. Tests indicate that radiated voltage levels produced by the lightning discharge are significant. At 400 MHz, an average field strength of 397 uV/m, at a 1 kHz bandwidth was measure for 37 flashes at a distance of one statute mile.

The major sources of damage to electrical/electronic systems are the coupled-surge voltages and overvoltages in sensitive circuits. Such damage can be prevented by using protective devices.

Many Military EMI control specifications require that equipment shall not sustain damage when a voltage transient of 50V(plus and minus) is placed on the power lines. MIL-STD-461 requires transients at twice the line voltage or 100 V. This is not enough to prevent damage due to lightning surges on the power lines. They may appear on any wire in any system and the power circuit will not be the only circuit that may be affected.

In the Home

The home is very vulnerable to the effects of lightning strokes. The electric light bulb is the first to go when an electrical storm approaches. Televisions are also very vulnerable, but seldom is a shorted tube, capacitor breakdown or blown fuse attributed to a lightning storm. The appropriate placement of surge arrestors near the fuse box could reduce the cost of utility and consumer product repairs significantly in localities which experience a high incidence of electrical storms. Household fuses, especially the slow-blow type usually open after the electrical damage has occurred.

Shielding Against Lightning

Shielding is the interception of lightning strokes by a good conductor well connected to earth. Lightning rods and overhead ground wires are good examples of shielding devices. Unless the mast or rod, used as shielding, is in excess of about 500 ft. in height there is no evidence that a shielding mast contributes to a lightning stroke formation. Whether the lightning rod is blunt or sharp is also inconsequential. A typical shielding mast offers about 99.9% protection against a direct stroke within a cone whose apex is at the top of the mast and whose surface makes an angle of 30^{o} with the vertical as shown in Figure 2.

In the foregoing discussion a conducting and well-grounded shield has been assumed.

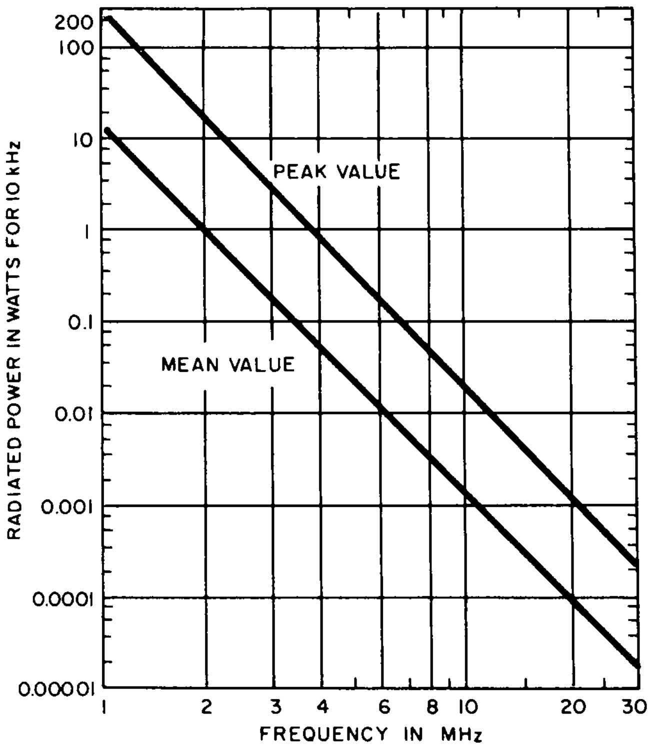

Fig. 1: Effective radiated power of a single stroke. This curve is derived theoretically from the measured current in the return stroke. The peak equivalent radiated power from a typical discharge, which is composed of a number of strokes averaging about 4 or 5, ranges from 200 W. at 1 GHz to MW at 20 GHz. The radiated power drops rapidly with increasing frequency.

Lightning Arresters General

Lightning arresters are devices that provide by-passes around insulation. If lightning strikes a circuit very high transient currents tend to flow. If there is a high impedance or insulation between point of entry and ground, very high and dangerous voltages are created. A lightning arrester must perform as an insulator under normal conditions but must be a good conductor for lightning currents and afterwards must return to its original insulator state to prevent system current from opening circuit breakers or fuses.

The closing mechanism in a lightning arrester is usually a spark gap. This is normally insulating but conducts by sparking when transient voltages reach the spark potential of the gap. This sparking forms the circuit for the lightning current. After the circuit is established, system current follows lightning current. Lightning arresters must be designed to interrupt these follow or system currents. In this respect simple spark gaps are unable to interrupt system or follow currents but depend on circuit breakers or fuses in the system to stop system power outages.

Spark Gaps

Simple spark gaps are more economical than lightning arresters. Circuits with very low voltages or those that are normally unenergized are ideal for application of simple air gaps for overvoltage protection from lightning. Figure 3 shows the operating ranges of some generic protective devices.

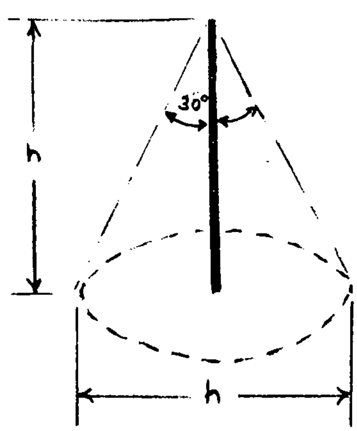

Fig. 2: Shielding Against Lightning

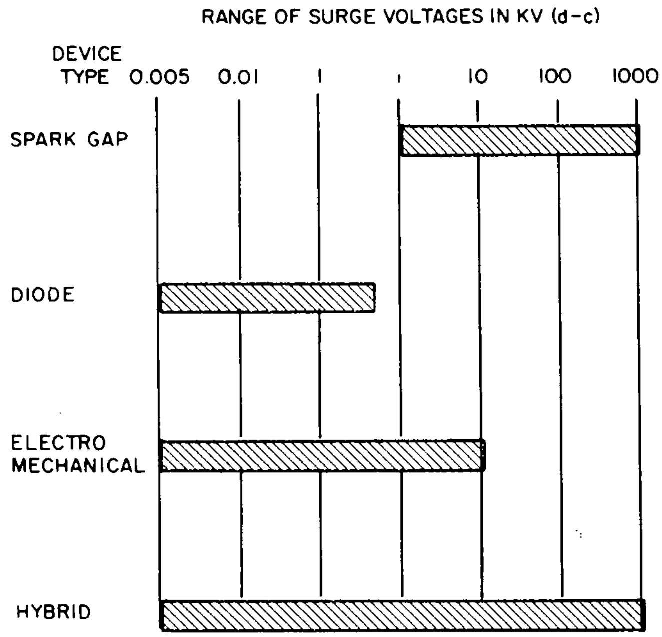

Figure 3: Operating ranges of generic protective devices. Note that the hybrid is the best protection for a complete system. But, it must be designed for the particular circuit in which it is to be used.

Types of Lightning Arresters for Low Voltage Circuits

In general, lightning arresters are classified as dc or ac arresters depending on where they are used. The main difference lies in the fact that it is more difficult to interrupt follow or system currents in dc than ac circuits, mainly because the dc current never passes through zero magnitude.

Generally, valve-type signal arresters or gap-type signal arresters are used on low voltage signal and control circuits. Valve type arresters limit the follow current by the action of the arrester itself, making the follow current independent of the system-short circuit currents.

A valve type arrester of a particular voltage rating can be applied to any system operating on the same voltage frequency; valve arresters have no system-current ratings. This voltage rating defines the maximum voltage applied across the arrester's line and ground terminals against which it will interrupt follow current reliably and restore itself to an insulator when it has been discharged by a surge. The normal rating for 120/208 volts AC systems is a 175 AC valve type. A typical dc valve type arrester rating is 75 VDC for high short circuit capacity.

Frequency of Occurrence of Discharge-current Crest of Arresters connected to unshielded lines in areas of 30-40 thunderstorm days/yr.

Amperes	*Frequency*
100,000	Once in 14,300 yrs.
65,000	Once in 4,000 yrs.
20,000	Once in 200 yrs.
10,000	Once in 45 years.
5,000	Once in 13 yrs.
1,500	Once in 3-½ yrs.
830	Once in 2 yrs.
100	Once in 1 year

Grounding

In order to have an effective lightning protection system, proper grounding from equipment ground to earth ground is essential. Earth resistivity depends on the moisture content and mineral salt content of the soil. There is a marked difference between ordinary resistance and resistance to high surge resistance due to sparking between particles of low soil resistibility under surge conditions. It has been determined that there is a definite limit in the number of parallel grounding rods that will appreciably lower the ground resistance from that of a single grounding rod over a particular land area. For example a simple 10' rod has a resistance of 25 ohms in order to reduce this to 5 ohms eight rods would be required over an area of 1000 sq. ft. An infinite number of rods in that area would be required to lower the ground resistance to approximately four ohms.

Lightning Arrester Ground

1. Coordination of lightning arrester ground subsystem and ground subsystem for noncurrent carrying parts.
2. Structure ground to earth ground resistance should be less than 25 ohms.

Lightning Protection

Size of Largest Conductor	**AWG No. of Copper Grounding Conductor**
No. 2 or larger	8
No. 1 or 0	6
00 or 000	4
over 000 to 250,000 cm	2
over 250,000 to 600,000 cm	1/0
over 600,000 to 1,100,000 cm	2/0
over 1,100,000 cm	3/0

Radome Protection

In order to permit a radar beamto pass through a radome, the radome must be nonmetallic. But this nonmetallic structure is nost vulnerable to lightning damage and may be heated so intensely by a heavy lightning discharge that it may explode or be severly damaged. A solution developed by the Douglas Aircraft Co. uses several thin strips of aluminum, .003" thick by .375" wide, taped to the outside of the radome. When a bolt strikes, the thin conducting strips vaporize creating an ionized path which carries the lightning charge safely past the radome to ground. This method was tested by artificial 1.5 megavolt lightning with current crests of over 100,000 amps and charge transfer of 100 coulombs and was found to work.

LIGHTNING AND STATIC ELECTRICITY CONFERENCE

The Air Force Avionics Laboratory, in cooperation with the Society of Automotive Engineers (SAE) sponsors the Lightning and Static Electricity Conferences. The first conference was held on December 3-5, 1968 in Miami Beach, Florida. (The second conference, at the time of this printing, was scheduled for December 9-11, 1970 in San Diego, California.)

The conference record, AF AL-TR-68-290, containing full unclassified conference papers, was published by the Air Force Avionics Lab, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. These papers discuss problems of lightning and static electricity as they pertain to aerospace vehicles. Research to solve these problems conducted by numerous US and foreign agencies, both governmental and industrial, is discussed. The sessions covered include fluids and fuels, grounding and bonding techniques, survivability of nonconductive materials in a lightning environment and the control of static electricity effects on nonconductive materials.

The Table of Contents is excerpted and condensed for reference as follows: