2nd Biennial

Movable Bridge Symposium

November 10, 11, & 12, 1987

St. Petersburg Beach, Florida

LIGHTNING SURGE SUPRESSION

FUNDAMENTALS AND APPLICATION

by

Frank C. Breeze
Electronic Systems Consultant

Tilden, Lobnitz & Cooper, Inc.

Orlando, Florida

Lightning Surge Suppression

Fundamentals and Application

Frank C. Breeze
Electronic Systems Consultant
Tilden, Lobnitz & Cooper, Inc
Orlando, Florida

Part 1 - INTRODUCTION

Lightning is among natures most beautiful phenomenons and has been with us since the beginning of our existence on this planet. Many researchers in biochemistry believe that lightning was partially responsible for formation of basic amino acids, and therefore ourselves, from the primordial soup which existed on our young earth. Today, lightning is viewed as a threat to both life and property. In this work we will examine the very nature of this phenomenon and take a close look at modern measures to protect ourselves and our equipment from its effect. We will address a number of frequently asked questions such as: Where does lightning come from? How strong is a lightning bolt? And How frequently does it occur?

There are many factors which influence our global weather system including density of solar radiation, rotation of the earth and topography of the land. These factors combine to produce circulating air currents and differences in air temperature, barometric pressure and humidity within our troposphere. Basic laws of physics come into play as these air masses interact with one another causing cloud formation and cyclic weather systems such as hurricanes and thunderstorm cells. Since lightning is our major concern, this discussion will focus on the mechanisms which form thunderstorm cells and resultant lightning.

PART 2 - THUNDERSTORM FORMATION

A thunderstorm cell is a defined system of circulating air currents caused by a frontal weather system or as the result of convective air movement within a localized area. A thunderstorm may consist of many such cells which form, become active and die during the course of a storm. This birth and death is a continuous process during the life of a storm with each individual cell lasting an average of twenty minutes.

Cell formation during a frontal storm occurs as a cool high pressure air mass encounters a warmer air mass of lower pressure. As this cooler, denser air mass encounters the warmer air, it slips beneath, forcing the warmer moisture laden air upward to higher and higher altitudes. Cloud formation occurs along the frontal line as the temperature of the upwardly moving air reaches the dew point, providing a distinct frontal squall line. Vertically circulating currents in this type of system set the stage for lightning.

Convective storm systems are caused by an upwelling of warm moist air as the result of solar radiation. These systems are often more random and less defined than frontal storms, generally occurring in the afternoon and early evening hours. Storms of this nature occur more frequently at lower latitudes where summertime solar radiation angles and relative humidity are high. Like frontal storms, the rising columns of warm moist air are replaced by cooler pockets of air and circulating currents are established.

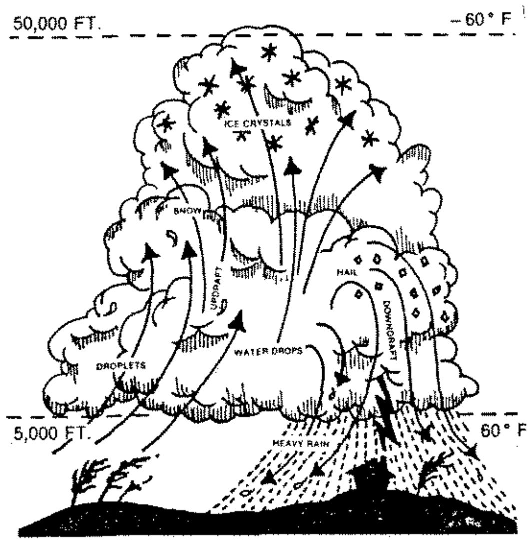

Figure 1
The Thunderstorm Cell

Figure 1 depicts the activity which occurs within a thunderstorm cell. Rising columns of warm moisture laden air cool as they migrate higher and higher in altitude. Liquid water droplets are formed which eventually freeze to form ice crystals. As the process continues, downward currents, usually near the perimeter of the cell carry these high altitude particles toward the earth where once again, they begin moving upward. While the exact mechanism of charge separation within the cell is cell is not fully understood, it is believed that the freezing and thawing of water molecules during this process creates an abundance of free electrons in lower regions of the cell. The upper area of the cell, with a deficiency of electrons assumes a net positive charge. As the process continues, the strong negative charge center at the base of the cell causes free electrons in the earth beneath the cell to be repelled resulting in a net positive charge on the earth. Charge separation continues with ever increasing potential differences between elements of the cell, with elements of adjacent cells and the earth below. Other cells involved in the storm are also executing this process at different states of charge.

When a sufficient state of charge is reached, oxygen between these charged bodies begins to ionize as a result of the strong electric field, forming pockets of higher than normal conductivity in the air. Point discharge currents or corona may be observed from the tips of tall objects as the process continues. Seamen often reported the crackling sound and bluish glow of this phenomenon as St. Elmo's Fire. Hair will often stand on end during these conditions as a warning of imminent danger. One story told in lightning circles involved a group of teen-agers found dead atop a knoll in one of our national parks. One youth was found with a camera which contained film of the others posing with their hair standing on end. This fatal warning had not been heeded.

Once sufficient breakdown potential is achieved, a faintly visible current known as a step leader leaves the cloud on its journey toward earth. Forking and branching occurs as the leader follows the pockets of ionized air along a tortuous path. This is a relatively slow process involving a number of milliseconds.

Upon nearing the earth, an upward streamer rises at a point near one or more of the approaching leaders. Tall objects within range of the leader are usually the first to generate a streamer, explaining why lightning rods work and why towers and other tall structures receive a great deal of lightning. Once the step leader and upward streamer join, a highly conductive path is established, setting the stage for the final scene.

Acting as a good electrical path between the highly charged cell and earth, the lightning channel carries extreme amounts of current in an attempt to neutralize these charge difference. This current, known as the return stroke changes from near zero to values up to several hundred thousand amperes over a period lasting only microseconds. The flash is bright and highly visible for miles. Air surrounding the channel is heated and expands at supersonic speeds, resulting in a loud clap of thunder. Heard close by, the report sounds like a sharp crack. At greater distances, a rumble is heard due to the varying times of arrival of sound from different parts of the channel and acoustic attenuation of higher frequencies by the atmosphere.

After the initial discharge, areas of the cloud and earth depleted of charge by the strike are quickly filled by remaining charge in the surrounding areas. With the lightning channel still well established, the process repeats itself until sufficient charge has been equalized to inhibit the process. These subsequent return strokes occur in rapid succession with up to forty-four recorded in a single strike. Our natural persistance of vision, rrestricts us to viewing the first and subsequent return strikes as one event.

Thus far we have discussed only cloud-to-ground strikes and have paid little attention to inter-cloud and intra-cloud discharges. These events occur in the same manner as described, but between charge centers of the same cell or between nearby charge centers of adjacent cells. This activity occurs more frequently than ground strikes, however, the only threat posed by this cloud-to-cloud activity is from radiated electromagnetic fields.

We are occasionally asked if lightning ever strikes from the earth upward, a process just the reverse of normal. This type of strike does occur, however rarely, usually triggered from a tall stack or tower to a charge center near the top of a thunderstorm cell. Currents associated with this phenomenon are normally larger than those found in a common strike.

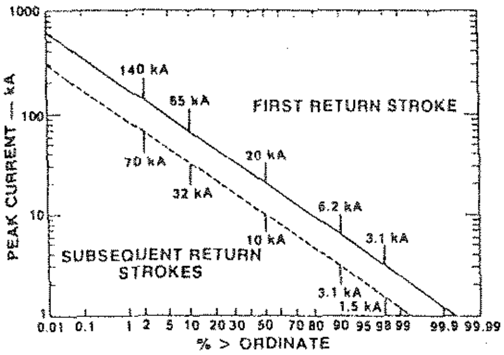

Figure 2 - Lightning Intensity
(Courtesy SRI International)
(Menlo Park, Ca)

Figure 2 is a compilation of recorded data produced by Cianos and Pierce at Stanford which should help remove some of the mystery over just how much current is involved in a typical lightning strike. Statistically, half of all strikes will produce currents of 20,000 Amperes and below. Larger strikes will occur with decreasing frequency in proportion to their amplitide, however, they do occur and must be dealt with.

The second lightning mechanism of concern involves the electromagnetic energy radiated from the lightning channel during the first and subsequent return strokes. Our physics instructors taught us that changing the flow of current in a conductor would cause a proportional change in the magnetic field around the conductor. We also learned that any wire placed in this changing field would produce a voltage across its length proportional to the rate of change. And so it is with lightning.

Figure 3 describes the electromagnetic frequency spectrum radiated from a typical lightning channel. Much like an a powerful AM radio transmitter, this energy is radiated through space and finds the many antennas which are our wiring systems. While driving between cities at night and listening to a weak AM radio station, it is common to hear crashing sounds from lightning great distances away.

Reviewing the figure, we find the energy contained in this field to be inversely related to frequency. This explains why lightning interference (and most powerline arcing interference) has a pronounced effect on communications at lower frequencies while higher frequencies are virtually immune.

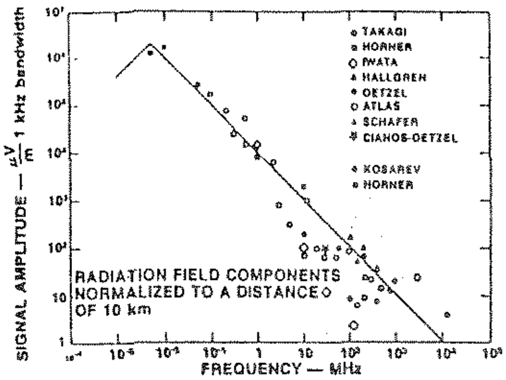

Figure 3 - Electromagnetic Radiation
(Courtesy SRI International)
(Menlo Park, CA)

The next time you observe such interference as speckles in the picture of a low-band VHF television signal, tune to a high VHF or UHF channel and the interference will be significantly reduced or disappear. Field intensities reaching one volt per meter are reflected in the graph, quite unremarkable until you note that measurements have been normalized to a distance of ten kilometers. The strength of the electromagnetic field radiated from a lightning channel behaves according to inverse square law. Consequently, it is quite easy to see that extreme field intensities will be present in locations close to a strike.

As a final note, it is important to understand the behavior of commonly used cable shielding materials exposed to this energy in the very low frequency spectrum. Permeability and thickness of the shield material is of increasing importance at lower frequencies. Aluminum foil and copper braid shields, familiar to us all, perform quite poorly. Earth cover at normal depths is also ineffective in preventing these fields from entering our wiring systems.

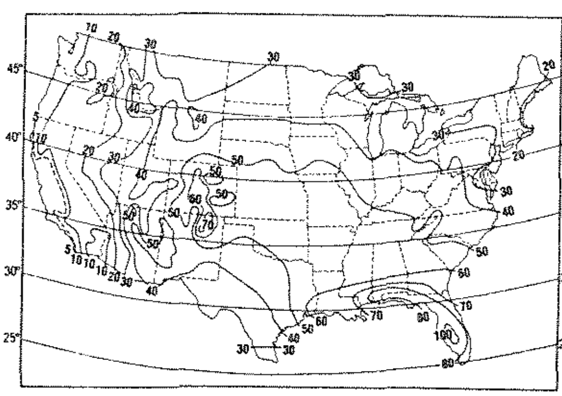

Figure 4 Average Thunderstorm
Days in the U.S.
(Courtesy N.O.A.A)

Experience has shown that interest in lightning and protection of equipment and systems from damage varies in proportion to the level of lightning exposure. Other factors such as system importance and cost also come into play. The following figures reflect clear differences in thunderstorm activity in various parts of the world.

Figure 4 is commonly referred to as an isocerraunic map, depicting the average number of thunderstorm days for various locations throughout the U.S. Technically, a thunderstorm day is "a day on which thunder is heard". This somewhat primitive method of quantifying lightning risk does not account for multiple thunderstorms occurring during the same day or for the number of lightning earth discharges which occur. It is important to note that values reflected in this type of chart are regional averages. In many areas, local pockets which range above and below the mean values may be found as the result of features in local terrain and the micro-climates they create. It is interesting to note that this map is used in risk assessment for structures and also tends to reflect the level of interest of the general population in lightning and surge suppression.

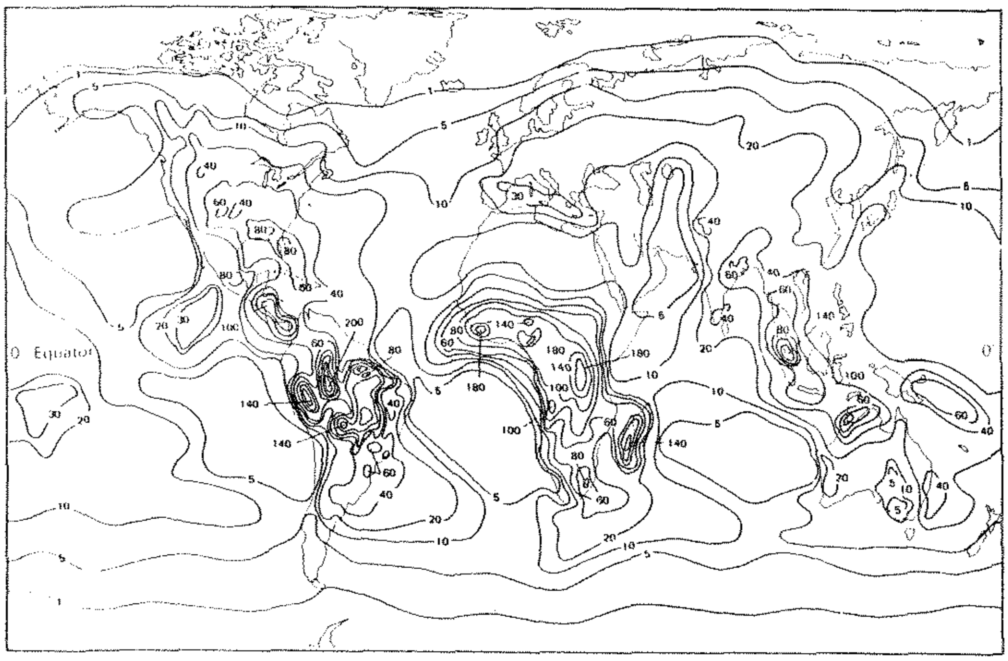

Figure 5 - Thunderstorm Activity in the World
(Courtesy World Meteorological Organization)
(Geneva, Switzerland)

Figure 5 provides thunderstorm data on a global scale. While central Florida, with over 100 thunderstorm days per year, leads the United States in lightning, it is easily outranked by countries in the tropics, especially where mountainous terrain is involved. Lightning in regions of high thunderstorm activity is not necessarily any more intense than in other areas, there is simply more of it.

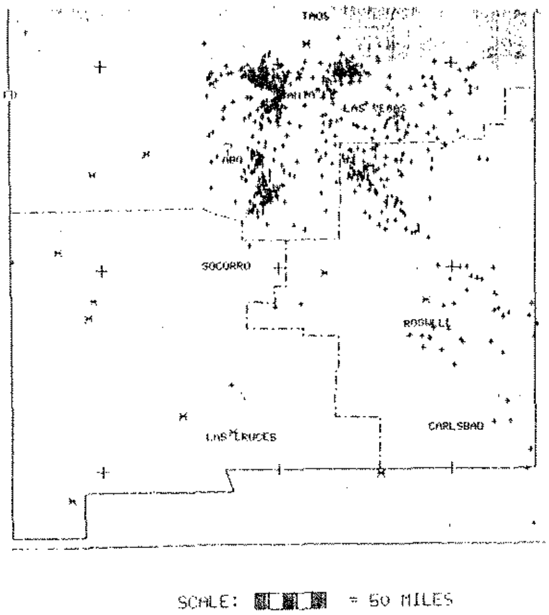

Figure 6 - Lightning Tracking
(Courtesy U.S. Bureau of Land Mgmt.)
(and Los Alamos Nat'l. Labs)

Figure 6 is typical of the data furnished by modern lightning tracking and location systems. Lightning, by virtue of its radiated electromagnetic field may be detected and located using a system of time synchronized receivers and computer triangulation. This data is recorded by the computer for plotting purposes or presentation on real-time display devices. Many systems "age" this display data causing strike indications to shift in color with the passage of time. Examination of this colorized data provides not only an indication of where the storm is, but also the direction in which it is moving. Most of the United States is served by such systems for such purposes as early detection of forest fires and to aid in protection of hazardous ordinance facilities. Much of this information is available to the general public, in fact, many television stations use this data as part of their weather forcasts. Activity indicated in figure 6 represents coverage of the state of New Mexico during a period of approximately two hours. The many marks are ground strikes, distinguished by the system from cloud-to-cloud activity using signature recognition techniques.

PART 2 - FUNDAMENTALS OF PROTECTION

Lightning and protection of our equipment from its effects is a matter of increasing importance in today's world of electronic technology. On occasion, we hear statements from system owners and technical personnel that lightning has become much worse in recent years. These statements usually follow a portion of their system being converted by lightning to a smoking pile of rubble or a non-functional mass of parts. Actually, lightningg is about the same as it has always been. It is our equipment which has become more sensitive to its effects.

Our objective in protecting any equipment or system is to effectively reduce the potential difference seen between any metallic conductors entering or leaving that system or item of equipment to a safe value. To achieve these goals, a system of grounding, bonding and surge suppression is utilized. For example, suppose you wish to protect a common television receiver which is operated from the 120VAC line and served by cable television. If one were to cut the power cord in half, cut the antenna cable in half, tie all the resulting metallic ends together under a single connector and make sure the set chassis was well isolated from ground, the set would not work, however, protection would be assured. In this case, if a large surge potential was seen on the power cord, the same potential would be seen on the antenna input. Likewise, a surge on the cable input would also be seen at the power terminals. Much like the bird at rest on the high voltage power line with no potential difference across his body, the set sees no potential difference between its external circuits, no current flows through the set and no damage occurs. It is obviously impractical to bond different types of active circuits permanently together to achieve protection. What is required is a method of providing a temporary bond between services during a surge and allowing the circuitry to return to its normal state afterward. This temporary bonding is the principle behind surge suppression.

Ideally, a properly protected system would consist of a network of equipment, interconnected by signal carrying cables, and connected to power and earth ground at only one point. In the real world, however, our electronic systems typically cover medium to large geographic areas of a building or site, often with many connection points to the electrical system and to local grounds. To achieve closer to an ideal situation, it is necessary to break the system into groups or "clusters" of equipment for the purpose of protection. Each cluster is then treated as a small sub-system with localized grounding and protection. A cluster may be compriseo of a large group of related equipment items within a single room or small building. It may also be as small as an individual item of equipment. The reason for breaking a system into small, closely located groups of equipment is related to the performance of conductors used for bonding equipment and surge suppressor grounds together. Remember, we are trying to equalize the potential seen across external wiring terminals for the system and poor performance of bonding conductors will affect our abbility to do this.

$$E = IR + L(di/dt)$$

Where:

- I = current in amperes
- R = conductor dc resistance in ohms
- L = conductor inductance in henries
- di = change of current in amperes
- dt = change of time in seconds (risetime)

Assuming:

- conductor length = 10 meters
- conductor material: copper
- conductor size = #6 AWG
- total DC resistance = .013 ohms
- total inductance = 10 microhenries
- current = 1,000 amperes
- risetime = 1 microsecond

$$E = (1000. \times .013) + .000010\ (1000/.000001)$$
$$E = 13 + 10{,}000$$
$$E = 10013 \text{ volts}$$

Figure 7 - Bonding Conductor Performance

Figure 7 describes the method of calculating bonding conductor performance under typical lightning surge conditions. In dealing with lightning transients, and differences in ground potential between various parts of a site, structure, or building, we find currents with magnitudes of many thousands of amperes and risetimes which may be as short as one microsecond. Under these conditions, inductance of bonding conductors becomes the critical factor in determining voltage differences in our bonding system These conductors, in combination with surge suppression devices, equalize potentials seen between various wiring terminals of our system. Making the conductors larger will reduce the resistance of the circuit, however, the effect on conductor inductance will be minimal. In our example, the thirteen volts produced due to the circuit resistance might be reduced to only a few volts, but the 10,000 volts produced by the inductance will remain virtually unchanged.

One common mistake found in grounding and bonding systems involves placement of insulated grounding and bonding conductors in metallic conduit. In our example, we used an inductance value of one microhenry per meter for our bonding conductor. When placed in conduit, this value rises to approximately 71 microhenries per meter, making the situation much worse than before. Recalculating the same example based on this new inductance value of 715 microhenries yields an overall voltage drop of over 700,000 volts! In other words, long bonding conductors, or those installed in metallic conduit might as well be non-existent for purposes of surge suppressor bonding and lightning grounding.

In view of the preceding discussion on bonding conductor performance, it becomes apparent why system equipment must be dealt with in small clusters rather than trying to run extremely long grounding and bonding conductors. Another frequent source of lightning damage further reinforces this point. Suppose for a minute, we are attempting to protect a system with equipment divided between equipment rooms in two buildings. These buildings are separated by some distance with only system wiring in between. Power for each building is referencing the local building ground system at each end wwhich provides a net grounding resistance of five ohms.

One rainy afternoon, one of the two buildings (or the building ligntning protection system) receives an average lightning strike current of 20,000 amperes. This current flows into the local five ohm building grounding system, causing a net rise in this ground system and everything connected to it of approximately 100,000 volts. Everything except the signal lines leaving the building and referencing the remote ground of the other building. Under this condition, a large current may be expected to exit the local equipment on its way to the remote building ground and damage to equipment at both ends of the site cable may be expected. This scenario is rather simplistic, however, we see this type of damage frequently in the data environment where a variety of remote peripheral equipment is connected to a central computer via large expanses of cable.

PART 3 - PROTECTING THE CLUSTER

Specific measures for protection of equipment will involve the following steps:

A. Identify equipment to be included within each protected cluster. Equipment for a cluster is usually located within the same room. In some cases, equipment such as a remote terminal and printer must be dealt with as a separate cluster due to physical distance from the main cluster and reference to local ground.

B. Establish a "window" at the cluster as a point of entry and exit for all power and signal wiring. This window should be no more than a few feet in any dimension.

C. Create a single point ground reference at the window location for all equipment within the cluster. Care should be exercised to ground equipment within the cluster ONLY to the single point ground at the window. All other stray ground connections should be eliminated.

D. Provide ground connections from the single point "window" ground to the building structure, earth ground, the electrical system ground and other points outside of the cluster as desired.

E. Install surge suppressors on all power and signal circuits as they pass through the cluster window.

The steps outlined above make use of a number of important principles. First, by keeping the equipment clusters small and providing power and signal line suppression at one point, the inductance of surge suppressor bonding conductors is minimized affording better control of potentials. Also, since a single point grounding system is used within the cluster, the risk of lightning currents flowing through the cluster and between equipment are minimized, again leading to better control of potentials. Lightning surges attempting to enter the cluster on power or signal lines will be diverted into the single point ground and flow only through conductors leading to structural and earth ground. Since a path to ground does not exist through bonding conductors serving equipment within the cluster, protected equipment items will remain at the same relative potential as their suppressors and the single point ground and no damage should be sustained. The "ground window" concept described herein has been used with a high degree of success for many years in telephone central office practice.

PART 4 – SUPPRESSION DEVICES

Most surge suppressors in common use today utilize three basic technologies. First among these are the spark-gap devices which break down as the applied voltage potential exceeds the breakdown rating of the device. These devices are packaged as two element units with one element connected to the protected circuit and the other to ground, or as three-element units which protect a conductor pair. In the three-element unit, two elements are connected to conductors of the pair with the remaining element connected to ground.

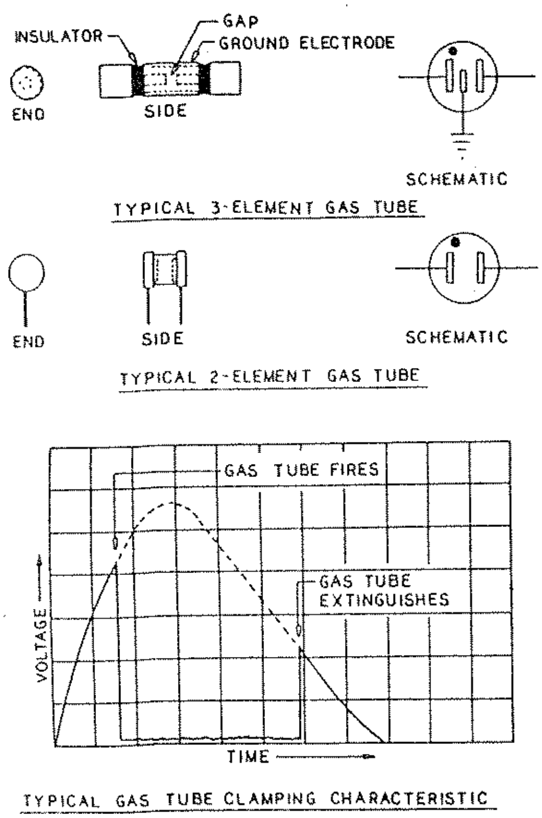

Figure 8 - Gas Tube Suppressor

The three element device offers the advantage of clamping all three elements together during either a differential (across the pair) or common mode (equal surge potential on both sides of the pair) surge at the same instant. Gas tubes are capable of conducting very high currents and provide reasonably good life. Gas tubes operate by striking an arc within their envelope. Ionization of the gas within the envelope must occur before this arc can be established, in much the same way that ionization precedes a cloud to-ground discharge during a storm. Consequently, much of the energy in a fast-risetime surge waveform can be "let through" by the gas tube before it operates. Once operated, a gas tube comes within a few volts of providing a dead short across its terminals. It also extinguishes at a lower voltage than the point at which it breaks down. When used in a power application, these factors may cause the tube to continue conducting after the surge has passed, as the result of normal line voltage on the circuit. Usually some form of limiting resistance (valve element) or circuit interrupting device is provided to permit the tube to extinguish once it has performed it's task.

Figure 9 indicates the internal construction and packaging for a typical metal oxide varistor or MOV. These units are comprised of one or more wafers of sintered zinc oxide particles which, in their final configuration, provide a non-linear resistance characteristic which varies with applied voltage. During processing, boundary

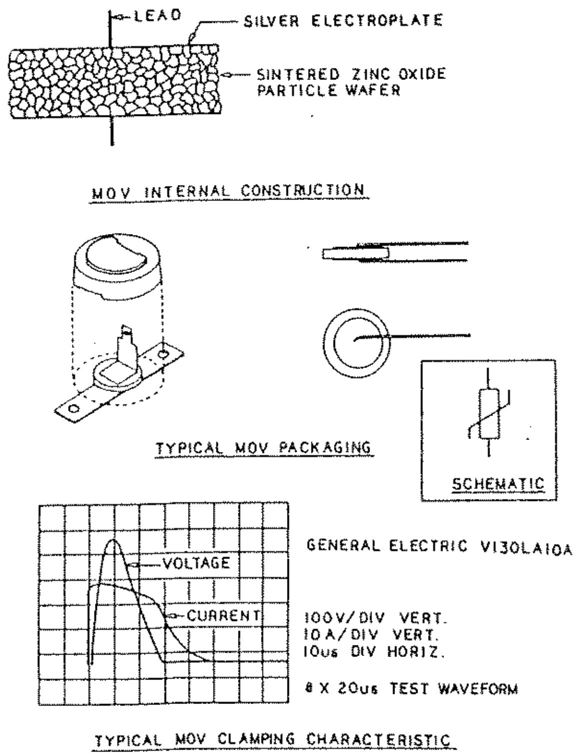

Figure 9 - Metal Oxide Varistor Suppressors

layers are created between particles, providing a relatively high resistance under conditions below the rated breakdown voltage of the device. As applied voltage increases above the device breakdown rating, these boundary layers begin to break down at a rapid rate causing more and more current to flow through the device. Once the event has passed, the varistor returns to normal condition provided its pulse/lifetime rating has not been exceeded.

Since turn-on is a rather gradual process, these devices are considered to be very fast acting in response to a surge. Varistors, however, do not provide a high degree of control over surge voltage. As the amount of surge current increases, the clamping voltage also increases, making use of the device questionable for situations where absolute clamping levels are desired. Varistor suppressors used in power applications must also be fused since they tend to fail partially shorted and may heat to high levels.

The last element in widespread usage for surge suppression is a specialized form of the silicon avalanche or zener diode. Like the zener diode, these units when installed between the protected circuit and ground, begin conducting vigorously when their breakdown rating is achieved. One common series of devices, known as Transzorbs (an acronym for transient absorber) utilize the same technology as conventional zener diodes but on a much larger scale.

The Transzorb diode provides a very hard clamping characteristic and reacts at speeds on the order of a few nanoseconds. Internally, the diode junction area of these units is much larger than a conventional diode and heavy silver plating is applied to both sides of the junction. The silver serves to provide uniform distribution of current across the junction and to act as a means for conducting heat away from the semiconductor material. Large external heat sinks will not be found on these diodes as you might expect for devices rated at several thousand amperes. The reason for this is the extremely short duration of most surges and the relatively long time required for surge generated heat to migrate through the packaging.

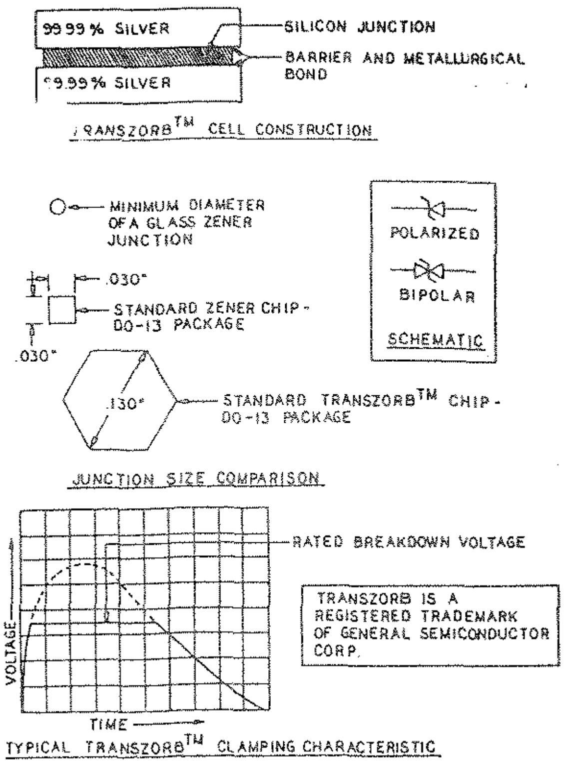

Figure 10 Silicon Avalanche Suppressors

At first it would seem that silicon avalanche diodes are the magic bullet for surge suppression, providing fast response and an almost absolute clamping level independent of current. This would be so if these units were not so sensitive to damage from overexposure to large currents. One manufacturer has addressed this issue by connecting sometimes hundreds of devices rated at 1500 amperes each in a series/parallel arrangement for power applications. At an average cost of $3.00 each in quantities of 1000, this can lead to quite an expensive suppressor. Other manufacturers have successfully combined these diodes with metal oxide varistors for power application and with either MOV's or gas tubes for signal line applications. The component combinations utilized in these "hybrid" suppressors use a high energy element in the first stage to deal with major components of surge energy, and a solid state second stage to provide the fast response and absolute clamping required for protection of many circuits.

PART 5 - POWER SURGE SUPPRESSION ASSEMBLIES

Protection of the electrical system serving a delicate apparatus or system is best approached using a multi-stage approach, taking advantage of the natural inductance found in our building wiring systems. During our discussion on bonding conductors we found that long lengths of wiring, especially when metallic conduits are involved, effectively resist the passage of lightning surge currents. When providing surge suppression, this can work to our advantage.

Typically it is wise to provide surge suppression at the electrical service to a building which will limit surge potentials to a value below the impulse breakdown rating of the interior wiring system. This breakdown value has been found to be approximately 6000 volts on systems with nominal line to ground voltages below 600 volts. This protective level will also afford protection for most motors, lighting fixtures and other durable equipment. Most suppressors of this type connect with relatively small conductors between each phase of the electrical service and the system neutral. A smaller suppression element is provided between neutral and ground for those applications where neutral and ground bonding is not provided at the service location. Since these devices bridge across the electrical service mains, it is extremely important to keep the suppressor leads short, and in no case should they be run through metal conduit. Since these devices are intended to clamp line to neutral surge potentials, any inductive voltage drop in the leads is directly additive to the rated clamping voltage of the unit. Figure 11 is representative of a typical service suppressor.

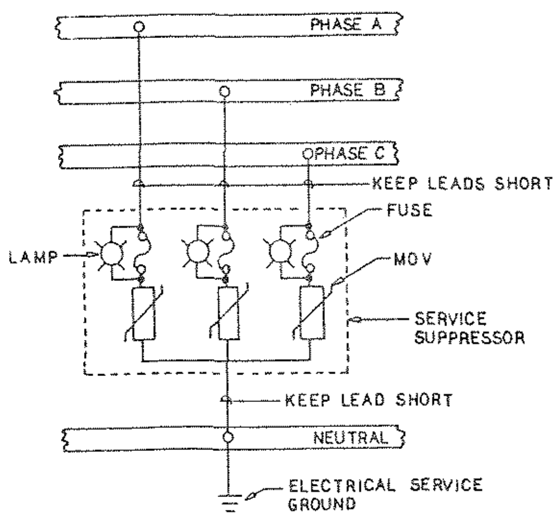

Figure 11 - Typical Service Suppressor

The suppressor shown in figure 11 utilizes one or more large metal oxide varistors between each active phase and the system neutral conductor. These varistors are typically rated to withstand a single impulse current up to 25,000 or 65,000 amperes depending on the specific model selected, however, they will tolerate hundreds or even thousands of smaller impulses, depending on the size of such pulses. Fusing is provided to remove a failed varistor from the circuit and light the indicator. It is not uncommon to see a varistor with a 25,000 ampere impulse rating protected by a thirty ampere fuse. Fuses melt according to a time/current curve and the brief duration of the surge does not permit the fuse sufficient time to open. Steady current from a failed varistor will, however, open the fuse. One word about indicator lamps and surge suppressors. Some manufacturers prefer to see a lamp placed across the protective suppressor element so it will illuminate as long as the suppressor is healthy. Others choose to place the lamp across the fuse to illuminate only when there is a problem. The moral to this story is that if you see a three-phase suppressor with all lamps lit it is either all good or all bad.

Secondary suppressors, normally located at the "window" to each equipment cluster provide much tighter clamping action, but with a reduced tolerance to surge energy. The natural limiting action of inductance within the building wiring system effectively limits the surge exposure these devices see, lengthening their lifespan. Figure 12 is a typical example of a hybrid power suppressor.

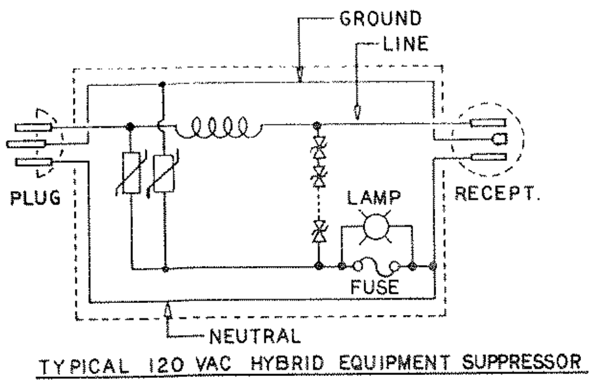

Figure 12 - Typical Hybrid Power Suppressor

The hybrid secondary power suppressor utilizes a large varistor first stage element between line and neutral with a secondary varistor element between neutral and ground. The neutral-to-ground clamp is necessary to control neutral-to-ground potentials during a building ground potential rise or due to voltage drop in the neutral caused by actuation of the suppressor itself. The second stage consists of a stack of bipolar silicon avalanche devices between line and neutral. If the first and second stages were connected directly in parallel, the diodes would attempt to do all the work until they were destroyed, leaving the varistor with virtually nothing to do. The inductor between the stages is an air core device wound with #12 or #14AWG copper wire to a value of approximately 100 microhenries. The voltage drop across this device limits second stage exposure by virtue of it's inductive voltage drop and properly coordinates the two stages.

PART 6 - SIGNAL LINE SURGE SUPPRESSION

The methods used for signal line surge suppression are quite similar to those used for power application, however, factors such as insertion loss, capacitance, and leakage resistance must be considered. Also, since many signal lines connect directly to rather sensitive circuitry, operating speed is of major concern. Hybrid suppressors are normally used in this application, with either gas tube or metal oxide varistor first stages and silicon avalanche second stages. Separation between stages is accomplished using small values of resistance or inductance.

Packaging for signal line suppressors is varied and depends largely on the type of circuit requiring protection. Telephone suppressors often take the form of their older carbon spark gap predecessors to permit direct plug-in replacement with a more modern technology. Suppressors for data line application will often be equipped with standard connectors which permit simple insertion into the data circuit. Units designed for protection of coaxial radio or data circuits are also available.

Quite often, signal line suppressors will be used in combination with a power suppressor for protection of remote equipment such as a personal computer or data terminal. When using multiple suppressors for this application, it is extremely important to interconnect the ground terminal of both suppressors with a short lead. If such interconnection is not accomplished, or if the length of the interconnecting conductor is too long, damage may result due to failure of the suppressors to track each other during a surge on either the power or data circuit. To overcome this problem and control the length of the power-to-data bonding conductor, several manufacturers are packaging both power and data (or power and telephone) suppressors in the same housing. One word of wisdom concerning signal line suppressors is appropriate. No matter how carefully you analyze your circuits there will always be one which exhibits a total resentment of conventional surge suppression devices. It is good practice to procure a sample suppressor for such special circuits before ordering in bulk.

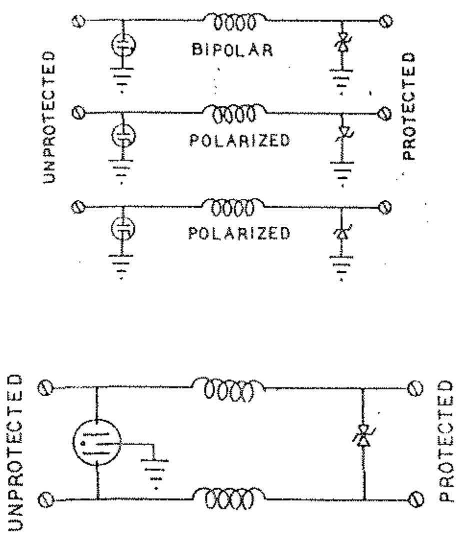

Figure 13 - Typical Signal Line Hybrid Suppressors

PART 7 SUMMARY

The surge suppression fundamentals discussed herein are universal in nature and apply equally to a variety of systems. The objective in any surge suppression system is to provide control of potential differences which may appear between various circuits leaving an item of equipment or cluster of such items. As we have learned from our discussion on ground potential rise and wiring system inductance, it is quite impossible to control the rise of such potentials through grounding alone.

In the pages which follow you will find a sample generic specification covering a variety of surge suppression applications. The practices outlined in this specification are consistent with those discussed in this work and may prove useful in your surge suppression endeavors. Practices are also discussed for special bonding using copper strip as a bonding material in those existing locations where power and signal circuitry cannot be brought closely together for the purpose of applying surge suppression as these wiring systems enter the cluster.

A list of relevant surge suppression standards practices and publications is also provided for the benefit of those who wish to delve into this subject in greater depth. Sources of catalog data from most of the major domestic surge suppression manufacturers have been provided.

Lightning is a powerful and sometimes misunderstood phenomenon and there is still much to be learned of its nature. Once this energy enters our wiring systems, however, it manifests itself as a predictable electrical signal. *And like other signals which we deal with on a daily basis, it too can be controlled.*

Manufacturers

Atlantic Scientific Corp.
2711 Harbor City Blvd.
Melbourne, Florida 32901
Telephone 305-725-8000
Telex 755959
Contact: Sales
Request complete catalog

Edco Incorporated of Florida
P.O. Box 1778
Ocala, Florida 32678
Telephone 904-732-3029
Contact: Bob Nabell
Request complete catalog

General Electric Company
5320 North 16th Street
Phoenix, Arizona 85016
Telephone 602-264-1751
Contact: Sales
Request: Transient Voltage Suppression Manual

General Semiconductor Ind., Inc.
2001 West Tenth Place
Tempe, Arizona 85281
Telephone: 602-968-3101
TWX: 910-950-1942
Contact: Sales
Request: Data Book (Transzorbs)

MCG Electronics, Inc.
160 Brook Avenue
Deer Park, New York 11729
Telephone: 516-586-5125
Telex: 645518
Contact: Mike Coyle
Request complete catalog

Poly-Phaser Corporation
P.O. Box 1237, 1425 Industrial Way
Gardnerville, Nevada 89410
Telephone: 800-325-7170
Contact: Sales
Request: Complete Catalog

TII Industries, Inc.
100 N. Strong Avenue
Lindenhurst, NY 11757
Telephone 516-842-5000
Telex 14-4631
Contact: Sales
Request complete catalog

Transtector Systems
P.O. Box 1299
Post Falls, Idaho 83854
Telephone 800-635-2537
Contact: Sales
Request complete catalog

Joslyn Electronic Systems
P.O. Box 817
Goleta, CA 93116
Telephone 805-968-3551
Contact: Sales
Request complete catalog

Hubbell Wiring Devices
State St & Bostwick Ave.
Bridgeport, CT 06605-0933
Telephone: 203-333-1181
Contact: Sales
Request data on suppressor receptacles

Erico (Cadweld), Inc.
34600 Solon Road
Cleveland, OH 44139
Telephone: 216-248-0100
Contact: Sales
Request complete catalog & info on computer grounding

Biddle Instruments
510 Township Line Rd
Blue Bell, PA 19422
Telephone: 215-646-9200
Contact: Sales
Request catalog on ground measurement equip & book

IEEE & ANSI Standards

IEEE Standard Test Specifications for Varistor Surge-Protective Devices, ANSI/IEEE Std. C62.33-1982

IEEE Standard for Surge Arresters for AC Power Circuits ANSI/IEEE Std. C62.1-1984

IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations, IEEE Std. 487-1980

IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System, ANSI/IEEE Std. 81-1983

IEEE Standard Test Specifications for Low-Voltage Air-Gap Surge Protective Devices, ANSI/IEEE C62.32-1981

IEEE Guide for Surge Voltages in Low-Voltage AC Power Circuits ANSI/IEEE C62.41-1980 (IEEE 587)

IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits, ANSI/IEEE C62.45 (May still be in approval cycle and unreleased)

Other Publications

Guideline on Electrical Power For ADP Installations
Federal Information Processing Standard 94
National Technical Information Service
US Dept of Commerce Springfield, Virginia 22161

Surge Protection Test Handbook
Keytek Instrument Corporation
12 Cambridge St. Burlington, MA 01803

Lightning Protection Guide for Radio Communications
PolyPhaser Corp.
P.O. Box 1237 Gardnerville, Nevada 89410

Lightning & 60HZ Disturbances at the Bell Operating Co. Interface
Technical Reference TR-EOP-000001, June 1984
Bell Communications Research
435 South Street Morristown, NJ 07960

How to Identify Powerline Disturbances
Dranetz Technologies, Inc.
P.O. Box 4019 Edison, NJ 08818-4019

Handbook of Design Requiremnents and Practices for Protection From Lightning Induced Effects, TM-667
John F. Kennedy Space Center, NASA
Kennedy Space Center, Florida 32899

A Discussion of Lightning Protection for Electronic Process Instrumentation, Bulletin 53E9007
Fischer & Porter Co. Warminster, PA

Rural Electrification Administration
Telephone Engineering & Construction Manual

Section	Title
801	Electrical Protection Fundamentals
805	Subscriber Station Protection
810	Elect. Protection of Central Office Equip.
815	Electrical Protection of Aerial Cable
816	Electrical Protection of Buried Plant
820	Open Wire Protection
821	Multi-Pair Wire Protection
822	Electrical Protection of Carrier Equipment
823	Electrical Protection by use of Gas Tube Prot.

For REA Practices contact John Arnesen, Asst. Administrator, Telephone, USDA/REA, 14th & Independence, SW , Washington, DC 20250 (202) 382-9554

SAMPLE SPECIFICATION

SURGE SUPPRESSION, BONDING & GROUNDING

PART 1 - GENERAL

1.01 APPLICABILITY

A. Surge suppression, grounding and bonding requirements outlined herein shall be fully applicable to all electronic systems which are provided as part of this contract under this division. It is intended that surge suppressors, grounding and bonding provisions as described herein be provided for each system or device by the contractor installing the system or device. Under certain circumstances, Surge suppression devices, bonding and special grounding may be required as provision for owner provided systems or equipment. Specific requirements for such additional surge suppression, bonding, and grounding will be indicated on the contract drawings or described elsewhere in this specification.

B. Surge suppression for each building service and for panels and switchboards which support electrical circuits which leave the protected confines of a building shall also be required. Technical requirements and installation criteria for these devices is included in this section to insure coordination of various levels of surge suppression, however, it is intended that these devices be furnished and installed by the electrical contractor.

C. Surge suppression, bonding and grounding shall be required on electrical and electronic systems apparatus residing outside the confines of a protected building. Pole mounted lighting, loudspeakers, devices mounted on fences, and fire alarm circuits connecting to backflow preventers are examples of these types of devices. Devices mounted on the exterior wall of a protected building below the roof line shall be considered as being within the protected building.

D. Requirements of this section shall be fully applicable to systems furnished under other divisions when reference is made to this section. References shall be by section number, name, or both.

1.02 REFERENCE STANDARDS AND PUBLICATIONS

A. The following standards and publications are referenced in various parts of this section and shall apply to this work:

1. ANSI/IEEE C62.41-1980 (IEEE 587) Guide for Surge Voltages in Low-Voltage AC Power Circuits. For purposes of this specification, category A and B exposures shall be as described. Category C exposure shall be assumed to be similar to category B in terms of surge waveforms, however, maximum voltage amplitude shall be assumed to be ten kilovolts and maximum current amplitude shall be assumed to be ten kiloamperes.

2. ANSI/IEEE C62-31-1977 (IEEE 465.1-1977) Standard Test Specifications for Gas Tube Surge Protective Devices.

3. ANSI/IEEE C62.1-1984 Standard for Surge Arresters for AC Power Circuits.

4. ANSI/IEEE C62.32-1981 Standard Test Specifications for Low-Voltage Air Gap Surge-Protective Devices.

5. ANSI/IEEE C62.33-1982 Standard Test Specifications for Varistor Surge-Protection Devices.

6. ANSI/IEEE Standard 81-1983 Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

7. Lightning and 60 Hz Disturbances at the Bell Operating Company Network Interface. Bell Communications Research Technical Reference TR-EOP 000001, Issue 1, June 1984

B. ANSI/IEEE standards may be obtained from the Institute of Electrical and Electronics Engineers,Inc. 345 East 47th Street, New York, NY, 10017.

C. Qualified surge suppression and equipment manufacturers may obtain a copy of the Bell Communications Research Standard through a Bell Operating Company representative. This document is also on file at the Engineer s office for review by interested parties. Permission to copy this document has not been granted.

1.03 SYSTEM PERFORMANCE CRITERIA

A. Surge suppression, grounding and bonding required by this specification for protection of electronic systems shall effectively protect the systems to which it is applied against lightning and other surge transients throughout the useful life of the system. Surge suppression devices and related grounding and bonding systems shall be designed and installed in such a manner that normal operation of the system is not impaired due to installation of such devices.

B. Calculations for suppressor pulse-lifetime ratings shall assume the devices are installed in areas of medium exposure when such devices are installed in ANSI/IEEE 62.41-1980 category A or B locations. Devices in category C locations shall be considered to be in an area of high exposure. Frequency of surge occurrence and surge amplitudes shall be as outlined in this standard with a required minimum suppressor lifetime of fifteen years.

C. Electronic system equipment shall be protected by dealing with each group of related devices as a "cluster" of equipment and protecting all metallic circuits which enter and leave the cluster. The cluster may be as large as a computer room, control room or equipment room or as small as an individual equipment cabinet. For purposes of establishing maximum size, all equipment within a protected cluster shall fall within a circular area of not greater than twenty-five feet in radius around a common point. All metallic circuits entering and leaving the equipment cluster shall be grouped together at a common point not larger than four by eight feet in dimension and protected with one exception. Circuitry which is supported by equipment within the cluster and extending beyond the cluster to serve devices within the building shall not require protection provided all of the following conditions are met:

1. Circuitry is enclosed within ferrous metal conduit.

2. No wiring within the raceways containing such circuits extends beyond the confines of the building.

3. No connection is made between this wiring and conduit ground outside of the protected perimeter established for the equipment cluster.

4. All devices connecting to such circuits shall have no connections to conduit or other grounds or other power sources outside the perimeter established for the equipment cluster.

5. All wiring to devices (and circuitry within devices) must be insulated from conduit and other grounds to a minimum impulse breakdown level of 5000 (five thousand) volts or greater.

D. All equipment chassis within a protected equipment cluster shall be effectively isolated from stray grounds and bonded only to a ground bar at the suppressor location for the cluster. The ground terminals of the suppressors protecting the equipment cluster shall also connect to this bar using a short direct route. The ground bar for each equipment cluster shall interconnect with each of the following external grounding systems:

1. Electrical "Green-Wire" grounds serving equipment within the cluster.

2. The building metallic structure at the closest point.

3. The nearest point of attachment to the building cold water piping system (if metallic).

1.04 SPECIAL REQUIREMENTS FOR COUNTERPOISE CONDUCTORS

A. Where non-ferrous metallic conduits or direct burial cables are used for electronic systems circuitry extending between buildings, or from buildings to various points on the site, counterpoise conductors shall be installed. This requirement shall be met on all such circuits including those installed in non-ferrous metallic ducts which are a part of a designated duct bank.

B. Counterpoise conductors shall be #4 AWG soft drawn bare copper installed a minimum of ten inches above single conduits or duct banks of less than thirty six inches in width. Wider duct banks shall be equipped with two such conductors spaced a minimum of ten inches above the duct bank and ten inches in from the upper outside corners.

C. Counterpoise conductors shall be bonded together (where two conductors are used) and to a 20'-0" driven ground at each of the following locations:

1. At 100 foot intervals along the duct bank or conduit.

2. At changes in direction greater than 45 degrees.

3. At each manhole, pedestal or pull box.

4. At each building termination.

D. Secondary bonding of counterpoise conductors shall be provided at each of the following locations:

1. To below grade perimeter bonding conductors installed around buildings as part of the building lightning protection system.

2. To fencing or other above grade metallic structures, where counterpoise conductors pass below or within three feet of the fence line or structure. Counterpoise conductors routed in parallel with metallic fence lines which fall within three feet of the fencing shall be bonded to the fence at all ground rod locations (100 foot intervals).

3. When counterpoise conductors terminate at a building, conductors shall be bonded to the nearest major steel structural element (steel structural systems) or to an exothermically welded pigtail extending from main reinforcing bars in the building foundation (reinforced concrete systems).

1.05 SPECIAL CABLING REQUIREMENTS

A. Cabling extended beyond the protected confines of a building, either direct burial or enclosed in non-ferrous conduit shall be designed for direct burial in a high lightning environment.

B. Cables shall be expected to carry significant potentials associated with the direct or induced effects of lightning and protection from pinhole sheath damage and subsequent electrolytic action shall be provided.

C. Cable design shall include a metallic shield and high density polyethylene outer jacket. Flooding compound shall be provided between the jacket and shield to heal pinhole jacket penetrations resulting from lightning. Standard direct burial telephone cables and CATV cables are acceptable for this application.

1.06 SPECIAL REQUIREMENTS FOR EXTERIOR POLE MOUNTED LIGHTING

A. Exterior pole mounted lighting fixtures shall be equipped with a surge suppressor designed for such applications. One suppressor shall be installed in the handhole of each pole base for each lighting circuit serving fixtures on the pole.

B. Metallic poles shall be provided with a 20'-0" driven grounding electrode installed at the base of the pole.

This electrode shall be bonded to the pole, the "green Wire" electrical ground, and to the surge suppressor ground lead with a #6 AWG bare copper conductor.

C. Concrete poles shall be equipped with surge suppression and grounding as described for metallic poles. In lieu of bonding to the pole, the #6 AWG copper conductor shall be extended internally up the pole and shall be bonded to each fixture. If the pole extends higher than the lighting fixture, the #6 AWG grounding conductor shall be extended in a straight, uniform manner to a height of twelve inches above the top of the pole.

1.07 EXEMPTION FROM EXTERNAL SURGE SUPPRESSION REQUIREMENTS

A. It is recognized that equipment and system manufacturers are beginning to address surge suppression as an inherent part of their equipment design and it is the intent of this specification to permit the use of such equipment without requiring supplementary external surge suppression.

B. Specific exemption will be granted for such systems and equipment upon receipt of documented tests from the manufacturer certifying the ability of the equipment or system to withstand common and differential mode surges on all metallic circuits using levels and waveforms described in ANSI/IEEE C62.41-1980 and as extended in the standards paragraph of this section. Pulse lifetime and withstand ratings for equipment shall be certified based on the appropriate category of exposure for a medium or high exposure location as appropriate to the location in which the equipment will be installed.

C. Exposure for circuits which connect to telephone company lines shall be determined from the Bell Communications Research Standard listed herein. Frequency of surge occurrence shall also be determined from this standard.

D. Surge suppression furnished as an integral part of the equipment or system shall be designed for a useful lifetime of fifteen years under conditions of exposure as outlined in the appropriate standard.

E. Grounding and bonding provisions described herein shall apply to all equipment which is internally protected by the equipment manufacturer.

F. In absence of a more relative standard, ANSI/IEEE C62.41-1980 exposure categories and waveeforms shall be utilized in determining protective requirements for both power and signal wiring. The branch circuit wiring systems providing power to various electronic systems are quite similar to signal wiring in terms of topography and electrical characteristics which determine their ability to propagate surge energy.

1.08 MANUFACTURER QUALIFICATIONS

A. All surge suppression devices shall be manufactured by a company normally engaged in the design, development, and manufacture of such devices for electrical and electronic systems equipment.

B. The surge suppressor manufacturer shall offer factory repair service for all non-encapsulated assemblies and replacement for all encapsulated units.

1.09 WARRANTY

A. All surge suppression devices and supporting components shall be guaranteed by the installing contractor to be free of defects in materials and workmanship for a period of one year from the date of substantial completion for the system to which the suppressor is attached.

B. Any suppressor which shows evidence of failure or incorrect operation during the warranty period shall be repaired or replaced at no expense to the Owner. Since "Acts of Nature" or similar statements include the lightning threat to which these suppression devices will be exposed, any such clause limiting warranty responsibility in the general conditions of this specification shall not apply to this section

1.10 SUBMITTAL

A. Surge suppression devices shall be submitted as an integral part of the equipment submittal for the system or equipment which they protect. Surge suppressors and their wiring, bonding, and grounding connections shall be indicated on the wiring diagrams for each system. Equipment grouped in clusters for the purposes of protection shall be indicated on the drawings by cluster and all bonding and grounding connections for the cluster shall be shown.

B. The surge suppression submittal shall also include, but shall not be limited to, the following additional data:

1. Complete schematic data for each suppressor type indicating component values, part numbers, conductor sizes, etc.

2. Dimensions for each suppressor type indicating mounting arrangement and required accessory hardware.

3. Manufacturers certified test data indicating the ability of the product to meet or exceed requirements of this specification.

4. A non-encapsulated sample of each suppressor type to be used for testing and evaluation. If requested by the manufacturer, sample will be held confidential unless cause is found to suspect that actual devices furnished do not match sample. Samples will not be returned.

5. It is recognized that certain manufacturers do not wish to divulge the contents of their products. Under these conditions, and in lieu of the required sample, the suppressor manufacturer may submit certified test data from a recognized independent testing laboratory indicating compliance with each element of this specification.

PART 2 - PRODUCTS

2.01 SUPPRESSORS FOR ELECTRICAL SERVICES

A. Surge suppressors shall be installed on each normal and emergency electrical service entering and leaving a building. Incoming service suppressors shall be installed at the first switchboard, panelboard, transfer switch, etc. the service encounters as it enters the building. Suppressors shall also be required on each switchboard, motor control center, or panelboard which provides power to other buildings or exposed equipment on the site. Exposed equipment shall include pole mounted lighting, lift stations, gate operators for fences, and other similar devices which are exposed to the direct effects of lightning. Roof-top ventilating equipment which is properly bonded to the building lightning protection system or to a close major member of a steel structural system is exempt from this requirement.

B. Suppressors shall be close-nippled to the device being protected in a position which will minimize lead length between suppressor and the buses or circuit breaker to which the suppressor connects. Suppressor leads shall not be extended beyond the suppressor manufacturers recommended maximum length without specific approval of the Engineer.

C. In 3-phase, 4-wire or 3-phase, 3-wire wye configurations, suppressors shall provide clamping action between each phase conductor and the system neutral. In such locations other than the building main electrical service (where neutral and ground are bonded), additional clamping action shall be provided between neutral and ground. Suppressors in delta wired locations shall provide clamping from each phase conductor to ground.

D. Suppressors shall meet or exceed the following minimum criteria:

1. Single impulse withstand rating: 65,000 Amperes (8 x 20 us waveform)

2. Pulse lifetime rating (10,000 Amperes 8 x 20 us): 100 occurrences.

3. Maximum Clamping voltage and energy rating (voltage with input current of 10,000 Amperes 8 x 20 us):

Normal Applied Circuit Voltage	Max. Clamp Voltage	Energy Rating
120 Volts	500 Volts	660 Joules
240 Volts	900 Volts	1080 Joules
277 Volts	1000 Volts	1170 Joules
480 Volts	2000 Volts	1650 Joules

(Energy rating @ 10 x 1000 us waveform)

4. Suppressors shall be listed and labeled by a recognized national testing laboratory and approved for the location in which they are installed.

5. Visible indication of suppressor failure shall be provided.

2.02 SUPPRESSORS FOR EXTERIOR POLE MOUNTED LIGHTING

A. Each pole mounted lighting fixture shall be equipped with a surge suppressor designed for such applications. Suppressors shall be installed with external in-line fusing to remove the suppressor and its associated lighting fixture(s) from the circuit upon failure of either the suppressor or fixture.

B. Suppressors shall be provided to match the operating voltage of each circuit and shall meet or exceed the following criteria:

1. Single impulse withstand rating: 25,000 Amperes (8 x 20 us waveform)

2. Pulse lifetime rating (10,000 Amperes 8 x 20 us): 2 occurrences.

3. Maximum Clamping voltage and energy rating (voltage with input current of 10,000 Amperes 8 x 20 us):

Normal Applied Circuit Voltage	Max. Clamp Voltage	Energy Rating
120 Volts	700 Volts	220 Joules
240 Volts	1250 Volts	360 Joules
277 Volts	1400 Volts	390 Joules
480 Volts	2600 Volts	550 Joules

(Energy rating @ 10 x 1000 us waveform)

4. Suppressors shall be listed and labeled by a recognized national testing laboratory and approved for the location in which they are installed.

2.03 POWER SUPPRESSORS FOR ELECTRONIC EQUIPMENT

A. Each item of equipment provided under this contract and connected by line cord or direct wired to the building electrical system shall be provided with a three stage single or multi-phase hybrid suppressor. Fusing shall be provided which removes the protective elements from the circuit upon failure. Visual indication or loss of output power shall be used to notify the user of device failure.

B. Suppressors shall be rated for a minimum of 125% of their continuous electrical load. Suppressors for cord connected equipment shall be equipped with standard NEMA cordsets one of which includes a molded grounding receptacle and the other, a molded grounding plug. Suppressor shall be installed in series with the power cord for the protected equipment. Where several items of equipment are grouped within the same cluster of equipment, one suppressor may be used in conjunction with properly sized grounding plugstrip to serve the equipment.

C. Suppressors for direct wired equipment shall be identical in internal design to the unit described for cord connected applications, however, protected screw terminals suitable for termination of solid copper wire shall be used for wiring terminations. One suppressor may be used to support several equipment cabinets provided all cabinets are located within the same equipment cluster and the maximum connected load shall not exceed eighty percent of the rated suppressor capacity.

D. Suppressors shall be constructed with a phenolic non-flammable exterior housing with provisions for mounting to the interior of equipment racks, cabinets, or to the exterior of free standing equipment. Suppressors shall be constructed as three stage devices. The first stage shall include a high energy varistor clamp between line and neutral and from neutral to ground. The second stage shall consist of series air-core inductor installed in the line conductor(s) to properly coordinate the action of the first and third stages. The third, fast acting, hard clamping stage shall consist of a network of silicon avalanche bipolar diodes between the neutral and line conductor(s).

E. Minimum suppressor performance characteristics shall be as follows:

1. Maximum single impulse line-to-neutral current withstand: 15,000 Amperes (8 x 20 us waveform)

2. Maximum single impulse neutral-to-ground current withstand: 10,000 Amperes (8 x 20 us waveform)

3. Pulse lifetime rating Category B worst case current waveform (8 x 20 us @ 3000 Amperes): 40 occurrences

4. Pulse lifetime rating for 200 Ampere (8 x 20 us waveform): 10,000 occurrences

5. Worst case response time: Five Nanoseconds

6. Worst case (Maximum Single Impulse Current Conditions) clamping voltage: 400% of nominal phase-to-ground RMS voltage.

7. Initial breakdown voltage: 200% of nominal phase-to-ground RMS voltage.

2.04 SUPPRESSORS FOR SINGLE CONDUCTOR PROTECTION

A. Suppression devices for single conductor protection shall be provided in multi-circuit pluggable packages suitable for the circuitry to be protected. Units for protection of data circuits which utilize standard connector configurations shall be equipped with connectors which install in series with the data cable to the protected equipment. Units intended for use with individual wiring conductors shall be equipped with accessory terminal blocks or strips suitable for the type of wiring being used. Suppressors installed outside of terminal or equipment cabinets (except at designated terminal boards) shall be provided with a housing approved for the location.

B. Suppression for each circuit shall consist of a two-element gas tube first stage, a series isolating element, and a silicon avalanche second stage. Resistive limiting elements may be used where the voltage drop across the series resistance has no effect on circuit operation. Inductive series elements may be used on other circuits to effectively pass DC or low frequency AC currents while limiting passage of fast risetime surge waveforms. Silicon avalanche devices shall be designed for surge suppressor applications and shall be polarized or bipolar as appropriate for each circuit.

C. Minimum performance criteria (each circuit) shall be as follows:

1. Maximum single impulse conductor-to-ground current withstand: 25,000 Amperes (8 x 20 us waveform)

3. Pulse lifetime rating Category B worst case current waveform (8 x 20 us @ 3000 Amperes): 10 occurrences

4. Pulse lifetime rating for 100 Ampere (10 x 1000 us waveform): 1,000 occurrences

5. Worst case response time: Five Nanoseconds

6. Worst case (Maximum Single Impulse Current) clamping voltage: 200% of normal operating voltage amplitude and polarized or bipolar as appropriate for each circuit type.

7. Initial breakdown voltage: 150 percent of normal operating voltage peak amplitude plus or minus five percent.

8. Capacitance: Capacitance for DC or low frequency lines shall not exceed 2000 picofarads measured line to ground at the rated diode breakdown voltage. Suppressors intended for use on high frequency or high baud rate circuits shall be designed for use on such lines. Capacitance of such units shall be equated to equivalent cable feet based on the type of cabling used for the particular circuit. The sum of equivalent cable feet for suppressors and actual cable footage shall not exceed manufacturers recommended maximum values for the system on which these devices are installed.

9. Circuit compensation: Any additional circuit compensation (gain or equalization) required to compensate for the insertion of surge suppression devices shall be provided as part of this contract.

2.05 <u>SUPPRESSORS FOR CONDUCTOR PAIR PROTECTION</u>

A. Suppression devices for conductor pair protection shall be provided in multi circuit pluggable packages suitable for the circuitry to be protected. Units for protection of data circuits which utilize standard connector configurations shall be equipped with connectors which install in series with the data cable to the protected equipment. Units intended for use with multiple wiring pairs shall be equipped with an accessory terminal blocks or strips suitable for the type of wiring being used. Single pair units shall be configured as encapsulated units with wire leads or screw-terminal wiring terminations. Suppressors installed outside of terminal or equipment cabinets (except at designated terminal boards) shall be provided with a housing to afford physical protection for the surge suppression modules.

B. Suppression for each pair shall consist of a three-element gas tube first stage, an isolating element in series with each conductor of the pair, and a silicon avalanche second stage. Second stage clamping shall be provided across the pair for differential mode protection and from each side of the pair to ground for common mode protection. Resistive limiting elements may be used on low current circuits where the effect of voltage drop across the series resistance has no effect on circuit operation. Inductive series elements shall be used on higher current circuits to effectively pass DC or low frequency AC currents while limiting passage of fast risetime surge waveforms. Silicon avalanche devices shall be designed for surge suppressor applications and shall be polarized or bipolar as appropriate for each circuit.

C. Minimum performance criteria (each circuit) shall be as follows:

1. Maximum single impulse conductor-to-ground or conductor to conductor current withstand: 25,000 Amperes (8 x 20 us waveform)

2. Pulse lifetime rating Category B worst case current waveform (8 x 20 us @ 3000 Amperes): 10 occurrences

3. Pulse lifetime rating for 100 Ampere (10 x 1000 us waveform): 1,000 occurrences

4. Worst case response time: Five Nanoseconds

5 Worst case (Maximum Single Impulse Current) clamping voltage: 200% of normal operating voltage amplitude and polarized or bipolar as appropriate for each circuit type.

6. Initial breakdown voltage: 150 percent of normal operating voltage peak amplitude plus or minus five percent.

8. Capacitance: Capacitance for DC or low frequency lines shall not exceed 2000 picofarads measured line to line

or line to ground at the rated diode breakdown voltage. Suppressors intended for use on high frequency or high baud rate circuits shall be designed for use on such lines. Capacitance of such units shall be equated to equivalent cable feet based on the type of cabling used for the particular circuit. The sum of equivalent cable feet for suppressors and actual cable footage shall not exceed manufacturers recommended maximum values for the system on which these devices are installed.

9. Circuit compensation: Any additional circuit compensation (gain or equalization) required to compensate for the insertion of surge suppression devices shall be provided as part of this contract.

2.06 COAXIAL SURGE SUPPRESSION DEVICES

A. Coaxial surge suppressors shall be configured for use on radio and television antenna, video, data and other services utilizing a coaxial format. Attenuation and return loss associated with each suppression device shall be included in all system performance calculations and compensated for accordingly.

B. Suppressors shall meet or exceed the following minimum requirements:

1. Mounting: All devices shall be flange mounted. Where multiple suppressors are used in a common location, flanges shall be secured to a common ground rail. Devices installed in through wall installations shall be flange mounted to a 1/4" aluminum bulkhead panel which serves to close the wall opening and provide an effective ground for all suppressors.

2. Impedance: Suppressor impedance shall be 50, 75, or 93 ohms as appropriate for the system being protected.

3. Connector type: Connectors on suppressor input and output shall be type F, BNC, UHF, or N to match connector type on protected equipment.

4 Return loss: Suppressors shall exhibit return loss characteristics of 26dB minimum (VSWR 1.1 to 1).

5. Insertion Loss: 0.2 dB maximum

6. Bandpass: Video suppressors shall provide a bandpass of DC to 15 MHZ. Suppressors for other circuits shall be selected with 3dB points on frequency response at least 3 MHZ above and below frequency limits for fully modulated carrier(s). DC and low frequency AC

continuity shall be provided as required to support cable powered preamplifiers or other equipment.

7. Maximum clamping voltage: 200% of measured maximum circuit peak-to-peak voltage, bipolar during maximum rated current impulse conditions (8 x 20 us waveform).

8. Impulse withstand rating, single impulse: 20,000 Amperes (8 x 20 us waveform).

9. Response time: 50 nanoseconds or less

10. Weatherproofing: Treat connector with Dow Corning compound #5 and enclose with sunlight resistant heat shrink tubing when devices are installed in exterior locations.

11. Ground isolation: Suppressors used for video or other ground loop sensitive applications shall be configured in such a manner that the shell of the coaxial connectors is isolated from ground except during surge conditions. Internal or external gas tubes may be used for this purpose.

2.07 BONDING AND GROUNDING CONDUCTORS AND MATERIALS

A. Conductors utilized for surge suppressor bonding shall be a minimum of #6 AWG solid uninsulated copper unless otherwise specified.

B. Ground bus or strip material shall be copper, a minimum of 26 gauge in thickness and three inches wide unless otherwise specified. Bus materials may be secured to surfaces with an appropriate mastic material or mechanical fasteners. Bus connections shall be bolted or brazed and reinforced as necessary on thin bus material to provide a permanent and secure connection.

C. Unless otherwise specified, all surge suppression grounding electrodes shall be 5/8" diameter copperweld rods, twenty feet in length.

D. Connectors, splices, and other fittings used to interconnect grounding conductors, bond to equipment or ground bars, shall comply with requirements of the National Electric Code and be approved by Underwriters Laboratories for the purpose.

E. Connectors and fittings for grounding and bonding conductors shall be of the compression or set-screw type in above grade locations. Connections below grade shall be exothermically welded or brazed.

F. Bonding connections between electrically dissimilar metals shall be made using exothermic welds or using bi-metal connectors designed to prevent galvanic corrosion.

PART 3 - EXECUTION

3.01 SEGREGATION OF WIRING

A. All system wiring shall be classified into protected and non-protected categories. Wiring on the exposed side of suppression devices shall be considered unprotected. Surge suppressor grounding and bonding conductors shall also fall into this category.

B. All wiring between surge suppressors and protected equipment shall be considered protected. Isolated circuitry exempted from surge suppression requirements in part one of this section shall also be considered protected.

C. A minimum of three inches of separation shall be provided between parallel runs of protected and unprotected wiring in control panels, terminal cabinets, terminal boards and other locations. In no case shall protected and unprotected wiring be bundled together or routed through the same conduit. Where bundles of protected and unprotected wiring cross, such crossings shall be made at right angles.

3.02 INSTALLATION OF SUPPRESSORS

A. Suppressors shall be installed as close as practical to the equipment to be protected consistent with available space. Where space permits and no code restrictions apply, suppressors may be installed within the same cabinet as the protected equipment. Suppressors installed in this manner shall utilize the equipment chassis as a medium for bonding of their ground terminals. Bonding jumpers not exceeding two inches in length shall be installed between the chassis and suppressor ground terminals. Bolted connections with star washers shall be used to insure electrical and mechanical integrity of connections to the equipment chassis.

B. Suppressors shall be installed in a neat, workmanlike manner. Lead dress shall be consistent with recommended industry practices for the system on which these devices are installed.

C. Bonding between ground terminals for power and signal line suppressors serving a particular item or cluster of equipment shall be kept as short as possible. Where practical, suppressors shall be installed in a common location for the cluster with their ground terminals bonded closely together. For installations requiring separation between the various suppressor grounds and equipment chassis within an equipment cluster, the following table shall be used to determine bonding conductor requirements (distances are measured between most distant suppressor or chassis grounds):

BONDING DISTANCE	MATERIAL
0 - 10 feet	#6 AWG Bare Copper (Solid)
10- 25 feet	1-1/2" Copper Strip 26ga. Min.
25- 50 feet	3" Copper Strip 26ga. Min.
Over 50 feet	6" Copper Strip 26ga. Min.

D. Where terminal cabinets are used to house surge suppressors, painted steel backboards shall be used to serve as a low impedance ground plane for bonding surge suppressor leads together. Terminal boards used for the same purpose shall be laminated with a single sheet of 14 ga. galvanized steel to serve as a ground plane for suppressors. Suppressors with ground terminals not inherently bonded to the ground plane through their mounting shall be bonded to this plane using a two inch maximum length of #12AWG copper wire and suitable lug. Ground planes and backboards shall be drilled to accept self tapping screws, any paint in the area of the bond shall be removed and star washers shall be used.

E. Supplementary grounding and bondingg connections required between the bonding bus or ground plane for each equipment cluster and other locations as indicated herein shall be accomplished using #6 AWG bare copper conductor and approved connections unless otherwise noted.

END OF SECTION