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LIGHTNING PROTECTION GUIDELINES FOR THE U.S. ARMY COASTAL ENGIN--ETC(U)
AUG 79 M CAMPI , J D PENAR
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General lightning protection guidelines are presented for the field research facility of the U.S. Army Coastal Engineering Research Center (CERC) at Duck, NC. This report draws heavily on existing lightning-protection codes, specifications, and publications, all of which are referenced for completeness.

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1. INTRODUCTION

The Coastal Engineering Research Center (CERC) facility at Duck, NC, has experienced operational outages from severe lightning environments, often resulting in damage to equipment. An on-going effort to provide specific and general lightning-protection recommendations for the phase III facility before its construction is seen as a cost-effective way to minimize the effects of lightning in the new facility. The oral and future written recommendations to CERC for this facility as well as for the existing pier are based on a number of studies, standards, and codes aimed at lightning protection. A more general set of guidelines is presented here to provide the background for the specific recommendations and to provide the basis of application to future CERC facilities and equipment.

The field research facility (FRF) currently existing at Duck, NC, consists of an instrumentation trailer and a concrete pier on concrete steel pilings. The pier is about 1840 ft (561 m) long and extends over the ocean about 25 ft (7.6 m) above the mean water line. So that specific weather-data-measuring instrumentation can be positioned, a research vehicle is planned which runs on rails for the total length of the pier. A galvanized steel handrail extends circumferentially around the pier for personnel protection. Equispaced ground connections are provided between the handrail and the metallic portion of the supporting piles. A cathodic protection network is electrically connected to the pier-supporting piles in order to retard corrosion of the piles. Data and ac power cables extend the pier length, housed in separate PVC (polyvinyl chloride) conduits. The data cable conduits are connected to junction boxes which are equispaced along the pier length. These boxes provide access to data cables for specific placement of sensor equipment. Continuous data on coastal phenomena such as waves, currents, tides, and beach changes can be monitored by these sensors during all weather conditions including severe storms.

Lightning can, by a direct strike or by induction, produce large electrical surges in the conductors traversing the pier, which then may penetrate the facility, thereby

a. causing arcing between the data-acquisition conductors and other conductors inside the building (explosion hazard),

b. destroying or damaging the instrumentation system, and

c. inducing false data signals.

Additionally, extended data lines from measuring sensors, gauges, or instrumentation cabinets on the pier must also be protected from currents arising from direct or induced current resulting from a lightning event.

The guidelines given here are applicable and directed toward minimizing the abovementioned hazards primarily through proper treatment, grounding, and shielding of conductor entries. A reasonable tolerance for lightning-induced transients in the data-acquisition system must be also accomplished through design. The primary protection provided by grounding and entry treatments cannot entirely eliminate lightning-caused transients, but can limit these transients to levels that a well-designed electronic system should be able to tolerate.

Finally, it should be recognized that it is very difficult to ensure that a severe lightning strike directly to the building (or to the power, telephone, plumbing, or other system conductors within a few feet of the building) will not cause hazardous arcing or equipment damage inside the building. However, the guidelines presented are those established by the National Fire Protection Association and Lightning Protection Institute, and are discussed in various military handbooks and standards for the protection of facilities from lightning events.

1.1 The Phenomenon of Lightning

Cumulonimbus clouds associated with thunderstorms are huge, turbulent air masses extending as high as 15 to 20 km into the upper atmosphere. These air masses generate regions of intense static charge which develop potential differences of hundreds, or perhaps thousands, of millions of volts between them. When the electric field strength exceeds the critical field intensity ($\sim 3 \times 10^6$ V/m), a lightning flash occurs and the charged areas are neutralized.[1] The charge distribution in a thundercloud is in the form of positive and negative charge centers, as illustrated in figure 1. A strong, negatively charged region exists in the lower part of the cloud with a counter-balancing positive charge region in the upper part of the cloud. In addition to these major charge centers, a smaller, positively charged region exists near the bottom of the cloud. Because of the strong negative charge concentration in the lower portion of the cloud, the cloud appears to be negatively charged with respect to the earth except immediately underneath the smaller positive charge concentration. As shown in figure 2, breakdown can occur between the charged regions within the cloud to produce intracloud lightning. It can also occur between the charged regions of separate clouds to produce cloud-to-cloud lightning. Intracloud and cloud-to-cloud discharges are not a direct threat to personnel or structures on the ground and thus tend to be ignored in the design and implementation of lightning protection systems. However, calculations of the voltages which could be induced in cross-country cables by such discharges indicate that they present a definite threat to signal and control equipment, particularly those employing solid-state devices.

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[1] *H. S. Denny et al, Grounding, Bonding, and Shielding Practices and Procedures for Electronic Equipments and Facilities, Vol 1, Georgia Institute of Technology (December 1975), ADA 022332.*

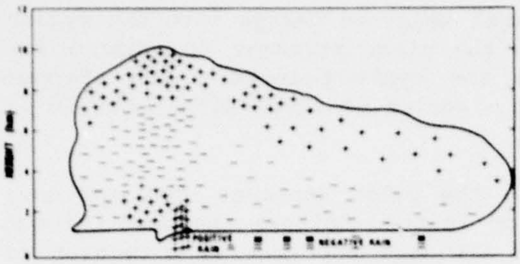

Figure 1. Charge distribution in a thundercloud (ref 1).

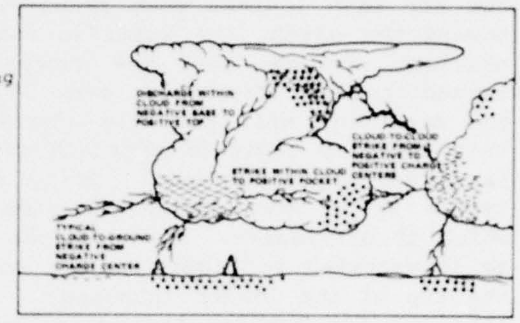

Figure 2. Schematic diagram showing electrical charge distribution in thunderstorms, including various lightning discharges: intracloud, cloud-to-cloud, cloud-to-ground, and cloud-to-space; *excerpt from N. A. Adams, Introduction to Lightning and Other Electrostatic Phenomena, Air Weather Service Technical Report 224 (August 1971), AD 730622.*

The cloud-to-ground flash is the one of primary interest to ground-based installations. By definition, such flashes take place between a charge center in the cloud and a point on the earth. This point on the earth can be of types as diverse as a flat plain, body of water, mountain peak, tree, flag pole, power line, residential dwelling, radar or communications tower, air traffic control tower, or multistory skyscraper. In a given area, certain structures or objects are more likely to be struck by lightning than others; however, no object, whether man-made or natural, should be assumed to be immune from lightning because of its height or geometrical shape. The high currents which flow during the charge equalization process of a lightning flash can melt conductors, ignite fires through the generation of sparks or the heating of metals, damage or destroy components or equipment through burning or voltage stressing, and produce voltages well in excess of the lethal limit for people and animals. The objective of all lightning-protection systems is to direct these high currents away from susceptible elements or limit the voltage gradients developed by the high current to safe levels.

1.2 Development of a Lightning Flash

As the charge builds up in a cloud, the electric field in the vicinity of the charge center builds up to the point where the air starts to ionize. A column of ionized air, called a pilot streamer, begins to extend toward the earth at a velocity of about 100 mps (160 km/s). After the pilot streamer has moved about 100 to 150 ft (30 to 45 m), a more intense discharge called a stepped leader takes place. This discharge lowers additional negative charge into the region around the pilot streamer and allows the pilot streamer to advance for another 100 to 150 ft, after which the cycle repeats. The stepped leader progresses toward the earth in a series of steps with about 50 μs between steps.[2]

In a cloud-to-ground flash, the pilot streamer does not move in a direct line towards the earth but instead follows the path through the air that ionizes most readily. Although the general direction is toward the earth, the specific angle of departure from the tip of the previous streamer that the succeeding pilot streamer takes is rather unpredictable. Therefore, each 100- to 150-ft (30- to 45-m) segment of the discharge will probably approach the earth at a different angle. This changing angle of approach gives the overall flash its characteristic zig-zag appearance. Being a highly ionized column, the stepped leader is at essentially the same potential as the charged area from which it originates. Thus, as the stepped leader approaches the earth, as illustrated in figure 3, the voltage gradient between the earth and the tip of the leader increases. The increasing field further encourages the air between the two to break down. The final stepped leader bridges the gap between the downward progressing column and the earth or an extension of the earth, such a tree, building, or metal structure that is equipotential with the earth. While the stepped leader is approaching the earth, positive charge equivalent to the negative charge in the cloud is accumulating in the general region underneath the approaching leader. Once the stepped leader contacts the earth (or one

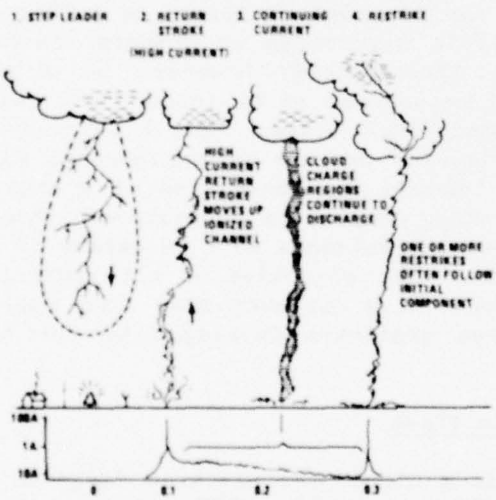

Figure 3. Mechanism of stroke passage to ground: *excerpt from J. L. Howe and E. Dalman, Transient and Surge Protection of Computer Controlled Building Automation Equipment, Report No. FAA-RD-77-84 Federal Aviation Administration, Florida Institute of Technology Workshop on Grounding and Lightning Protection (May 1977), ADA 043908.*

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[2] *ORDER 6950.19--Practices and Procedures for Lightning Protection, Grounding, Bonding, and Shielding Implementation, Department of Transportation, Federal Aviation Administration (July 1978). (This reference has incorrect units for pilot streamer velocity of mph (km/h).)*

of its extensions), the built-up positive charge in the earth flows rapidly upward through the ionized column established by the stepped leader to neutralize the strong negative charge of the cloud. This return current constitutes what is generlly referred to as the lightning stroke. If additional pockets of charge exist in the cloud, these pockets may discharge through the ionized path established by the initial stroke. Continuous dart leaders proceed from a remaining charge pocket toward the earth down this path. Once the dart leader reaches the earth, another return stroke of positive charge propagates up the channel to neutralize the secondary charge in the cloud. This cycle may be repeated several times as succeeding charge centers in the cloud are neutralized.

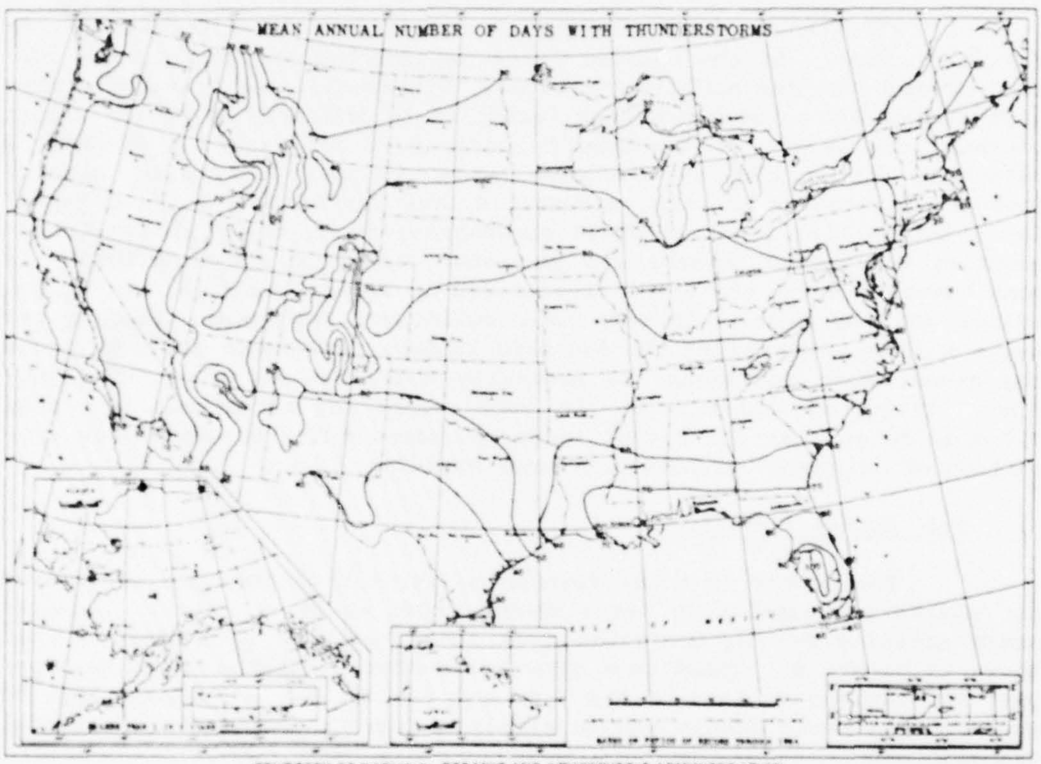
1.3 Influence of Structure Height

Flashes to earth are normally initiated by a pilot streamer from the cloud. As the charged leader approaches the ground, the voltage gradient at the surface increases. Ultimately, the voltage becomes high enough for an upward-moving leader to be induced. Over flat, open terrain, the length of the upward leader does not exceed a few meters before it unites with the downward leader to start the return stroke. However, structures or other extensions from the earth's surface experience intensified electric field concentrations at their tips. Consequently, the upward leaders are generated while the downward leader is some distance away; the upward leader can be several hundred meters long before the two meet. At very tall buildings, the upward leaders can begin to form even before the downward leaders have begun to form within the cloud; such incidents are generally described as triggered lightning. Triggered lightning is not very common for structures less than 150 m in height; as the height increases above this threshold, the proportion of triggered strikes increases rapidly.

1.4 Strike Likelihood

The number of total flashes to which the structure is exposed is related principally to local thunderstorm activity. Local thunderstorm activity can be projected from isokeraunic maps similar to that shown in figure 4. These maps show the number of thunderstorm days per year for various regions of the U.S. and the world. Additional maps of worldwide keraunic levels can be obtained from the World Meteorological Association.

A thunderstorm day is defined as a local calendar day on which thunder is heard irrespective of whether the lightning flashes are nearby or some distance away. To an observer at a specific location, the average distance at which lightning may occur and thunder will be heard is about 10 km. Therefore, a thunderstorm day means that at least one lightning discharge has occurred within an area of about 300 km^2 surrounding the position of the observer. The actual number of strikes in the immediate vicinity of the observer may be considerably higher or lower than the number of thunderstorm days might indicate, depending upon the duration and intensity of a specific storm or series of storms. In spite of the relative inexactness of a prediction of a lightning strike to a specific object that is based on the keraunic level, the thunderstorm day is the only parameter related to lightning incidence that has been documented extensively over many years. Its primary value lies in the qualitative information which it provides. In an area of frequent thunderstorms such as the west coast of Florida, for example, the number of outages in areas where there was no protection could be unacceptably high; in an area of few thunderstorms (e.g., southern California or Alaska), the expected outage from lightning might be once every few years.



COURTESY OF NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Figure 4. Mean number of thunderstorm days per year for the United States.

1.5 Lightning Effects

Flash parameters.--During the short interval of a lightning flash, several discharges occur. The sequence of events in a multiple-stroke flash is illustrated in figure 5. The initial path for the discharge is established in 50 μs. Intermediate return stroke currents of about 1 kA follow the initial return stroke and last for a few milliseconds. Subsequent strokes occur at intervals of 50 to 60 ms. The return stroke period may include a continuing current of approximately 100 A which flows for several milliseconds or until the start of the next return stroke. The lightning discharge involves the transfer of large amounts of electric charge between the cloud and the earth. The typical flash transfers 15 to 20 C (coulombs) (1 C = 6.2×10^{18} electrons) with some flashes involving as much as 400 C of charge. The energy per flash of lightning has been estimated[1] to be as high as 10^{8} J. Table 1 summarizes the range of values for selected lightning parameters.

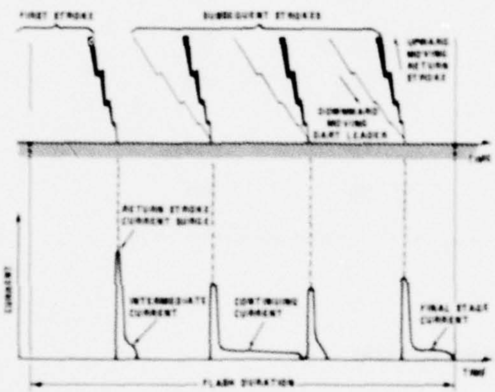


Figure 5. Illustration of processes and currents which occur during a lightning flash to ground (ref 1).

Mechanical and thermal effects.--The fast rise time and high peak current amplitude of the stroke can produce severe mechanical, thermal, and electrical effects. The damage caused by these currents to objects in the discharge path is closely related to the electrical conductivity of the object. For example, metals generally receive a discharge with little damage. In most cases, even slender conductors such as telephone and electric power cables handle the current without fusing (melting) except at the point where the current enters or leaves the metal. Discharges of high peak currents (>4 kA) and associated large amounts of charge (>200 C), however, can melt or burn holes in solid metal plates. This burning effect is not usually of primary concern for a typical building or structure, because if an adequate protection system is installed, the principal effect will be a small deformation at the tip of a lightning rod or a small melted area on the intercepting cable. The dominant concern of lightning-induced melting for earth-based systems is the threat to exposed tanks of volatile gases or fuels. Such effects are of even greater concern to airborne systems. Burning can perforate the fuselage and cause loss of pressure or penetrate the skin of fuel tanks and possibly ignite fuels.

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[1] *H. S. Denny et al, Grounding, Bonding, and Shielding Practices and Procedures for Electronic Equipments and Facilities, Vol 1, Georgia Institute of Technology (December 1975), ADA 022332.*

TABLE 1. RANGE OF VALUES FOR LIGHTNING PARAMETERS (ref 1)

Parameter	Minimum	Typical	Maximum
Number of return strokes per flash	1	2 to 4	26
Duration of flash (s)	0.03	0.2	2
Time between strokes (ms)	3	40 to 60	100
Peak current per return stroke (kA)	1	10 to 20	250
Charge per flash (C)	1	15 to 20	400
Time to peak current (μs)	< 0.5	1.5 to 2	30
Rate of rise (kA/μs)	< 1	20	210
Time to half-value (μs)	10	40 to 50	250
Duration of continuing current (ms)	50	150	500
Peak continuing current (A)	30	150	1600
Charge in continuing current (C)	3	25	330

2. BASIC REQUIREMENTS FOR LIGHTNING PROTECTION

In order to reduce the potential hazard from lightning and offer a measure of protection for structures such as buildings, towers, and other tall or exposed objects, the following requirements must be fulfilled.

a. Air terminals (lightning rods), must be provided to intentionally attract the leader stroke.

b. A low-impedance electrical path must be provided that connects this terminal to a ground electrode so that the lightning discharge will follow this path in preference to any other arbitrary path.

c. The ground electrode-to-earth resistance must be made low to sufficiently dissipate the discharge energy.

When these requirements are met, a lightning discharge enters or exits the earth and passes through only conducting parts of a structure. One of the following two methods may be used to satisfy the above requirements, each having specific applications:

1. the installation of an integral protection system consisting of air terminals interconnected with roof and down-conductors (continuation of roof conductors) to form the shortest practicable distance to ground, or

2. the installation of a separately mounted system consisting either of a mast-type metal pole which acts as both air terminal and down-conductor, or of two or more poles supporting overhead ground wires connected to an earth electrode subsystem (ring ground) with down-leads.

The system using air terminals along with roof and down-conductors is one used most commonly on buildings.

2.1 Lightning-Protection Codes

The lightning-protection system should conform to an accepted set of guidelines. Codes and standards have been established in many countries to provide the necessary guidelines. Every code or requirement has one thing in common: diverting a direct strike to earth. The primary difference in the various codes is the philosophy used in achieving an effective protection system.

The U.S. has two nationally accepted codes: The National Fire Protection Association's Lightning Protection Code[3] (ANSI/NFPA 78) and the Underwriters' Laboratories Master Labeled Lightning Protection System[4] (Standard UL 96A). The requirements of these two codes are quite similar and are probably equally utilized on structures throughout the nation. The major difference between the two is that the Master Label can be certified under UL 96A upon both a factory inspection and labeling of the lightning protection materials and upon performance of a field inspection by an authorized inspector.

The requirements of neither NFPA 78 nor UL 96A are adequate to protect the electrical distribution system, signal and control cables, or sensitive electronic equipment from surges produced by either direct or indirect strokes. Thus even though basic protection is provided for the structure by the master labeled system, supplemental steps should be taken (for example, providing lightning arrestors on power lines and on outside signal and control cables, providing counterpoise cables for overhead and underground cables, providing comprehensive electromagnetic shielding on sensitive cables, and installing fast-response surge-protection devices on circuits exposed to lightning discharges).

[3]*ANSI/NFPA 78, Lightning Protection Code 1977, National Fire Protection Association.*

[4]*UL 96 A, Installation Requirements, Eighth Edition.*

2.2 Procedure for Acquiring a Master Label

Assume that it has been determined that a lightning-protection system is to be certified. The procurement specification should indicate that the system is to be certified *Master Labeled System* in accordance with UL 96A. If the system is not to be certified then it should be specified to be installed, noncertified, in accordance with the NFPA 78 or UL 96A.[5]

The first step in acquiring a certified system is to design the system using the guidelines set forth in UL 96A. Then, construction of the system is contracted out and the contractor assumes the responsibility for supplying the certified system.

Another means of acquiring the Master Label is to contract for both design and construction through a UL-approved manufacturer of lightning-protection equipment. Often this route is the easier means of getting a certified system.

Upon completion of this installation and the field inspection, the application is signed by the owner and contractor and forwarded to the Underwriters' Laboratories. Underwriters' Laboratories then returns a 2.5 by 4 in. brass Master Label for attachment to the facility.

The procurement of a lightning-protection system installed in accordance with NFPA 78 involves a procedure that is basically the same as that for a certified system. However, closer supervision is necessary to ensure that the system is installed as required by the code.

The installation of the lightning-protection system does not mean that it will forever provide protection. Periodic inspections should be performed. Over a period of time, air terminals can be damaged by direct strikes, and corrosion on connectors and at joints may increase the lightning path resistance. Also, the inspection can reveal unprotected areas or areas where additions to the structure have not been properly protected.

3. LIGHTNING-PROTECTION SYSTEM

When designing and installing an integral system of protection, the following measures should be taken.

a. Air terminals should be erected on the points of highest elevation and on other exposed areas to intercept the stroke before it has

[5] *R. S. Smith, Lightning Protection for Facilities Housing Electronic Equipment, Florida Institute of Technology Workshop on Grounding and Lightning Protection (May 1977), ADA 043908.*

an opportunity to damage the structure, equipment, or components. The terminal points must be placed high enough above the structure to eliminate the danger of fire from the arc.

b. Roof and down-conductors should be installed so that they offer the least possible impedance to the passage of stroke currents between the air terminals and the earth. The most direct path is the best.

c. Ground connections should be distributed symmetrically about the circumference of the structure rather than grouped to one side.

d. All metal objects close to the discharge path should be interconnected to prevent side flashes.

e. Make certain that the mechanical construction of the air terminal system is strong and that the materials used offer high resistance to corrosion.

3.1 Cone of Protection

The ability of tall structures or objects to attract lightning to themselves serves to protect shorter objects and structures. In effect, a taller object establishes a protected zone around it. Within this protected zone, other structures and objects are protected against direct lightning strikes. As the heights of surrounding objects increase, the degree of protection provided to these shorter objects decreases. Likewise, as the separation distance between tall and short structures increases, the protection afforded by the tall structure decreases. The protected space surrounding a lightning conductor is called the cone (or zone) of protection.

The cone of protection provided by a grounded vertical rod or mast is conventionally defined as the space enclosed by a right circular cone with its axis coincident with the mast and its apex at the top of the mast, as illustrated by figure 6(a). Similarly, the zone protected by a grounded horizontal overhead wire is defined as a triangular prism with its upper edge along the wire as illustrated in figure 6(b). In either case, the zone of protection is expressed as the ratio of the horizontal protected distance, D, to the height, H, of the mast or wire. This ratio is the tangent of the shielding angle.* Some commonly recommended zones of protection and the associated shielding angles are illustrated in figure 7.

**The shielding angle is defined as the angle between the surface of the cone and a vertical line through the apex of the cone, or between the side of the prism and the vertical plane containing the horizontal wire.*

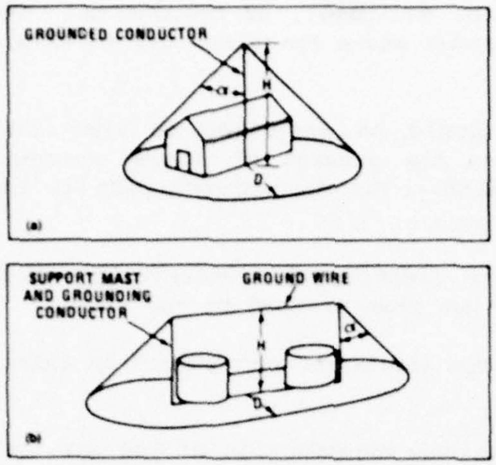
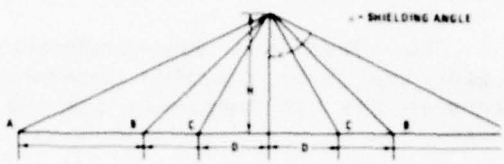


Figure 6. Zones of protection: (a) cone of protection provided by a vertical grounded conductor of height H, and (b) zone of protection provided by a horizontal aerial ground wire at height *H* (ref 1).



ZONE	D/H	α	REFERENCE	RECOMMENDED FOR
ADA	2/1	63°	NFPA 78	ORDINARY CASES
BOB	1/1	45°	NFPA 78 BRITISH CODE	IMPORTANT CASES ORDINARY STRUCTURES
COC	0.58/1	30°	BRITISH CODE	CRITICAL STRUCTURES

Figure 7. Some commonly used lightning shielding angles (ref 1).

The NFPA Lightning Protection Code recommends that a 1:1 zone of protection (α = 45 deg) be provided in important areas while a 2:1 zone (α = 63 deg) is acceptable for less important areas. The British Standard Code of Practice states that a shielding angle of 45 deg provides an acceptable degree of protection for ordinary structures, but that for structures with explosive or highly flammable contents the shielding angle should not exceed 30 deg.

Large structures with flat or gently sloping roofs do not lend themselves to the straightforward application of the 1:1 or 2:1 zone-of-protection principles. To establish even 2:1 type coverage on large buildings, exceptionally tall air terminals would be required. Experience, however, shows that extremely tall terminals are not needed for effective protection. Both the NFPA Lightning Protection Code and the UL Master Labeled Protection System specify air terminals that extend from 10 to 36 in. (256 to 910 mm) above the object to be protected. The British Standard Code of Practice does not require the use of air terminals at all.

Although the existence of a 1:1 zone of protection does not absolutely guarantee immunity to lightning, documented cases of the 1:1 zone being violated are very few. Thus for all facilities except those associated with the storage of explosives or fuels, a 1:1 zone of protection can safely be used as a basis of design of lightning-protection systems. If more than one rod or wire is used, the protected zone is somewhat greater than the total of all the 1:1 zones of the rods or wires considered individually. For adjacent structures, the codes specify that a 2:1 zone of protection may be assumed for the region between the structures.

3.2 Air Terminals (Lightning Rods)

Air terminals are the topmost elements of the lightning-protection system, designed to intercept a direct stroke. They typically consist of solid or tubular rods made of copper, aluminum, or bronze. The minimum diameters are 1/2 in. (1.27 cm) for solid copper or bronze rods and 5/8 in. (1.59 cm) for solid aluminum rods. The size and location of the air terminals should be as follows.

a. Air terminals must extend at least 10 in. (25.4 cm) above the object being protected. Rather than choosing the shortest terminal which will provide this minimum height, all parts of the structure must be checked graphically or analytically to determine whether the zone of protection provided by the terminal is adequate. Where taller terminals are required to provide complete protection, adequate support and bracing as specified by UL 96A or NFPA 78 must be provided.

b. Additional clearance must be provided where air terminals are mounted on or very near (less than 5 ft--1.5 m) vents or stacks which emit potentially explosive or ignitable dusts, vapors, or gases. Specifically, the following must apply:

1. Over hooded vents, the air terminals should extend at least 5 ft above the opening.

2. Above open stacks, air terminals should extend at least 15 ft (4.5 m) above the opening.

c. Air terminals should be located along the ridges of gable, gambrel, and hip roofs, and placed on the corners and along the edges of gently sloping roofs. (Gently sloping roofs are defined as (1) having a span of 40 ft--12 m--or less with a rise-to-run ratio--pitch--of 1/8 or less or (2) having a span greater than 40 ft and a rise-to-run ratio of 1/4 or less.)

d. On flat roofs, air terminals should be positioned around the perimeter. Additional terminals should be placed at 50-ft (15 m) intervals over the interior of flat and gently sloping roofs more than 50 ft wide.

e. Terminals should be provided within 2 ft (0.6 m) of corners, the ends of ridges, or edges of main roofs.

f. Air terminals up to 24 in. in height should be spaced 20 ft (6 m) or less. Terminals taller than 24 in. may be placed at intervals not exceeding 25 ft (7.5 m).

3.3 Grounding Conductors

Each air terminal should be provided with a two-way path to earth through the installation of roof and down-conductors conforming to table 2 for structures not greater than 75 ft (22.5 m) in height, and conforming to table 3 for structures greater than 75 ft in height.[6]

TABLE 2. MINIMUM REQUIREMENTS FOR ROOF AND DOWN-CONDUCTORS ON STRUCTURES NOT GREATER THAN 75 ft (23 m) HIGH (ref 6)

Type of conductor		Copper		Aluminum	
		Standard	Metric	Standard	Metric
Cable	Min size ea. strand	17 AWG	1.15 mm	14 AWG	1.63 mm
	Wgt. per 1000 ft[a]	187.5 lb	85 kg	95 lb	43 kg
	Cross-sect. area[a]	59,500 CM	0.30 cm^2	98,500 CM	0.499 cm^2
Solid strip	Thickness	14 AWG	1.63 mm	12 AWG	2.05 mm
	Width	1 in.[b]	25.4 mm	1 in.[b]	25.4 mm
Solid bar	Wgt. per 1000 ft	187.5 lb	85 kg	95 lb	43 kg
Tubular bar	Wgt. per 1000 ft	187.5 lb	85 kg	95 lb	43 kg
	Min wall thickness	0.032 in.	0.815 mm	0.0641 in.	1.63 mm

[a] *Acceptable substitutes are No. 2 AWG copper cables and No. 1/0 AWG aluminum cables.*
[b] *This is the minimum width for a strip void of perforations. If the strip has perforations, the width should be increased equal to the diameter of the perforations.*

TABLE 3. MINIMUM REQUIREMENTS FOR CONDUCTORS ON STRUCTURES GREATER THAN 75 ft (23 m) HIGH (ref 6)

Note: Equivalent standard AWG cable: copper--2/0; aluminum--4/0

Conductors	Copper		Aluminum	
	Standard	Metric	Standard	Metric
Minimum wire size	16 AWG	1.30 mm	13 AWG	1.83 mm
Weight per 1000 ft	375 lb	170 kg	190 lb	86 kg
Cross-sectional area	115,000 CM	58 mm^2	192,000 CM	97 mm^2

[6] *Lightning Protection Institute, Installation Guide LPI-175.*

3.3.1 Roof Conductors

- Roof conductors should be routed along the ridges of gable, gambrel, and hip roofs, and around the perimeter of flat and gently sloping roofs.

- Roof grounding conductors routed throughout decks, flat surfaces, and flat roofs should be interconnected to form closed loops to ensure that all the air terminals have at least two paths to earth.

- On roofs more than 50 ft wide, an additional conductor should be routed lengthwise across the roof with the ends connected to the perimeter conductor. One such conductor is necessary for each additional 50 ft of roof width. If this conductor is longer than 150 ft, a cross-conductor should be connected to the perimeter conductor at intervals no greater than 150 ft. By these requirements, the roof will be covered with conductors forming rectangles having dimensions no larger than 50 by 150 ft.

- Conductors should be routed around obstructions which lie in a horizontal plane with the conductor. Bends in the conductor should form angles larger than 90 deg and should maintain a radius of 8 in. (20.3 cm) or greater. When routing around obstructions, wide gradual bends are preferred.

- Roof conductors should be securely attached directly to the ridge roll or roof with UL-approved fasteners every 3 ft (1 m).

3.3.2 Down-Conductors

- Down-conductors should be coursed over the extreme outer portions of the structure and separated from each other as far as possible. Preferred locations for two down-conductors are at diagonally opposite corners of the building.

- At least two down-conductors are required on all buildings.

- One additional down-conductor should be provided for each additional 100 ft (31 m) or fraction thereof on buildings having a perimeter exceeding 250 ft (77 m). With flat or gently sloping roofs, the number of down-conductors should be such that the length of the average roof conductor joining them does not exceed 100 ft.

- Multiple conductors should be as close as practical to air terminals and to the most convenient places for attaching the conductors to the earth electrode system of the building. The down-conductors should be equally and symmetrically spaced about the perimeter of the building.

• Down-conductors should be placed or be provided to avoid roof conductor dead ends longer than 16 ft (5 m).

• Down-conductors should be routed downward. As with roof conductors, sharp bends or turns are to be avoided.

• Where it is determined to be necessary, down-conductors should be guarded to prevent physical damage or displacement. Guards of wood or plastic (rigid PVC) are acceptable. Whenever possible, the use of electrically conductive tubing (such as iron, steel, or copper) should be avoided. If such materials are necessary, the conductor must be bonded to the top and bottom of the metal pipe or tubing. Guards of not less than 6 ft above grade level should be provided for the down-conductors to ensure conductor protection.

3.4 Hardware (Fasteners, Connectors, Clamps, and Fittings)

• Connectors, clamps, and fittings should be used to securely attach air terminals and roof and down-conductors to the building or other objects upon which they are placed.

• Fasteners (including nails, screws, or other means by which connectors, clamps, and fittings are attached) should be well constructed, not subject to breakage, and should be of the same material as the conductor.

• All hardware, component parts, and joints that are not welded should be readily accessible for inspection, maintenance, or repair.

• Fasteners should be spaced not more than 3 ft apart on all conductors. Nails, screws, or bolts used to secure the fasteners should be of the same material as the fasteners or be of a material which is as resistant to corrosion as that of the fasteners.

• Galvanized or plated steel nails, screws, or bolts are not acceptable.

• Where future testing of the protection system may be required, disconnectors should be installed on all but one ground terminal of the building. Acceptable disconnectors are

(1) clamps used for connecting down-conductors to driven ground rods,

(2) bimetallic fittings used to connect aluminum conductors to copper conductors or ground electrodes,

(3) special bolt-pressure disconnectors used at locations dictated by job conditions in cases where the actual ground connectors are inaccessible, and

(4) sufficiently tight-bolted compression fittings used for connection to metal tracks, gutters, downspouts, ventilators, or other metal parts about the structure.

Approved crimp-type or bolted clamps of stamped or cast metal may be used on structures 75 ft high or less. Bolted clamps and splices should be used for structures higher than 75 ft.

3.5 Earth Electrode System

3.5.1 General

Generally, the earth is used to neutralize excessive electrical charges caused by man-made and natural sources that might injure personnel and damage equipment. To be effective, earth grounding must provide a low-impedance path at all relevant frequencies to the soil. The local soil condition will determine how elaborate the earth ground system installation must be. If a soil of uniform resistivity is assumed, the greatest resistance is in the shell immediately surrounding the electrode buried beneath the ground, which has the smallest cross section of soil at right angles to the flow of current through it. Each succeeding shell of this electrode has a larger cross section and, therefore, lower resistance. At a distance of 8 to 10 ft (2.5 to 3 m) from the buried electrode, the area is so large that the resistance of successive shells is almost minute compared to that of the shell immediately surrounding the electrode. Where the conductive shell is small, the resistivity of the soil is an important factor in the effectiveness of the ground connection to earth. The moisture content of the soil causes a marked difference in its resistivity; the variation of only a few percentage points in the moisture content, especially below 20 percent, will change the buried electrode resistance to earth over a wide variety of soils.

Earth electrode connections to the earth provide the means of obtaining the lowest possible impedance contact with the earth. Two basic types of electrodes are used: (1) those specifically placed in the earth as electrodes, such as driven rods, buried wire, mats, straps, plates, and other objects as required to establish a low electrode impedance to earth, and (2) those serving another function, such as water pipes, metal well casings, foundation reinforcing bars, buried metal tanks, and other miscellaneous metal objects buried in the earth. Regardless of the electrode type used to establish an earth electrode subsystem, all electrodes must be electrically interconnected by appropriate conductors to form one continuous network. The actual shape of the electrode network is relatively unimportant. For lowest surge impedance, the radial network is probably the best. For new installations, a grid ground electrode underneath the building is usually considered convenient for its multiple attachment possibilities. Ring or perimeter ground electrodes consisting of interconnected ground rods are very cost effective and can be installed conveniently around existing facilities. This type of system is suggested to be used for the CERC facility at Duck, NC.

3.5.2 Driven Ground Electrodes

Driven ground electrodes of rods or pipes are used where bedrock is more than 10 ft deep. Ground rods are commercially manufactured in 3/8-, 1/2-, 5/8-, 3/4-, and 1-in. diameters. For most applications, the 1/2- and 3/4-in. diameter rods in lengths of 6, 8, and 10 ft are normally used. The National Electric Code specifies that steel or iron rods be at least 5/8 in. in diameter and rods of nonferrous materials be not less than 1/2 in. in diameter. The Military Standard on Grounding, Bonding, and Shielding (MIL-STD-188-124) calls for ground rods to be copper-clad steel with the copper jacket being not less than 0.012 in. in thickness. Copper-clad steel, one of the most common rod types, permits driving to a considerable depth without damaging the rod itself. The outer copper coating provides direct copper-to-copper connection between a copper wire typically used for down-conductors and the rod. Galvanized steel or stainless steel rods or pipes also provide an excellent means of obtaining low impedance. The minimum diameter of a ground rod is limited by mechanical rather than electrical criteria. The usual practice is to select a ground rod with a cross section large enough and strong enough to be driven into the soil at a given location. However, MIL-STD-188-124 specifies that the ground rods be not less than 3/4 in. in diameter, or 10 ft in length, and spaced apart by not more than twice the rod length. The rods should be interconnected with a No. 1/0 AWG (or equivalent) bare copper cable buried at least 2 ft below grade level. The interconnecting cable should be brazed or welded to each ground rod and should close on itself to form a complete loop with the ends brazed or welded together.

3.6 Service Entry

3.6.1 General

For most facilities, the power required for day-to-day operation is derived from commercial utility sources. At the CERC facility at Duck, NC, power from these sources is used for the essential data-acquisition equipment as well as for noncritical functions such as lighting, personnel accommodations, and other purposes not essential to the retrieval of data obtained by instrumentation about the pier. Because commercial power is subject to occasional failure, particularly during storms and lightning activities, most permanent facilities also contain emergency generators of sufficient capacity to carry the essential equipment loads.

From the standpoint of lightning protection, the primary concern is not with preserving the external source of ac power, but rather with controlling the lightning-induced or transmitted currents carried into the facility on power or other penetrating conductors.[7] As illustrated in figure 8, the ac power wiring in a communication facility provides a hardwire path from the utility distribution system outside the building to the low-voltage wiring inside the building. The overhead utility distribution lines outside the building form a very large lightning diverter, attracting a strike to the lines rather than to lower nearby structures. Because it behaves as a current source, a typical lightning strike to the power lines would raise the power-line potential to millions of volts, were it not for arcing, insulator flashover, or lightning arrestor actuation. Similarly, a direct strike (having peak currents of about 20,000 A) to a building ground system (e.g., a ring ground) having a 10-ohm impedance will raise the potential of the ground point to 200,000 V relative to the undisturbed potential far from the strike point. Although in this case the building and its contents might be raised to the same high potential, potential differences between metallic objects or equipment within the building could be negligible. A direct strike to an unprotected building or its nearby external cabling or plumbing is most likely to produce internal sparking or equipment damage. However, it is not the most likely event to occur. The most commonly encountered (and least severe) lightning interference will be transients induced in service cables and power lines by lightning strokes within a few kilometers of the building. Peak currents of 10 to 1000 A may be induced on buried cables, power lines, and similar conductors by these strikes. Such transients have been observed to damage electronic components connected to long, buried, or aerial interconnecting cables.

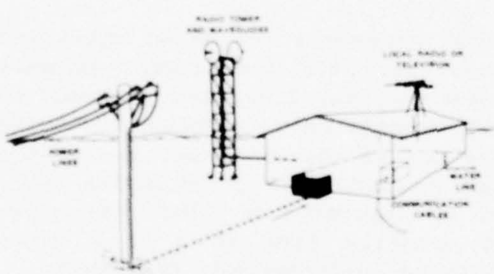


Figure 8. Excitation of facility by exposed penetrating power conductors (ref 7).

3.6.2 Power System, ac

The elements of a typical low-voltage ac power system in a facility are illustrated in figure 9. The distribution transformer and all distribution lines, switch gear, and substation equipment to the left of the distribution transformer are usually owned and controlled by the utility company. The service entrance from the transformer to the main disconnect and all wiring inside the building are customer-owned and -controlled, subject to national and local electrical codes.

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[7] *E. F. Vance et al, Technical Inputs and EMP Design Practices for Intrasite Cabling of Telecommunication Facilities, Stanford Research Institute Project 4587, Final Report (June 1977).*

The main disconnect and main distribution panel may be in separate cabinets, as illustrated, but they are often in the same cabinet. An emergency generator driven by a gasoline, diesel, or turbine-engine is shown connected to the building load by a transfer switch near the main distribution panel. This generator is usually employed to supply power to the facility (or to the critical loads in this facility) in the event of a commercial power failure. The transfer switch may be manual or automatic; the automatic switches sense the power failure, start the engine generator, sense its voltage and frequency, and close the switch connecting the generator to the facility load.

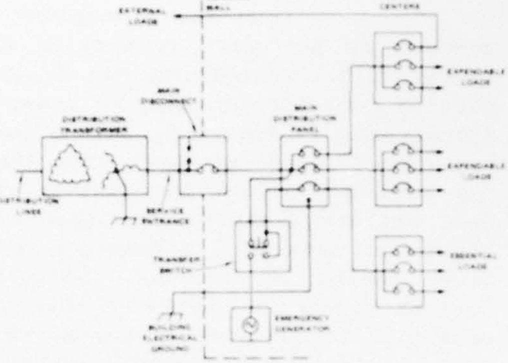

Figure 9. Typical elements of ac power system for a communication facility (ref 7).

The treatment of penetrating conductors in a facility to eliminate arcing and limit the surges coursing to internal equipment relies primarily on voltage-limiting devices. Secondary lightning arrestors can be applied to almost any penetrating conductor to limit the peak voltage to a few thousand volts, and less rugged gas-tube or solid-state surge arrestors can then be used to further reduce the peak voltages to a few tens or hundreds of volts. Surge arrestors can thus be used to limit the voltages carried into buildings on conductors such as power leads, telephone lines, and data-acquisition cables that cannot be continuously grounded.

Distribution-type lightning arrestors are often installed between the phase conductors and ground near the transformer primary bushings of pole-mounted transformers and near the line-side potheads on shielded cables supplying ground-based transformers. These lightning arrestors are usually spark-gap devices containing nonlinear resistance elements. They are designed to protect transformers or shielded cable insulation from voltage surges caused by lightning or line switching. Distribution-type lightning arrestors normally fire at 3 to 5 times their line voltage rating with slowly rising (microsecond) transients.

Secondary lightning arrestors are often installed on the low-voltage conductors as they enter the main circuit breaker panel. These secondary arrestors usually fire at voltages of 1000 to 2000 V and are intended to protect the low-voltage insulation in wiring and equipment. They can also be effective in limiting the induced surges that pass through the transformers and distribution lightning arrestors.

A typical installation of surge arrestors at the main circuit-breaker panel for a 60-Hz power penetration is shown[8] in figure 10. In this example, three-phase, grounded neutral service cable entering in grounded metal conduit is used. The undesired transient is thus a common-mode voltage on the phase conductors with the conduit acting as the common-mode current return path. Secondary lightning arrestors are shown mounted on the metal circuit-breaker cabinet with one side grounded to the cabinet (a separate ground lead from the surge arrestors to the ring ground would usually degrade the performance of the surge arrestors by adding a large unnecessary lead inductance). In applying surge arrestors to any conductors that enter the facility in grounded conduit or a grounded shield, the ground side of the surge arrestor should be connected to the conduit or shield rather than through a separate long lead to the ring ground.

In general, all electrical service entrances should be installed in rigid steel conduits with tight threaded couplings, and the entrance conduit should be grounded as it enters the facility. Service, maintenance, and electrical code requirements usually make it convenient to install secondary lightning arrestors in the main circuit-breaker cabinet and to install line filters adjacent to the main circuit-breaker cabinet on the load side of the main circuit breakers. If all 60-Hz wiring inside the facility and external loads are installed in metal conduit in accordance with the National Electric Code, filtering requirements can be met with a single set of line filters installed adjacent to the main circuit-breaker panel as illustrated in figure 11. If electromagnetically exposed electric wiring, cords for appliances, tools, heaters, and temporary extensions are used, inputs to susceptible equipment may require filters. Unless considerable configuration control is exercised, the latter conditions will usually apply.

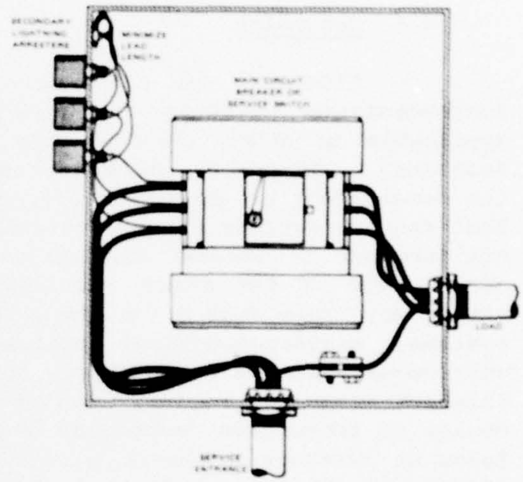

Figure 10. Illustration of secondary lightning arrestors at main circuit-breaker panel (ref 8).

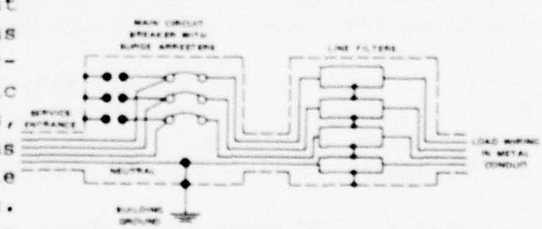

Figure 11. Line filters installed on 60-Hz power conductors (ref 8).

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[8] *E. F. Vance, Design Guidelines for Treatment of Penetrations Entering Communication Facilities, Stanford Research Institute Project 3149 (August 1975), ADB 007076L.*

Line filters should be installed on the neutral as well as the phase conductors since the lightning-induced interference may enter on the neutral as easily as on the phase conductors.

Readily available line filters provide over 60 dB of attenuation in the frequency spectrum above 100 kHz. Because the distribution transformers, distribution lightning arrestors, and secondary lightning arrestors normally suppress the spectrum below about 200 kHz, the peak lightning-induced voltage passed by the line filters, when these protective devices are used, may be less than 1 V.

4. PROTECTION OF DATA INSTRUMENTATION SYSTEM

4.1 Grounding

Although the following paragraphs refer specifically to instrumentation systems, the practices and techniques discussed are applicable to other low-frequency analog systems (e.g., voice communications). Generally, data instrumentation systems are concerned with the measurement or detection of physical phenomena (or changes in them) that require periods of observation or measurement that range from a few milliseconds to several minutes or longer. Because of the relatively slow nature of the event, the fundamental frequency of the transducer output may range from 0 (dc) to a few hundred hertz. Power-distribution systems, electromechanical switches, and atmospheric noise produce extraneous voltages whose energy content is strongly concentrated within this low-frequency region. Because of this overlap of signals, special design or protection techniques are generally required to keep the voltages or currents produced by the extraneous sources from obscuring the transducer outputs. Data instrumentation systems may employ either analog or digital signals, or a combination of both. It is not assumed that only analog instrumentation will be employed at the CERC facility; however, the methods of grounding analog systems are emphasized in this report, although the physical principles of interference reduction from lightning for digital systems are basically the same.

Since analog signals are primarily low frequency in nature, a basic single-point ground system should be implemented. The signal return lines should be grounded at one end only. Similarly, shields around signal lines should be grounded at one end only.

4.1.1 Grounded Transducers

The bonded (grounded) transducer (e.g., thermocouple), illustrated in figure 12, is used with a single-ended data amplifier whose output drives recording devices such as oscillographs, strip-chart recorders, and magnetic tape recorders. The following practices are recommended in order to reduce common-mode noise and transient pickup.

a. The shield which surrounds the transducer signal leads should be grounded at the same point as the transducer to ensure that the shield and signal leads are at virtually the same potential.

b. When single-ended amplifiers are used, the recorder should be left ungrounded.

c. When a bonded thermocouple is connected to an isolated differential amplifier as shown in figure 13, the shield of the input cable should be connected to the amplifier internal guard shield to continue the signal shield to within the amplifier. In this figure, a grounding bus is shown connected between the data system signal reference and earth ground of the test area. This ground bus is necessary in any instrumentation system which uses isolated differential amplifiers in order (1) to provide the earth reference for the signal circuitry within the recording system, (2) to reduce high-voltage hazards, and (3) to minimize the common-mode potentials that would otherwise exist between the amplifier's input and output (if the data recording system were grounded to a separate earth ground). In this example the amplifier case and output shield are connected to the data system (load end) ground.

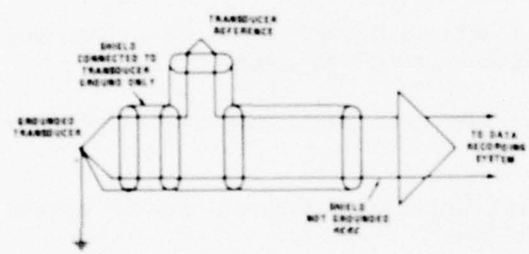

Figure 12. Grounding practices for single-ended amplifiers (ref 2).

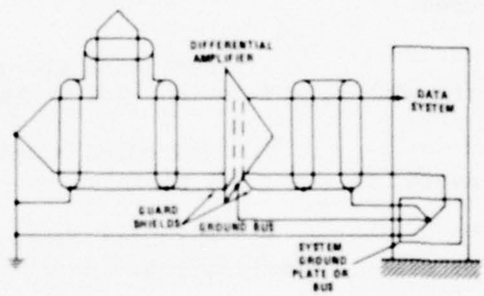

Figure 13. Grounding practices for differential amplifiers (ref 2).

d. Grounded bridge transducers should be excited with a balanced dc source (fig. 14). This allows the entire bridge to be balanced with respect to ground; the unbalanced impedance presented to the amplifier input is due only to the leg resistances in the bridge. Although a ground loop still exists, its effect is greatly reduced by a balanced excitation supply.

e. Wherever possible, an isolated amplifier should be used with bridge transducers in the manner illustrated in figure 15. With this configuration, both the transducer and the amplifier can be grounded without degrading system performance.

f. A low-impedance earth ground connection should be used.

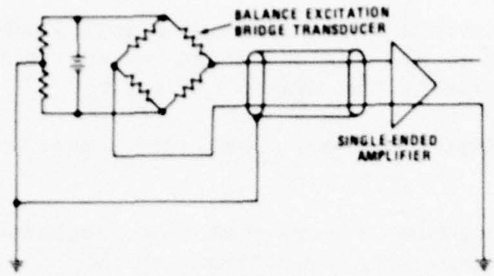

Figure 14. Method of grounding bridge transducers (ref 2).

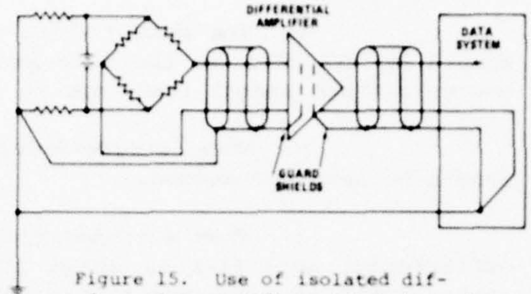

Figure 15. Use of isolated differential amplifier with balanced bridge transducer (ref 2).

g. A single common signal reference point should be provided for all grounded transducers at the test location.

h. The instrumentation cable shield of each data channel should be connected as close to the transducer ground connection as possible.

i. Twisted shielded transducer extension wires should be used.

j. When a single-ended data amplifier input is a grounded transducer, a floating load on the output should be used.

k. The guard shield of the data amplifier should be connected to the input cable shield.

l. Shielded cables with insulated jackets should always be used in data instrumentation systems.

4.1.2 Ungrounded Transducers

Figure 16 illustrates the grounding techniques recommended for ungrounded transducers. The metallic enclosure of the transducer is connected to the cable shield and both the enclosure and the shield are bonded at the transducer. If the load on the cable signal line is a single-ended amplifier as shown in figure 16a, the shield of the input cable should not be connected to the amplifier. The case of the amplifier should be grounded at the load.

Figure 16b shows the recommended way of grounding the system when an isolated amplifier is used. Certain types of nonisolated differential amplifiers require that a transducer ground path be provided for proper amplifier operation. The instructions supplied by the amplifier manufacturer should be consulted for correct procedures. The following practices should be followed to reduce transient pick-up and noise.

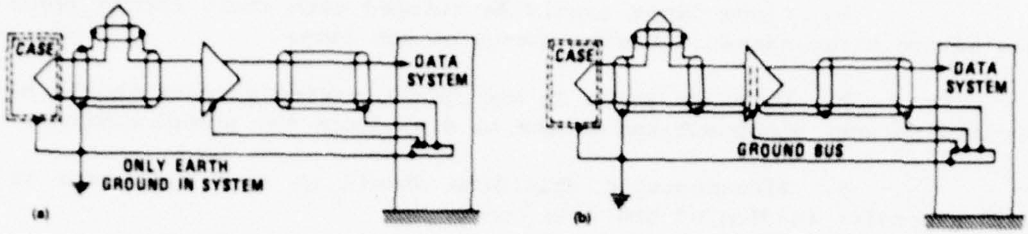

Figure 16. Recommended grounding practices for floating transducers: (a) single-ended amplifier and (b) isolated differential amplifier (ref 2).

a. A single common reference point should be provided for all cable shields.

b. All input cable shields should be bonded at the transducer.

c. A continuous overall shield for signal wires should be provided from the transducer case to the input of the data amplifier.

d. The isolated amplifier guard shield should be connected to the input cable shield.

e. The inner shield of each input cable should not be grounded at more than one point.

4.1.3 Amplifiers

Single-ended amplifiers should not be used with (a) grounded transducers, in order to avoid channel-to-channel ground loops, and (b) bridges, to avoid short circuiting one leg of the bridge. The amplifier output guard shield should be connected to the data system. If an unavoidable ground exists at the test area as well as at the data system, isolated differential amplifiers should be used to break the ground loop.

4.1.4 Digital Data Systems

A digital circuit operates by recognizing the state of a two-level voltage or current signal (square pulse) which has very fast rise and fall times. The high frequencies associated with fast rise and fall times are likely to be capacitively or inductively coupled to other circuits which may respond to the signals. Every precaution should be taken to shield and minimize these coupling effects. Some of the precautions are listed below.

a. Clock lines should be twisted with their return leads to minimize stray magnetic field pick-up on the lines.

b. Multiple paths in the ground wiring network should be provided between equipment and ground to distribute the ground current.

c. Electrostatic shielding should be used with care to avoid excessive loading of the data lines.

d. All digital circuits should be wired using the shortest wire lengths possible.

e. All ground wires must converge to a common system ground point.

f. Maximum physical separation should be maintained between digital circuits and low-level analog circuits.

g. If the data system must house both analog and digital circuits in the same equipment cabinet, physical separation must be kept between them as much as possible (e.g., they should be at opposite ends of the cabinet). A common ground plate for the system can be located in the center of the cabinet, or two ground plates can be used, one for analog ground and one for digital ground. These two ground plates must be tied together with a low-inductance bus and then tied to the system ground.

4.1.5 Strip-Chart Recorders

The strip-chart recorder is a nulling device. Its input impedance will change with deflection of the stylus. This impedance change and the accompanying voltage feedback can be coupled directly from the strip-chart input over the input of a parallel device such as an analog to digital (A/D) converter. Gross error can result in the A/D channel. This difficulty can be resolved by using resistive isolation as shown in figure 17 or by employing dual amplifier outputs, one for each channel, and by grounding as illustrated in figure 18.

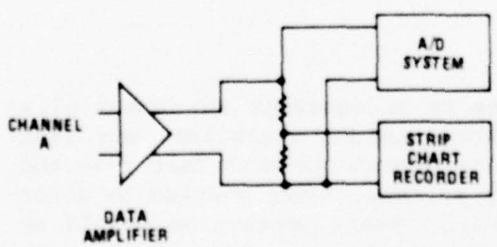

Figure 17. Resistive isolation of data channels (ref 2).

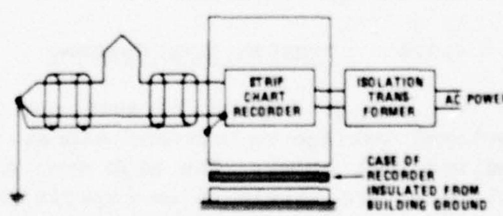

Figure 18. Grounding for single channel strip-chart recorder (ref 2).

4.1.6 X-Y Plotters

X-Y plotters are available in either digital or analog input configurations. The digital plotters are usually connected as peripheral devices to computers or A/D systems and should be grounded in accordance with the practices recommended for digital equipment. Analog X-Y plotters are normally single-ended and should be grounded and connected in the same manner as strip-chart recorders.

4.2 Signal and Data Transmission Lines

Signal and data transmission circuits may provide paths for lightning currents and voltages to enter sensitive equipment. Circuits totally contained within protected buildings and having no direct exposure to lightning currents can usually be designed without consideration of lightning effects. Circuits which are not totally contained within protected buildings or are connected to or are a part of circuits not within protected buildings must be designed to accommodate lightning effects.

Lightning effects fall into two general categories, the first of which is mechanical. These effects include all the burn and blast damage which can occur when an object is struck by lightning. The most direct way of minimizing mechanical damage is to provide a means of intercepting the stroke before it actually contacts a transmission circuit. The interception can be accomplished by enclosing the circuits in metal conduit or by providing guard wires. For data circuits that run below grade in direct burial or in cable trenches, the best protection is provided by two bare guard wires buried 3 to 4 ft above and to either side of the data circuit. Aboveground data lines must be protected by an overhead guard wire that is grounded at intervals not exceeding 250 ft and is at least 8 ft above the data circuitry to be protected from direct stroke burn and blast effects.

The second category of lightning effects includes all electrical aspects. These are immensely complicated; it is difficult to generalize on the proper protective measures which should be applied. An effective design from a lightning viewpoint must include both the voltage-tolerance levels of the equipment and the expected magnitudes of the lightning-induced voltages. The following subsections present lightning-protective measures necessary to obtain minimum induced voltages when common construction practices are followed. The quality of each of the construction types, from a lightning effects viewpoint, varies quite widely.

4.2.1 Metal Conduit Systems

The use of rigid steel conduit to form a continuous grounded metal shield around ac power, signal, and data lines results in a system which should be as completely free of lightning effects as possible. Such a system may need no additional protective devices at the input/output ends of the lines.

Measurements[9] of lightning-induced voltages on circuits within a 2-in. 5000-ft-long rigid steel conduit indicated 30 V between the conductors and ground (known as common-mode voltage), and 0.2 V between the conductors themselves (known as differential voltage). The common-mode voltage is a function of the conduit permeability, conductivity, cross section, and the rate of change of the transient current, while the differential voltage is primarily due to the flux leakage coupling at the cable joints and bends, therefore varying nearly linearly with length. The use of conduit of larger diameter and/or shorter length will result in lower voltages.

Use of nonferromagnetic metal conduit will result in significantly higher voltage coupling to the internal lines, even if the nonferromagnetic metal conduit has a higher dc conductivity. For instance, the use of 2-in. aluminum in place of 2-in. rigid steel for conduit can result in an approximately 42-fold increase (32 dB) in coupling of the voltage transients to the protected lines, even though the dc conductivity of the aluminum conduit can be 17 times that of steel.[9] This seeming inconsistency is due to the large difference in permeability between steel and aluminum. For the case of 2-in. rigid steel conduit and a lightning-like current pulse, the effective transient conductivity has been measured to be 1000 times the dc conductivity. Consequently, use of nonferromagnetic metal conduit will result in significantly higher coupling of transients to the signal, data, and power lines that are coursed through the conduit. If nonmetallic conduit such as PVC is used, the lines are further exposed electrically to the lightning environment and are subject to burning and blast damage from a direct strike.

4.2.2 Aboveground Cable Trays with Guard Wires

Aboveground cable trays with guard wires are frequently used in facilities in warm geographical regions; this type of construction provides the greatest flexibility for adding or subtracting cables. This construction requires the following special bonds and grounds in addition to the guard wires described above.

Grounding.--The cable trays must be grounded to driven rods at intervals not exceeding 250 ft and to the building ground electrode system. If soil conditions prohibit driving rods, equivalent counterpoises should be installed.

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[9] *T. J. Blalock, Lightning Protection Guideline for STADAN Ground Equipment, Goddard Space Flight Center S-523-P-8 (November 1967).*

Bonding.--All trays must be bonded together to form a continuous electrical structure.

Cables.--All signal and data cables should have a continuous overall metal braid or shield (not spiral tape) that is bonded to the building ground system.

Since this shielding will not provide the protection that is obtained with steel conduit, some sensitive circuits may require special protective devices. Transient voltages between the conductors will be approximately an order of magnitude larger than those produced with the use of conduit.

4.2.3 Buried Nonmetal Conduits with Guard Wires

This type of construction does not provide the protection that is obtainable with cable trays or conduits. In addition to the guard wires, all signal and data cables should have a continuous overall metal braid or shield (not spiral tape) that is bonded to the building ground system.

Voltages between the conductors will be approximately 100 times larger than those produced with the use of conduit, and sensitive circuits connected to long runs will require protection devices.

4.3 Protective Devices

4.3.1 General

Individual items of electrical and electronic equipment that directly interface any externally exposed equipment lines, including commercial ac power lines as discussed in section 3.6, may require transient protection that may well be designed as an integral part of the equipment. Externally exposed lines are defined as lines exposed to outside weather elements and environmental conditions. The lines may run overhead, run along grade surface, or be buried in earth. Transient protection should be placed in equipment which interfaces with these lines. The level of protection required is dependent on (1) the damage susceptibility of the equipment of interest, (2) the level of transient suppression provided at the building entrance on externally exposed lines, or external equipment termination, and (3) the level of transient energy that is estimated to be conducted to the equipment. Precise calculation of the number of lightning-generated transients that will occur at a specific location in a specified time interval is not possible. However, enough observations have been made to permit statistical evaluation of the number of lightning flashes that are likely to occur in an area with a known average number of thunderstorm days per year. Some flashes may not produce any transients while others will produce several transients. However, the available data,[2] after considerable averaging and rounding, show that over 10 years, a facility will experience 175 lightning surges in a low-incident area (one with 10 thunderstorm days per year) and 1750 lightning surges in a high-incident area (one with 100 thunderstorm days per year). When used in conjunction with figure 4, these figures permit calculation of the number of lightning surges that will occur anywhere in the U.S. in a 10-year period. As an example, the FRF at Duck, NC, has an estimated number of 45 thunderstorm days per year. This is 45 percent of 100 thunderstorm days; therefore, 45 percent of 1750 (or about 788) lightning surges should be expected at the facility in a ten-year period.

Measured current amplitudes from direct lightning strikes on ac service conductors have varied from 1 to 250 kA. Table 4 presents the peak current amplitudes measured for 2721 flashes. The medium peak value for the peak currents was approximately 15 kA. Nondirect lightning strikes, because of their close proximity and high intensity, will couple onto the ac service lines through the service transformer. Because electromagnetic fields are attenuated by propagation through air and losses due to earth resistance and the service transformer winding, the amplitude of the coupled and induced transients will be reduced by at least 50 percent of the direct strike amplitude. Therefore, 85 percent of the transient current surges appearing at a facility main service disconnect means will be 20 kA or less, and the greatest percentage (68 percent) of the surges will be in the 0.5 to 1.0 kA range. Table 5 provides a tabulation of transient amplitudes and the percentage of transients on incoming ac lines that will, as a maximum, be of the amplitude listed.

Transients occurring on landlines have been defined[2] as 10 by 1000 μs, 1000-V peak pulses where 10 μs is the time from the start of the transient to peak voltage, and 1000 μs is the time from the start of the transient until the amplitude exponentially decays to 50 percent of the peak value. Source impedance cannot be precisely defined but for design purposes is assumed to be 1 ohm. Therefore, a typical worst-case lightning-induced transient can be defined as 10 by 1000 μs, 1000-V peak with a peak surge current of 1000 A. Using table 5, the 1750 transient pulses defined above, and the worst-case transient of 1000-V peak, the number of transients of varying amplitude would be as listed in table 8 (p. 39) for externally exposed lines in a high-incident lightning area (average of 100 thunderstorm days per year over a 10-year period). For areas around Duck, NC, the number of transients should be reduced by 45 percent.

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[2] *ORDER 6950.19--Practices and Procedures for Lightning Protection, Grounding, Bonding, and Shielding Implementation, Department of Transportation, Federal Aviation Administration (July 1978).*

TABLE 4. PEAK CURRENTS FROM DIRECT LIGHTNING STRIKES (ref 2)

Range of current (A)	No. of flashes with peak current in range	No. at or above level	Percentage at or above level
1,000 to 5,000	567	2,721	100
5,001 to 10,000	611	2,154	79.2
10,001 to 20,000	640	1,543	56.7
20,001 to 30,000	296	903	33.2
30,001 to 40,000	227	607	22.3
40,001 to 50,000	140	380	14.0
50,001 to 60,000	80	240	8.82
60,001 to 70,000	61	160	5.88
70,001 to 80,000	22	99	3.64
80,001 to 90,000	21	77	2.83
90,001 to 100,000	11	56	2.06
100,001 to 110,000	11	45	1.65
110,001 to 120,000	9	34	1.25
120,001 to 130,000	9	25	0.918
130,001 to 140,000	7	16	0.588
140,001 to 150,000	2	9	0.331
150,001 to 160,000	3	7	0.257
160,001 to 170,000	0	4	0.137
170,001 to 180,000	1	4	0.147
180,001 to 190,000	0	3	0.110
190,001 to 200,000	1	3	0.110
200,001 to 210,000	0	2	0.073
212,000	1	2	0.073
218,000	1	1	0.037
Total	2,721		

TABLE 5. TRANSIENTS PROJECTED TO OCCUR ON EXTERNALLY EXPOSED LINE IN HIGH-LIGHTNING-INCIDENT AREA OVER 10-YEAR PERIOD (ref 2)

No. of transients	Percentage	Peak voltage (V)	Peak current (A)
2	0.1	750 to 1000	750 to 1000
15	0.9	500 to 749	500 to 749
18	1	400 to 499	400 to 499
53	3	300 to 399	300 to 399
140	8	200 to 299	200 to 299
332	19	100 to 199	100 to 199
420	24	50 to 99	50 to 99
403	23	25 to 49	25 to 49
367	21	5 to 24	5 to 24

Manufacturers do not normally specify damage or upset threshold levels for components. Therefore, an analysis must be performed to determine these levels for each item of equipment that directly interfaces any exposed lines, including ac input lines. Estimates of transients that are conducted to equipment are provided in tables 6 to 8. The transients listed in the first two tables represent clamp or holding voltages that will be reflected across equipment by the facility secondary ac arrestor installed at the main service disconnect means (see sect. 3.6.2) when this arrestor is discharging transient surges. Table 8 indicates the number and amplitude of conducted transients estimated to be at each land-line equipment interface, assuming that the lines are not enclosed in metal conduit.

TABLE 6. TRANSIENT SURGES, LINE-TO-GROUND, PROJECTED TO BE REFLECTED ACROSS EQUIPMENT BY SECONDARY AC SURGE SUPPRESSOR OVER 10-YEAR PERIOD (ref 2)

Surge current amplitude (8 by 40 μs)		No. of surges
Peak voltage (kV)	Peak current (A)	
1.5	100	1500
2.0	200	700
2.5	300	375
3.0	500	50
3.5	1000	5
4.0	1500	2
4.5	2000	1

TABLE 7. TRANSIENT SURGES, LINE-TO-LINE, PROJECTED TO BE REFLECTED ACROSS EQUIPMENT BY SECONDARY AC SURGE SUPPRESSOR OVER A 10-YEAR PERIOD (UNGROUNDED SERVICE ONLY) (ref 2)

Surge current amplitude (8 by 40 μs)		No. of surges
Peak voltage (V)	Peak current (A)	
500	50	1000
750	100	100
1000	200	50
1500	300	10

TABLE 8. TRANSIENT SURGES PROJECTED TO OCCUR IN 10-YEAR PERIOD ON EXTERNALLY EXPOSED LAND LINES (ref 2)

Surge current amplitude (10 by 1000 μs)		No. of surges
Peak voltage (V)	Peak current (A)	
100	50	1000
500	100	500
750	375	50
1000	1000	5

4.3.2 Susceptible Components

Integrated circuits, discrete transistors, diodes, capacitors, miniature relays, transformers, and switches used in the design of solid-state equipment are very susceptible to damage from lightning-generated transient surges. Other components are not immune to damage but are susceptible to a much lesser degree. Standards do not exist for specifying the threshold level against lightning transients for most equipment and components. Therefore, accurate information must be obtained from manufacturers, laboratory tests, or conservative engineering estimates. Typical threshold limits for some common types of equipment and components are as follows.[2]

Item	Limit
integrated circuits	2 times static breakdown voltage
discrete transistors	2 times normal-rated junction voltage
diodes	1.5 times peak inverse voltage
miniature relays, transformers, and switches	3 times rated voltage
capacitors	1.5 times dc working voltage unless transient dielectric punch-through voltage is known

[2]*ORDER 6950.19--Practices and Procedures for Lightning Protection, Grounding, Bonding, and Shielding Implementation, Department of Transportation, Federal Aviation Administration (July 1978).*

Item	Limit
dc power supplies with step-down transformer and diode bridge	1.5 times diode peak inverse voltage (PIV) rating times the transformer secondary to primary voltage ratio
small motors, small transformers, and light machinery	10 times normal operating voltage
large motors, large transformers, and heavy machinery	20 times normal operating voltage

4.3.3 Surge Arrestors

Various types of surge (over-voltage) arrestors are presently available for purchase as off-the-shelf items from a multitude of manufacturers. There are two basic types of surge arrestors: those which switch to a low-impedance state on sensing an over-voltage, thus causing the impressed voltage to collapse to a low voltage, and those which maintain the voltage at a particular constant level even when stressed by an over-voltage. Examples of the first type (switching devices) are spark gaps and arcing dielectric. Examples of the second type are Zener diodes and varistors which clamp the voltage at a particular level by virtue of their nonlinear voltage-current relation. There are also devices which, on sensing an overvoltage, interrupt the power or signal flow to the load. If this interruption is accomplished by electromechanical means, such devices are not considered transient protection devices because they are inherently slow to respond.

Switching devices inherently offer greater power-handling capability for surges than do the nonlinear devices.[10] The instantaneous power dissipated in a surge arrestor is the product of the surge current flowing through the device and the voltage across the device. Since a switching device has a low voltage across it while in the conducting state, it will have less power released in it for a constant surge current than a device like a Zener diode across which the surge voltage remains high. For a given surge power-handling capability, a spark gap will also be smaller physically than a Zener diode or varistor device.

Some devices have the capability of shunting to ground tremendous amounts of current, but turn on relatively slowly (150 to 200 ns) after the turn-on voltage appears across the device terminals. Other types turn on more rapidly (50 ns or less) but will not transfer

[10] *Space Shuttle Program: Lightning Protection Criteria Document, National Aeronautics and Space Administration, NASA TM-74974 (November 1975).*

to ground as much current as the slower devices. Solid-state arrestors are available which have very fast turn-on times, but most of them are limited in current-shunting capability except for expensive units that range in cost from $7,500 to $25,000. Several hybrid units are currently under development that consist of a solid-state suppressor for dissipation of low-energy transients, and a separate suppressor section for dissipation of high-energy transients. The two suppressor sections are normally separated by a choke in series with the protected line. The three most important characteristics of a surge arrestor are the capability to shunt to ground the required levels of current, maintain a low discharge (clamp) voltage during the transient, and a fast response time. The fast response time is important to preclude reflection of high transient energy (over-shoot voltage) across protected equipment for an intolerable length of time before the arrestor turns on and clamps.

Some fundamental differences between switching devices and nonswitching devices are related to their recovery characteristics after the surge has passed. If a line is protected by a spark gap and if that line is connected to a source of energy (a power bus, for example), that energy source must be disconnected from the line before the spark gap can switch back from its low-impedance conducting state to its high-impedance nonconducting state. Generally, this requires opening a circuit breaker on the line. A Zener diode or varistor effectively ceases to conduct as soon as the voltage returns to its normal value. However, all types of over-voltage protection devices inherently operate by reflecting a portion of the surge energy to its source and by diverting the rest into another path, all with the intention of dissipating the surge energy in the ground and in the interconnecting loads. The alternative to reflecting the energy is to absorb the surge energy in an unprotected load. Reflection and diversion of the surge energy are not without their hazards. Some of the hazards commonly encountered follow.

a. The reflected energy can appear on other unprotected circuits.

b. Multiple reflections may cause the transient to last longer than it would otherwise.

c. The spectral density of the energy may be changed, with either high or low frequencies being enhanced. Interference problems on other circuits may well be enhanced even though the risk of damage to the protected circuit is reduced.

A summary of the advantages and disadvantages of the various transient protective devices (surge arrestors) is given in table 9.

TABLE 9. COMPARISONS AMONG VARIOUS TYPES OF TRANSIENT PROTECTIVE DEVICES (ref 10)

Device type	Advantages	Disadvantages	Remarks
Spark gap	Simple and reliable; easily fabricated; very low voltage drop during conducting state; bilateral operation--same characteristics on either polarity	Relatively high spark over-voltage; arc must be extinguished by removing voltage; seldom available in conveniently packaged assemblies; must be designed for each specific use	Generally consists of two metal electrodes separated by air with a minimum spark over-voltage of 1500 to 3000 V
Gas diode	Low cost; small size; low spark over-voltage (usually 60 to 100 V); can pass high current for short times; self-healing	Poor volt/time characteristics; will continue to conduct if driving voltage is above 60 to 100 V	Neon bulb is typical example
Zener diode	Small size; easily mounted; low firing voltage; low dynamic impedance when conducting; self-extinguishing--when applied voltage drops below Zener level, conduction ceases	Expensive; not bilateral; voltage across diode does not switch to low value when conducting, but remains at Zener voltage; not available for voltages below about 5 V; normally not available for voltages above a few hundred volts	Can be used to clip a surge voltage and limit the surge to the Zener voltage; well adapted to semiconductor protection
Forward-conducting diode	Small size; low cost; provides protection at very low voltage levels; good surge-current ratings	Not bilateral; conduction may occur at normal signal levels with possibility of clipping and frequency multiplication effects; relatively high capacitance	Includes standard germanium and silicon diodes
Silicon-controlled rectifier	Excellent surge-current rating; low voltage drop when conducting; suitable for low voltage circuits	Must be triggered by an auxiliary circuit; does not reset automatically; not bilateral; expensive	Can be used as one-polarity spark gap to prevent surges
Varistor	Low cost; small size; passes higher current than Zener diodes; self extinguishing; may be bilateral device; operates at either polarity	May have high capacitance; cannot be clamped at lower voltages; not available with ratings as low as Zener diodes	More adaptable to terminal boards, distribution panels, and printed circuits; zinc oxide types have best overall performance

5. PERSONNEL PROTECTION

Lightning is responsible for only a small number of deaths and severe injuries compared with other causes of fatalities. Nevertheless, the number could be further reduced if people were made aware of the inherent danger and followed proper guidance when caught in a thunderstorm. Such advice, given in several national codes and articles on safety, is presented in lists of proper and improper procedures. Although it is impossible to visualize all contingencies requiring safety precautions, it is nevertheless useful to present information on personnel protection to avoid needless risk.

5.1 Protection Outdoors

A person standing on open ground constitutes a lightning conductor and the probability of his being struck is roughly proportional to the square of his height above ground. The first rule is therefore not to increase one's height artifically by standing on top of a structure such as a roof, by holding up a metal object such as an umbrella or ladder, by riding on a bicycle or an open vehicle, or by standing in an open boat when fishing. In order to reduce one's effective height even further, one is advised to squat or kneel down and to do so in a hollow of the ground, avoiding high-lying places. A better alternative is to shelter under a high-voltage transmission line but it is advisable to keep away from the pylons since, when a pole or tower is struck, high step voltages are present around its base (see fig. 19).

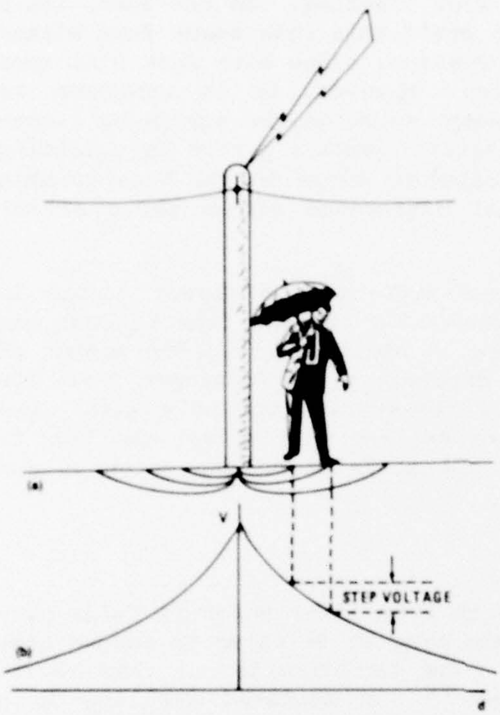

Figure 19. Lightning strike: (a) current distribution in ground and (b) potential (volts) along ground surface.

The best protection against a direct stroke is to seek shelter in a protected facility, such as is being planned for the phase III building at FRF or in an all-metal structure such as the research vehicle on the pier. A car driver should, however, be warned to drive slowly in a heavy thunderstorm. Accidents have been caused occasionally by drivers who lost control of the steering when lightning struck in front of them, causing a frightening display of fireworks on a wet road surface.

The usual response of a person caught in a thunderstorm in the open is to run for the nearest large tree or tall structure to be protected from the rain. Every year there are reports of people who have been killed under trees, usually from a side flash from the tree trunk or one of its branches. An isolated structure or tree in open ground is particularly vulnerable to strike.

Side flashes can also occur from metal fences mounted on insulating posts or other large metal bodies above ground, such as antenna towers, flag poles, pipes, or railings unless they are adequately grounded. It is therefore advisable to keep a distance of several meters from such components. This is all the more necessary as such a component can give rise to a side flash not only as the result of a direct strike but also by the electrostatic induction effect due to a nearby ground flash.

Another type of side flash can occur between several people who are crowded together if one of them is struck by lightning. In such a case, part of the lightning current can flash from shoulder to shoulder of adjacent persons and multiple fatalities are known to have occurred. It is therefore advisable to avoid crowding together in the open during a thunderstorm.

High step voltages also occur in the open near a lightning strike. This can affect a large number of people caught in the strike vicinity even without the presence of side flashing. In the open, there is little that an individual can do to avoid this risk apart from either keeping both feet closely together or running, since both feet will then never touch the ground simultaneously. However, it is important to avoid the neighborhood of any tall object which can be struck by lightning, particularly if it is made of metal. When a person is squatting on the ground, the knees should be pulled up close to the body as this ensures the minimal possible potential difference across parts of the body.

The probability of a swimmer attracting a direct stroke is remote but he is liable to be subjected to a current flow through his body when the water is struck anywhere in his vicinity. The amount of current discharged through the body depends on his distance from the strike and the salinity of the water. However, since only small currents are needed to produce muscle contractions this effect may lead to panic and drowning. Swimmers should therefore leave the water on the approach of a thunderstorm.

5.2 Protection Indoors

The safest place indoors is in a building which is fully protected against lightning. Even in this case it is safer to assume that the protection provided is imperfect. The justification of this advice can be illustrated by a typical case.[11] An isolated dwelling in a wooded hilly area had a modern form of lightning protection including an earth termination bonded to the sheath of the electric-supply cable and to the water system. When the house was struck by lightning a man who was using the telephone was knocked unconscious; he was later revived and recuperated gradually. While telephoning, he was touching a refrigerator, and a metal part of another piece of electrical household equipment was close to the back of his neck. Burn marks on his body and behind his ear indicated that side flashes had occurred to his body from the two electrical apparatuses, while further burns under a metallic necklace which he had worn suggested that this may have saved his life by diverting part of the lightning current from his interior. The side flashes were due to the omission of a bonding connection between the

[11] *R. H. Golde, Lightning Protection, Chemical Publishing Co., Inc, New York, N.Y., First American Edition (1975).*

metal sheath of the telephone cable and the earth termination of the lightning-protective system, a fact of which the occupant of a dwelling would not normally be aware.

Side flashing constitutes almost the only risk in a building and it is therefore advisable during a thunderstorm to remain near the middle of a room and to keep away from all large metal parts (e.g., electric, telephone, gas, and water installations, equipment connected to outdoor antennas, metal stoves, and window frames). The widespread belief that it is dangerous to sit in the pathway between an open window and a door may be due to experiences with ball lightning, the path of which is often reported to be governed by air currents. However, insufficient information exists on ball lightning to provide reliable advice regarding any protection against it.

5.3 Effects of Electric Shock

The effects of electricity may be direct or indirect, either of which may cause death. A direct effect is due to the passage of current through the body, while an indirect effect may be a consequence of the effect produced by the current. Although the exact path of currents less than 1 mA may be influenced by various body tissues, the body behaves as a structureless gel for larger currents.[12] In the living body there are no preferred electrical paths, such as blood vessels, which are followed by the current. In a lightning accident, whether due to a direct strike or a side flash, the current generally follows a direct path from the head, neck, and shoulders to the feet.

Sudden muscular contraction caused by passage of the current through the body may cause a fall resulting in serious injuries. However, death from mechanisms which are in no way unique to electric shock (ventricular fibrillation and respiratory arrest) may also occur.

5.3.1 Ventricular Fibrillation

The heart has two main pumping chambers--one to pass blood around the body (the left ventricle) and the other to pump it through the lungs (the right ventricle). The thick walls of the ventricles consist almost entirely of muscle, and it is the simultaneous contraction of all the individual muscle fibers which establishes a sufficient pressure within the ventricles to circulate the blood.

An electric current passing through the heart may disturb the coordination of these individual muscle fibers so that instead of contracting simultaneously, they contract individually, each at its own

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[12] *W. R. Lee, Lightning Injuries and Death, Volume 2: Lightning Protection, edited by R. H. Golde, Academic Press (1977).*

rate. A head pressure is no longer established in the ventricles, blood circulation ceases, and death occurs within about four minutes. Some authorities have claimed that with very high currents associated with lightning accidents, the heart is simply arrested (cardiac arrest) rather than put into ventricular fibrillation. Although this difference may be of theoretical interest, cardiac arrest and ventricular fibrillation both result in arrest of circulation, the treatment of which is external cardiac massage.

The symptoms of ventricular fibrillation (or cardiac arrest) are noticeable[13] when the following conditions occur:

a. victim is unconscious,
b. breathing is stopped,
c. no pulse is detectable,
d. the pupils of the eyes are greatly enlarged, and
e. the skin usually turns a gray-blue color.

Since (a) and (b) may occur for other reasons than heart stoppage and (e) takes a few minutes to develop, the most accurate indication is lack of pulse. The best way to determine this is to place the pads of the fingers (which are more sensitive than the finger tips) alongside the victim's Adam's apple and check for pulse. If no pulse can be detected, the rescuer should also check the victim's pupils. If they are enlarged and do not narrow down in response to bright light when the lid is raised, the heart has stopped or is fibrillating. (Observing the pupils should be a countercheck on the pulse, although some eye defects cause the same effect.) If all indications are that the heart has stopped or is fibrillating (no blood is being pumped), the victim should be placed on his back on a hard surface, such as the ground, the bed of a truck, the floor of a building, etc. The rescuer then kneels at the victim's side, gives the victim half a dozen quick breaths, and starts heart compression. To do this, he places the heel of one hand on the lower third of the victim's breastbone (sternum) and the other hand on top of the first. A simple way to find this spot is to put a finger on the xiphoid (bottom end of the breastbone) and place the hand alongside it. With the fingers extended so that no pressure is applied to the ribs, the rescuer presses down firmly and quickly, so that the breastbone is depressed about 1-1/2 to 2 in. (With children, the pressure from one hand is sufficient; with babies, two fingers suffice.) He then releases the pressure. This cycle is repeated once a second.

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[13] *D. G. Fink, Editor-in-Chief, and J. M. Carroll, Associate Editor, Standard Handbook for Electrical Engineers, Tenth Edition, McGraw-Hill Book Co. (1968).*

If the rescuer is working alone, he must interrupt heart compression about every 15 or 20 strokes to give two or three breaths of air to the victim. If another rescuer is avilable, one rescuer should apply heart compression (60 cycles/min) while the other gives mouth-to-mouth respiration (12 cycles/min).

Heart compression (and mouth-to-mouth respiration) should be continued until

a. the victim revives,

b. medical help arrives (or the victim is taken to a hospital or doctor's office), or

c. rigor mortis sets in.

Even after the victim revives, he must be closely watched, because he may have a relapse and require resuscitation again. Also, both heart compression and respiration must be continued in the ambulance and hospital room until a doctor is able to take other measures.

Heart compression should not be done when the victim's pulse can be felt, or when the ribs are broken, or when the pupils do not remain widely dilated.

5.3.2 <u>Respiratory Arrest</u>

An electric shock might affect respiration in two ways. It may cause a sustained arrest of respiration continuing after the shock current has ceased to flow, or the passage of the current may cause the muscles of the chest to contract, thereby preventing respiratory movement. In the latter case, the effect persists only as long as the current passes and because a lightning current flows for only about a few tenths of a millisecond, the effects produced are negligible. On the other hand, if respiration is arrested in the first way, in which the arrest persists even after the shock current has ceased, immediate treatment of artificial respiration must commence. There is no single ideal method of artificial respiration, but the currently preferred method is mouth-to-mouth respiration because it assures positive movement of air into the lungs.

a. As soon as artificial respiration has been started and while it is being continued, an assistant (if available) should loosen any tight clothing about the victim's neck, chest, or waist. Liquids are not to be given by mouth until the victim is fully conscious.

b. Resuscitation should be carried on at the nearest possible location to where the victim was injured. He should not be moved from this location until he is breathing normally, and then only upon his own volition, and while lying down. Should it be necessary, because of extreme weather conditions, to move the victim before he is breathing normally, resuscitation should be carried on while he is being moved.

c. A brief return of normal breathing does not necessarily indicate that resuscitation should be discontinued. Not infrequently, the victim, after temporary recovery, stops breathing again. He must be watched, and if normal breathing stops, artificial respiration must be resumed at once.

d. Artificial respiration must be continued (4 hours or longer, if necessary) until natural breathing is restored or rigor mortis sets in.

e. To avoid strain on the victim's heart when he revives, he should be kept lying down and not be allowed to sit up or stand. If he revives before the doctor arrives, he should be given a stimulant, such as ammonia by inhalation, or a hot drink, such as coffee or tea. The victim should be kept warm. However, when heating devices are applied to an unconscious person, great care must be taken to prevent possible burns. The heating devices should be tested on one's own body before use and, if too hot, should be wrapped in a towel or other suitable insulation or allowed to cool to the proper temperature.

If it becomes necessary to change operators, this change should be made without losing the rhythm of respiration. By this procedure no confusion results at the time of change and a regular rhythm is kept up.

6. CONCLUSION

Lightning varies widely in both intensity and frequency of occurrence throughout the U.S. The application of protective designs to facilities can reduce damage effects to structures and equipment as well as provide a measure of personnel protection. Since many of these practices would involve extensive modification to existing structures and ground systems, it is recommended that they be implemented during initial construction. Whether the general guidelines presented here are applied to new or existing facilities, personnel experienced in installation of lightning-protection systems should be used to ensure that all elements of the system perform their designed function in providing the required lightning protection.

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(13) D. G. Fink, Editor-in-Chief, and J. M. Carroll, Associate Editor, Standard Handbook for Electrical Engineers, Tenth Edition, McGraw-Hill Book Co. (1968).

GLOSSARY

Air terminal: A pointed solid or tubular rod of specified material provided with a mounting base having a proper conductor connection. Commonly known as a lightning rod.

Bonding: Connection between a conductive or inductive metal object and an element of a lightning-protection system to accomplish electrical continuity between the two.

Cable: A conductor formed of a number of wires stranded together.

Conductor: The portion of a lightning-protection system designed to carry the lightning discharge between air terminals and ground. (a) Main conductors interconnect air terminals and serve as downleads to ground. (b) Secondary conductors are used to accomplish various bonding and other electrical connections.

Counterpoise: A network or radial system of wires just above the ground. Used to capacitively couple equipment or cables to the ground when the ground resistance is high.

Fastener: An attachment to secure the conductor to the structure.

Ground terminal: That portion of a lightning-protection system extending into the earth, such as a ground rod, ground plate, or the conductor itself, serving to bring the lightning-protection system into electrical contact with the earth.

Guard wire: Bare solid copper or aluminum cable. Used for electromagnetic shielding of sensitive cables that are installed either overhead or underground.

Lightning-protection system: A complete system of air terminals, conductors, ground terminals, interconnecting conductors, arrestors, and other connectors and fittings required to complete the system.

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