Grounding & Lightning Protection

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Building Grounding and Lightning Protection

Grounding, or Earthing, is a fundamental topic for the correct operation of electrical systems and devices. However, few people understand this matter or the reason it is used.

Grounding is a huge topic full of standards, practical rules, misconceptions, surprises, and some magic. The rules for grounding are quite difficult, and at times appear unclear.

This introductory article discusses the basic principles of grounding, provides an overview of the main grounding applications, and lays the basis for examining these applications from first to last.

What is Grounding?

In analyses of electrical installations, you will frequently see the terms ground, grounded and grounding. There are several formal definitions of these terms in different standards and codes. However, as its name suggests, grounding is a connection of the electrical system, electrical devices, and metal enclosures to the ground. It is also known as earthing, i.e., connection to the earth.

Even though non-grounded electrical systems do exist — either because they are excepted from grounding by codes or by operational reasons — most arrays are grounded in one way or another.

There are several important reasons why a grounding system should be installed. But the most important reason is to protect people.

Secondary reasons include protection of structures and equipment from unintentional contact with energized electrical lines.

The grounding system must ensure maximum safety from electrical system faults and lightning.

A good grounding system must receive periodic inspection and maintenance, if needed, to retain its effectiveness. Continued or periodic maintenance is aided through adequate design, choice of materials and proper installation techniques to ensure that the grounding system resists deterioration or inadvertent destruction. Therefore, minimal repair is needed to retain effectiveness throughout the life of the structure.

The grounding system serves three primary functions which are listed below.

- Personnel Safety.

  Personnel safety is provided by low impedance grounding and bonding between metallic equipment, chassis, piping, and other conductive objects so that currents, due to faults or lightning, do not result in voltages sufficient to cause a shock hazard. Proper grounding facilitates the operation of the overcurrent protective device protecting the circuit.

- Equipment and Building Protection.

  Equipment and building protection is provided by low impedance grounding and bonding between electrical services, protective devices, equipment and other conductive objects so that faults or lightning currents do not result in hazardous voltages within the building. Also, the proper operation of overcurrent protective devices is frequently dependent upon low impedance fault current paths.

- Electrical Noise Reduction.

  Proper grounding aids in electrical noise reduction and ensures:

1. The impedance between the signal ground points throughout the building is minimized.

2. The voltage potentials between interconnected equipment are minimized.

3. That the effects of electrical and magnetic field coupling are minimized.

Another function of the grounding system is to provide a reference for circuit conductors to stabilize their voltage to ground during normal operation. The earth itself is not essential to provide a reference function. Another suitable conductive body may be used instead. The function of a grounding electrode system and a ground terminal is to provide a system of conductors which ensures electrical contact with the earth.

TYPES OF GROUNDING

As noted above, grounding and bonding are not the same. In addition, not all grounding is the same.

Types of grounding and bonding that are widely used in the electrical industry. Topics of primary interest are:

• Power System Grounding Including the "Service Entrance"

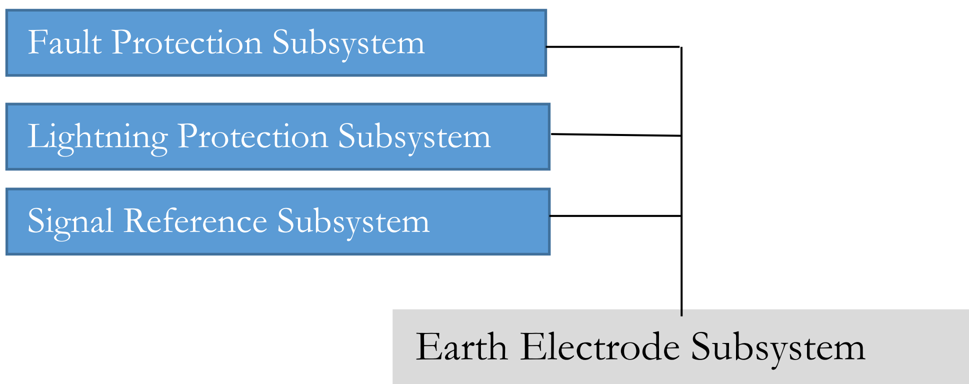
• Bonding

• Grounding Electrical Equipment

• Lightning Protection

• Protection of Electronic Equipment

Grounding is a very complex subject. The proper installation of grounding systems requires knowledge of soil characteristics, grounding conductor materials and compositions and grounding connections and terminations.



GROUND RESISTANCE

While many factors come into play in determining the overall effectiveness of the grounding system, the resistance of the earth itself (earth resistivity) can significantly impact the overall impedance of the grounding system. Several factors, such as moisture content, mineral content, soil type, soil contaminants, etc., determine the overall resistivity of the earth. In general, the higher the soil moisture content, the lower the soil's resistivity. Systems designed for areas which typically have very dry soil and arid climates may need to use enhancement materials or other means to achieve lower soil resistivity.

Ground resistance is usually measured using an instrument often called an earth resistance tester. This instrument includes a voltage source, an ohmmeter to measure resistance directly and switches to change the instrument's resistance range. Installers of grounding systems may be required to measure or otherwise determine the ground resistance of the system they have installed. Requires are a single electrode consisting of rod, pipe, or plate that does not have a resistance to ground of 25 ohms or less shall be augmented by one additional electrode . Multiple electrodes should always be installed so that they are more than six feet (1.8 m) apart.

Spacing greater than six feet will increase the rod efficiency. Proper spacing of the electrodes ensures that the maximum amount of fault current can be safely discharged into the earth. To properly design a grounding system, the earth resistivity must be measured. Several methods can be used to measure earth resistivity: the four-point method, the variation in-depth method (three-point method) and the two-point method. The most accurate method is the four-point method. The details of making these measurements and the set-up for the measurements are included with the testing equipment.

BUILDING GROUNDING

Electrical design and installation professionals need to consider several different building grounding systems for any building or structure on which they may work. Building grounding components can be broken down into several subdivisions:

- The building exterior grounds
- The electrical service grounding
- The building interior bonding
- Equipment grounding and bonding
- Lightning protection

BUILDING EXTERIOR GROUNDS

It is important to keep in mind that the requirements contained in the minimum electrical installation requirements. For many types of installations, do not go far enough. These minimum requirements cannot ensure that the equipment operated in these buildings will perform in a satisfactory manner. For these reasons electrical design personnel often will require additional grounding components.

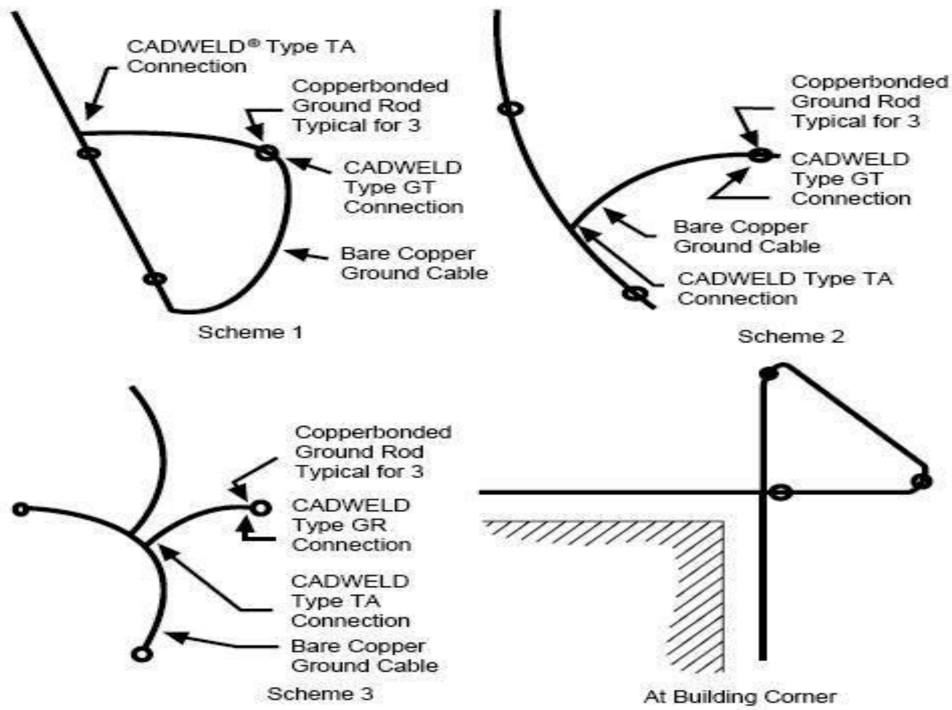
One of the most common of these consists of a copper conductor that is directly buried in the earth and installed around the perimeter of the building. The steel building columns are bonded to this conductor to complete the grounding system.

The columns around the perimeter of the building are excellent grounding electrodes and provide a good path into the earth for any fault currents that may be imposed on the system. The electrical designer, based on the size and usage of the building, will determine whether every column or just some of the columns are bonded at least one column every 50 feet shall be connected to the above described ground ring.

When grounding large buildings, and all multiple building facilities, perimeter grounding provides an equipotential ground for all the buildings and equipment within the building that are bonded to the perimeter ground. The purpose of this perimeter grounding is to ensure that an equipotential plane is created for all components that are connected to the perimeter ground system. The size of the ground ring will depend upon the size of the electrical service but is seldom less than 1/0 AWG copper.

In some cases, an electrical design requires ground rods to be installed in addition to the perimeter ground ring. The use of ground rods helps to minimize the effects of dry or frozen soil on the overall impedance of the perimeter ground system. This is because the ground rods can reach deeper into the earth where the soil moisture content may be higher or the soil may not have frozen. It offers a complete line of ground rods from 1/2 inch to 1 inch in diameter to meet the needs of the designer and installer.

It is recommended that the ground ring and ground rods be copper or copper bonded steel and installed at least 24 inch from the foundation footer and 18 inch outside the roof drip line. This location will allow for the greatest use of the water coming off of the roof to maintain a good soil moisture content. Although less common than in the past, "triad" ground rod arrangements (rods placed in a triangular configuration) are sometimes specified, usually at the corners of the building or structure.



"Triad" Ground Rod Details

Triad arrangements are not recommended unless the spacing between the ground rods is equal to or greater than the individual ground rod length.

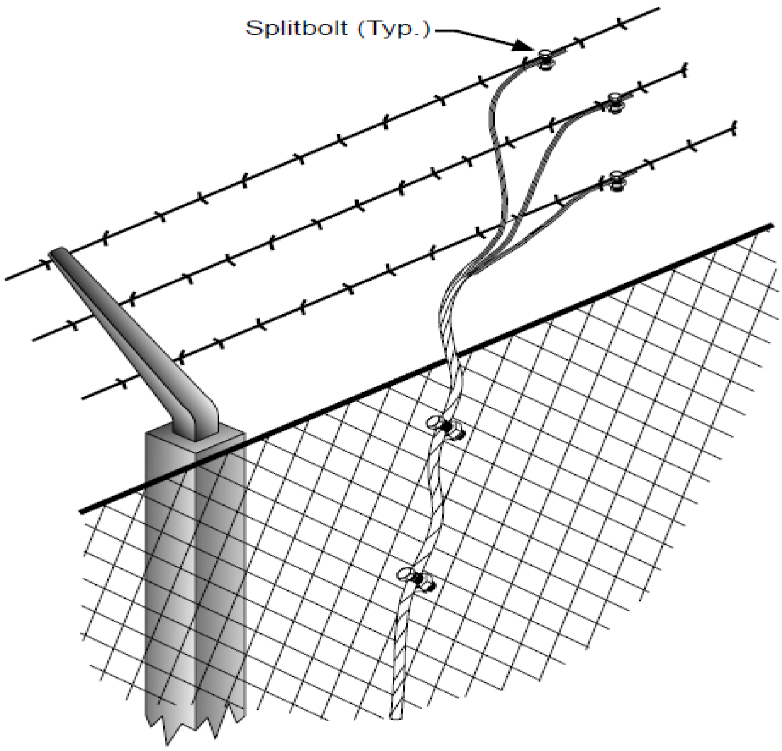
Three rods in a straight line spaced at least equal to the length of the individual ground rods are more efficient and result in a lower overall system impedance.

Installers of these perimeter ground systems need to provide a "water stop" for each grounding conductor that passes through a foundation wall. This is especially important when the grounding conductor passes through the foundation wall at a point that is below the water table.

The water stop ensures that moisture will not enter the building by following the conductor strands and seeping into the building. A CADWELD Type SS (splice) in the unspliced conductor and imbedded into the concrete wall provides the required water stop.

When the required resistance is not achieved using the usual grounding layouts, a complete line of prefabricated wire mesh products in sizes ranging from No. 6 to No. 12 solid conductors. Another method which can be used to lower the grounding system impedance is ground enhancement materials. These materials can be added around ground rods or other conductors to enhance system performance.

Any fence around a substation on the property should be grounded and tied into the substation ground system. If a facility fence meets the substation fence, it is recommended to isolate the two fences to prevent any fault in the substation from being transferred throughout the facility using the fence as the conductor.



Other items that are located on the outside of the building that should be considered are lighting fixture standards, pull box covers and rails. Handhole, manhole and pull box covers, if conductive, should be bonded to the grounding system using a flexible grounding conductor.

The electrical service grounding

The grounding electrode system is designed to provide multiple electrical paths into the earth. As stated in the Preface, grounding of electrical systems helps to ensure personnel safety, provide equipment and building protection and achieve electrical noise reduction.

The component of the grounding electrode system is the metal frame of the building. If the metal frame of the building is effectively grounded, meaning it is intentionally connected to the earth by means of a low-impedance ground connection, it must be bonded to the grounding electrode system. The connection of the grounding electrode conductor to the building steel must be accomplished by the use of exothermic welding (cadweld).

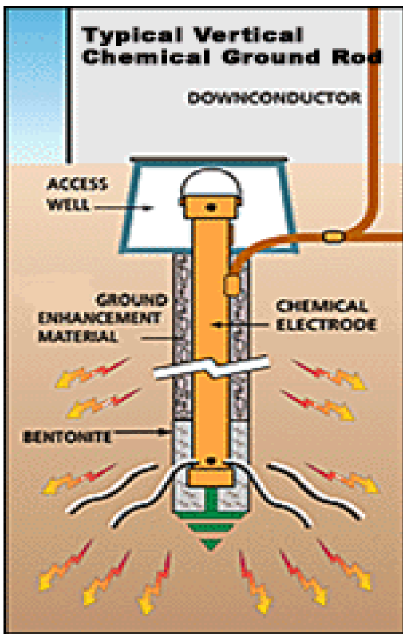
If the building steel is dirty or contains nonconductive coatings, must remove coatings, such as paint, lacquer and enamel, from contact surfaces to ensure good electrical continuity.

The other component of the grounding electrode system is a ground ring. It's requires that if a ground ring is available it shall be bonded to the grounding electrode system. A ground ring should consist of at least 20 feet (6.4 m) of No. 2 AWG bare copper or larger which encircles the building. The ground ring should be in direct contact with the earth at a depth below the earth surface of at least 2 1/2 feet (0.75 m).

We should note that while the ground ring is frequently not "available," it is becoming more and more prevalent as a supplemental grounding system component, especially when highly sensitive electronic equipment is installed within the building. As noted above, the connection to the ground ring will more than likely be a direct burial connection so the ground clamps or fittings must be listed for direct soil burial.

Also fitting into this category are chemical type ground electrodes consisting of a copper tube filled with salts. Moisture entering the tube slowly dissolves the salts, which then leach into the surrounding earth thru holes in the tube.

This lowers the earth resistivity in the area around the electrode, which reduces the electrode resistance. For maximum efficiency, its recommend back-filling the electrode with bentonite for the lower 1 to 2 feet and then GEM to the level marked on the electrode. Alternatively, the electrode can be back-filled only with earth for an even lower efficient installation.



Occasionally during construction, a grounding conductor may be damaged where it is stubbed through the concrete. Installers should note that ERICO features a full line of CADWELD connections that can be used to repair the conductor without any loss of capacity in the conductor. Repair splices are available for both horizontal and vertical conductors. A minimum amount of concrete may need to be chipped away in order to make the splice.

All of these components, when installed, comprise the grounding electrode system for the building or structure served. All of these must be bonded together and when they are installed where multiple grounding systems are present, such as lightning protection systems, they shall be installed at a point which is not less than 6 ft (1.8 m) from any other electrode of another grounding system.

When an AC system is connected to a grounding electrode system, the same electrode shall be used to ground conductor enclosures and equipment in or on that building. Separate grounding electrode systems are not permitted within the same building.

In the event that a building is supplied by two or more services, the same grounding electrode system shall be used. Two or more electrodes which are bonded together are considered a single grounding electrode system. We must understand that these grounding connections are critical to the overall electrical power distribution system and they must take great care when they make these connections.

Lightning Protection

LIGHTNING - AN OVERVIEW

Lightning is an electrical discharge within clouds, from cloud to cloud, or from cloud to the earth. Lightning protection systems are required to safeguard against damage or injury caused by lightning or by currents induced in the earth from lightning. Clouds can be charged with ten to hundreds of millions of volts in relation to earth. The charge can be either negative or positive, although negative charged clouds account for 98% of lightning strikes to earth. The earth beneath a charged cloud becomes charged to the opposite polarity.

As a negatively charged cloud passes, the excess of electrons in the cloud repels the negative electrons in the earth, causing the earth's surface below the cloud to become positively charged. Conversely, a positively charged cloud causes the earth below to be negatively charged.

While only about 2% of the lightning strikes to earth originate from positively charged clouds, these strikes usually have higher currents than those from negatively charged clouds. Lightning protection systems must be designed to handle maximum currents. The air between cloud and earth is the dielectric, or insulating medium, that prevents flash over. When the voltage withstand capability of the air is exceeded, the air becomes ionized. Conduction of the discharge takes place in a series of discrete steps. First, a low current leader of about 100 amperes extends down from the cloud, jumping in a series of zigzag steps, about 100 to 150 feet (30 to 45 m) each, toward the earth. As the leader or leaders (there may be more than one) near the earth, a streamer of opposite polarity rises from the earth or from some object on the earth. When the two meet, a return stroke of very high current follows the ionized path to the cloud, resulting in the bright flash called lightning. One or more return strokes make up the flash.

Lightning current, ranging from thousands to hundreds of thousands of amperes, heats the air which expands with explosive force, and creates pressures that can exceed 10 atmospheres. This expansion causes thunder, and can be powerful enough to damage buildings.

New detection devices have been installed. Which count the total number of lightning strokes reaching the earth. This data results in precise occurrence of the total strokes for a particular period of time for any particular area rather than thunderstorm days per year. Lightning is the nemesis of communication stations, signal circuits, tall structures and other buildings housing electronic equipment. In addition to direct strike problems, modern electronics and circuitry are also highly susceptible to damage from lightning surges and transients.

These may arrive via power, telecommunications and signal lines, even though the lightning strike may be some distance from the building or installation.

LIGHTNING PROTECTION

Lightning protection systems offer protection against both direct and indirect effects of lightning. The direct effects are burning, blasting, fires and electrocution. The indirect effects are the mis-operation of control or other electronic equipment due to electrical transients. The major purpose of lightning protection systems is to conduct the high current lightning discharges safely into the earth.

A well-designed system will minimize voltage differences between areas of a building or facility and afford maximum protection to people. Direct or electromagnetically induced voltages can affect power, signal and data cables and cause significant voltage changes in the grounding system.

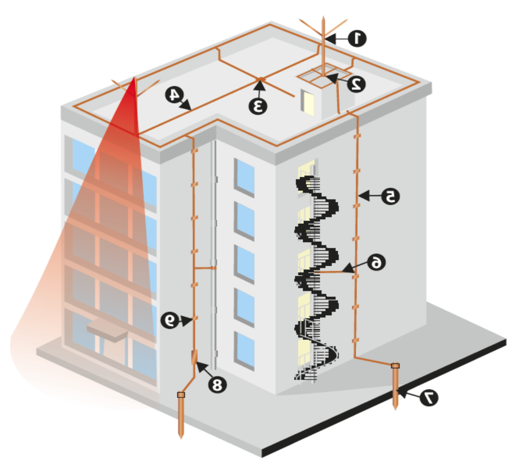
A well-designed grounding, bonding and surge voltage protection system can control and minimize these effects. Since Ben Franklin and other early studiers of lightning, there have been two camps of thought regarding the performance of direct strike lightning protection systems.

Some believe that a pointed lightning rod or air terminal will help prevent lightning from striking in the immediate vicinity because it will help reduce the difference in potential between earth and cloud by "bleeding off" charge and therefore reducing the chance of a direct strike. Others believe that air terminals can be attractors of lightning by offering a more electrically attractive path for a developing direct strike than those other points on the surface of the earth that would be competing for it.

These two thought "camps" form the two ends of a continuum upon which you can place just about any of the direct strike lightning protection theories.

There is general agreement that the best theoretical lightning system is a solid faraday cage around whatever it is that is being protected. An airplane is an example of this. But even in the case of the airplane, there are incidents reported of damage from direct lightning strokes.

On the ground, a complete faraday cage solidly tied to ground is an attractive protection scheme, but is expensive to accomplish. If it is a general area, and not a structure that you are trying to protect, the faraday cage approach is very impractical. While lightning cannot be prevented, it is possible to design a lightning protection system that will prevent injury to people and damage to installations in the majority of lightning strikes. Standards and codes for passive lightning protection materials and installations that ensure safety and minimize damage and fire hazards.



A well-designed lightning system exceeds the minimum code requirements, providing not only safety to people and protection against fire, but also providing protection for equipment and the integrity of data and operations. Manmade structures of steel, concrete or wood are relatively good conductors compared to the path of lightning through the ionized air. The impedance of a structure is so low compared to that of the lightning path that the structure has virtually no effect on the magnitude of the stroke. As a result, lightning can be considered a constant current source. The current may divide among several paths to earth, along the outside walls, sides and interior of a structure, reducing the voltage drop to ground. Better protection is provided by multiple paths to ground, including the many paths through the steel building structure. All structural metal items must be bonded.

PURPOSE OF LIGHTNING PROTECTION

The overall purpose of a lightning protection system is to protect a facility and it's inhabitants from the damage of a direct or nearby lightning strike trying to prevent a lightning strike is unreliable, the best way to protect is to shunt the lightning energy "around" the vital components/inhabitants of the facility and dissipate that energy into the earth where it wants to go anyway.

The first step in that process is to make sure that lightning, when approaching the facility, is attracted to the strike termination devices that have been installed on the structure for that purpose. The role of a lightning strike termination system is to effectively launch an upward leader at the appropriate time so that it, more so than any other competing feature on the structure, becomes the preferred attachment point for the approaching down leader (lightning strike).

As the down leader approaches the ground, the ambient electric field rapidly escalates to the point where any point on the structures projecting into this field begin to cause air breakdown and launch upward streamer

currents. If the ambient field into which such streamers are emitted is high enough, the partially ionized streamer will convert to a fully ionized up-leader. The ability of the air termination to launch a sustainable up-leader that will be preferred over any other point on the structure, determines it's effectiveness as an imminent lightning attachment point.

The Franklin Rod or conventional approach to lightning protection has served the industry well. Many years ago Lightning protection then was principally a defense against fire. Wooden buildings, when struck by lightning, would often burn. Buildings like mosquitoes Barns and churches were the main facilities seeking this protection due to their height. Today, fire is still a concern, but not always the main concern.

A modern facility of almost any kind contains electronic equipment and microprocessors. Facility owners are concerned about avoiding downtime, data loss, personnel injury & equipment damage as well as fire. The materials used to construct facilities have changed dramatically also.

Steel columns and the steel in reinforced concrete compete as low impedance conductors for lightning energy. The myriad of electrical/electronic equipment and conductors that crisscross every level of the facility are at risk just by being near conductors energized from nearby lightning strikes.

The lightning codes of the past don't adequately address these issues. Bonding of downconductors to electrical apparatus within 3 to 6 feet is required and can add substantial wiring to a facility if there are a lot of downconductors. Further, the need for lightning protection for these electrically sophisticated facilities is growing. The amount of knowledge about lightning has increased dramatically also.

Information about the behavior of leaders, the changing of electrical fields leading up to a strike, the effects of impedance of various competing downconductors, and diagnostic equipment has all increased dramatically. This gives today's designers of lightning protection systems a large advantage over those of years ago. These technological advances and market demands for more cost effective lightning protection systems have prompted many new and novel approaches to lightning protection.

LIGHTNING PROTECTION COMPONENTS

A lightning protection system is comprised of a chain of components properly specified and properly installed to provide a safe path to ground for the lightning current. The lightning protection system provides an uninterrupted conductive (low impedance) path to earth.

Lightning does not always strike the highest point. The rolling ball theory of determining what is protected from lightning strikes, described below, is widely accepted as a sound approach to sizing and positioning air terminals on the top of structures, and for tall structures, on the sides of the structure. Properly designed lightning protection systems based on existing standards ensure adequate conducting and surge diverting paths which have been proven safe for people, structures and equipment in the great majority of cases. Other systems exist which are not covered in standards.

The following are basic components for a lightning protection system. Sketches at the end of this section depict the many requirements discussed.

Air terminals, often called lightning rods, lightning points or strike termination devices are blunt or pointed, solid or tubular rods of copper, bronze, stainless steel or aluminum. On large (over 500 sq. inch [0.323 sq. m] flue cross section), tall (over 75 feet or 23 m) smoke stacks, the air terminals must be stainless steel, monel metal or lead jacketed solid copper.

Conductors, connect the air terminals to each other, to the metal structure of the building, to miscellaneous metal parts of the building and down to the counterpoise and/or earth electrodes. Building connections are made to the steel columns or to the rebars (steel reinforcing bars) used in concrete construction.

In most large buildings, the heavy steel structure provides a much lower impedance path to earth than separate down conductors installed as part of the lightning protection system. These steel columns can be used as the down conductors.

Since the lightning current is not effected by the structure, multiple down conductor paths in parallel will result in lower voltage differences between the top of the building and the foundation. This voltage differential can be important in buildings with electronic equipment interconnected between floors, in antenna towers and similar instances. The size of the conductors is not too important although they must meet the minimum requirements of the lightning code. For example, a 4/0 conductor is only slightly better (lower impedance). than a conductor for the short duration (high frequency) of the lightning stroke. Although the ampacity (DC resistance) of these two conductors are different (by a factor of approximately 8), short time impulses have voltage drops that are usually within about 20% of each other.

The lightning down conductors must be bonded to the building steel. Also included are any conductive items which may cause side flashes resulting from instantaneous voltages that exceed the voltage withstand capability of the air or other insulating material between the conductor and the conductive item. Side flashes can occur between lightning conductors and building steel, permanently mounted ladders, equipment, etc. even though all are connected to a common ground or earthing point. The instantaneous voltage difference can become dangerously high because of the high impedance of the various paths to the steep wave front lightning current, resulting in large voltage drops.

Even when no side flash occurs, the large voltage differences can cause electronic noise and component failure. Often, latent component failure, created by repeated voltage stress, will cause equipment failure at a time when no lightning or other outside influence is present. This problem is likely to be made much worse where there are separate equipment grounds, not bonded together (which is a violation of the National Electrical Code [NEC]) requires electrical raceways, equipment, etc. that are within 6 feet (1.8 m) of a lightning conductor to be bonded to the conductor at the location where that separation distance is less than 6 feet (1.8 m).

In addition, that lightning conductors and driven rods or pipes, or any other made electrode that is used for lightning system protection shall not be used in lieu of the grounding electrode system. This is not to say that the two systems shall not be bonded together, only that there must be two systems with two distinct purposes that are interconnected. The interconnecting or bonding of the two systems helps to ensure that there is little possibility of a difference of potential between the two systems or the two systems' components.

Moist clay. The electrode shall extend vertically at least 10 feet into the earth. The rod size shall be at least 1 /2 inch by 8 feet (5/8 x 8 for buildings over 75 feet high) shallow top soil. If bedrock is near the surface, the conductors are laid in trenches extending away from the building. The trenches shall be 1 to 2 feet (0.31 to 0.62 m) deep and 12 feet (3.7 m) long in clay soil (Fig. 2-12) and 2 feet (0.62 m) deep and 24 feet (7.4 m) long in sandy or gravelly soil. (Fig. 2-13) In rare cases where this is impracticable, the lightning cable shall be buried in 2 feet (.62 m) deep trenches. Where this is impossible, the cable may be laid directly on top of the bedrock at least 2 feet (0.62 m) from the foundation or exterior footing. This cable must be terminated on a buried copper plate at least 0.032 in (0.813 mm) thick and 1 square foot (0.093 square m) area.

Sandy or gravelly soil. In sandy or gravelly soil, the lightning conductor shall extend away from the building in a trench at least 12 inch deep. The ground rod shall be 20 feet long or greater or there shall be 2 or more rods separated at least 10 feet driven vertically to a minimum 10 feet below grade. If the soil is less than 12 inch thick, a counterpoise (or network of conductors) in a trench or rock crevices shall surround the structure. The counterpoise conductor must be copper, sized to meet Class I main cable size. If the structure is over 75 feet in height, the cable must be sized to meet Class II main size copper. These cable sizes are listed in the various lightning codes. In extreme cases, copper plates may also be required.

SOME IMPORTANT POINTS ABOUT GROUNDING

(1) Typically the safety grounding of equipment is exactly the same for electronic equipment as it is for any other kind of apparatus, whether it is a refrigerator or a printing press. The "green wire" and conduit/raceway system's grounding. Safe equipment grounding requires fast clearing of circuit breakers or fuses and minimization of voltage differences on exposed metal surfaces of equipment to levels that are safe for people. This is called the control of "touch potential.

(2) Protection of data circuits generally requires additional considerations. Protection of data circuits from disruption or even damage does not always

involve grounding, although good grounding makes this protection a lot easier. Aircraft have no earth grounds while they are flying. The airplane carries its own "grounding" system for its ac and dc systems, and signal grounding purposes. This grounding system is entirely metallic in nature and it is often called a self contained power and signal reference system, which is a more accurate description. Even direct lightning "hits" are not likely to cause equipment damage or even disruption to signals.

(3) The circuits of most electronic systems are almost always sensitive to voltages of a few tens of volts or even to as little as one or two volts. As a result, these systems are designed with great care to keep transients out of the actual circuitry and off of the signal paths between interconnected units of a system. To accomplish this, some equipment uses electrostatically shielded isolation transformer techniques and ac-dc power supplies designed to reject transients. However, for these techniques to be fully effective, good grounding and bonding practices.

(4) Data signals inside most electronic systems consists of bits of information processed as square waves or impulses at about 5 volts in amplitude and clock speeds which can exceed 200 MHz. Data transferred between equipment often has a magnitude of 12-18 volts, and the speed of transfer is lower than that of the signal processing speed available inside of the equipment. In any case, the signal rise-times of the clock and most other signal pulses such as those used to transfer bits, are far faster than the typical lightning strike. Yet, even at these speeds the systems can be made to have high reliability and to be relatively immune to interference if good grounding and bonding practices are followed.

(5) Lightning related waveforms are usually the "worst case" situation for transients on most ac power system wiring and related grounding systems. This makes lightning the principal threat.

(6) Fast electrical transients are created in some equipment with electromechanical contactors. The interference problem from these items

could be serious, but it is easy to solve by installing RC snubbers (consisting of resistors and capacitors) across the contacts, coils, or both items of the offending device. This kind of interference with electronic circuits can sometimes be controlled by more stringent shielding, or grounding and bonding practices. However, the root cause of this kind of problem is really not a shielding, or grounding and bonding related problem. Instead it is an equipment circuit modification problem and this is the kind of thing which typical electrical contractors should normally not be expected to identify or to solve.