

Bonding & Grounding a Digital World

The most significant new issue is the cost of failure

Dan McMenamin

Dan McMenamin & Associates

63 Tattersall Drive, West Deptford, New Jersey 08051 USA

Dan@danmcmnamin.com

Abstract - The intent of this paper is to show why Bonding, Grounding and Electrical Protection are increasingly important elements of any telecommunications equipment installation and to illustrate the kinds of mistakes often made by engineers and installers deploy systems.

^[1]At the 2006 International Conference on Lightning Protection in Kanazawa, Japan, Japanese insurance companies reported \$US 5 billion in lightning-related insurance claims for the year 2000. This was three times higher than 10 years earlier. These kinds of damage claim increases are fairly typical around the globe. This author believes that the reasons for this escalating cost is that weather patterns are more disruptive than they were a decade ago, there is more electronic equipment “out there” than before and the cost of modern electronic equipment is significantly higher than that of a decade ago and the revenue losses associated with those failures is quite high.

As the world becomes a more digital place the boundaries of traditional telephone central offices stretch to cover a much wider geography. No longer is a central office constrained wire-line telecom. Fiber systems carrying digitized telecom traffic are able to reach for many miles and with that extended boundary the number of lines served from a central office can grow dramatically. A large central office might have switched traffic for 75 – 85,000 telephone lines a decade ago, or even five years ago. Now, with fiber remotes backhauling traffic from more distant areas some telcos and cellular carriers are deploying “Super-switches” capable of processing traffic for a half-million lines and more.

With the “pipe” carrying that much traffic (and associated revenues) the social and financial impact of a service lapse becomes much more costly and increasingly less tolerated by a world grown used to instant communications and nearly flawless system reliability. Further, with the expansion of cellular based wireless communications systems, the rapid deployment of Base Stations and information “back-haul” infrastructure, these systems often are installed by people with little or no formal training in the proper Bonding and Grounding of the radio systems, power plant(s) towers, antenna structures and transmission lines.

Bonding and Grounding (Earthing) remains among the least well understood science in telecommunications. This flies in the face of the fact that the key principles of Bonding and Grounding flow from well founded scientific and electrical theories proffered more than a century ago. Names like Kirchoff and Faraday are as relevant and vital to the electrical world today as are the great masters DaVinci and Michelangelo for their contributions to the art world.

This paper will illustrate the types of grounding mistakes most frequently seen today, why these are important and the correct way to resolve them. Equally important, just because a Bonding and Grounding standard changes, it doesn't automatically follow that the whole network should be rewired. This paper will illustrate the kinds of Bonding and Grounding items that should be “grandfathered” in place rather than replaced in a costly and needless upgrade.

I. WHY DO NEARBY LIGHTNING STROKES PRESENT SUCH A THREAT?

Lightning strikes do not flow deep into the earth, instead the energy dissipates across the surface. Therefore, when lightning strikes the earth it energizes a large area of soil often called a “Ground Potential Rise (GPR). Until the voltage is dissipated, this area of raised potential therefore has a much higher voltage potential than the surrounding soil. From the site of the lightning strike to a place that is totally unaffected by the GPR could be as much as kilometer or more. This area that is unaffected is called “Remote earth” for it is remote to the area of the GPR. Depending on the soil characteristics, mineral content, water content etc, the soil has a certain value of electrical resistance. Because of soil resistance, the soil therefore gives the electrical appearance of a network of series parallel resistances between the point of the lightning strike and Remote Earth as shown in Figure 1.

Picking the hypothetical values of a half million Volts and a kilometer area of GPR with respect to Remote earth, the series voltage drop across each meter of earth could be 500 Volts.

This is the reason that farm animals often succumb to lightning strikes, the so called “Step potential” or the voltage drop across the span of their legs is great enough to cause death. Indeed, in a lightning related accident near Philadelphia early this summer, a man standing in his front yard was injured when lightning struck nearby. The legs of his denim jeans burst off him in flames and torn tatters and his legs suffered serious skin burns yet the man's upper body had no damage. Step potential is the likely cause of this frightening injury.

Applying the hypothetical values in the example above to a building some 40 meters square as shown in Figure 2, the difference in potential could be some 20 KV. Obviously such voltages could cause significant injury or equipment damage unless very detailed means are employed to minimize the voltage stresses across equipment buildings and the systems within them. Bonding building columns to a buried electrode ring is one useful technique and another is to use a fairly tight concrete reinforcement mesh. In addition to strengthening the concrete floor slab, the mesh reduces the overall resistance of that area essentially providing a shunt path for the unwanted current. Often, swimming pools are protected the same way with a well grounded conductive mesh beneath the pool.

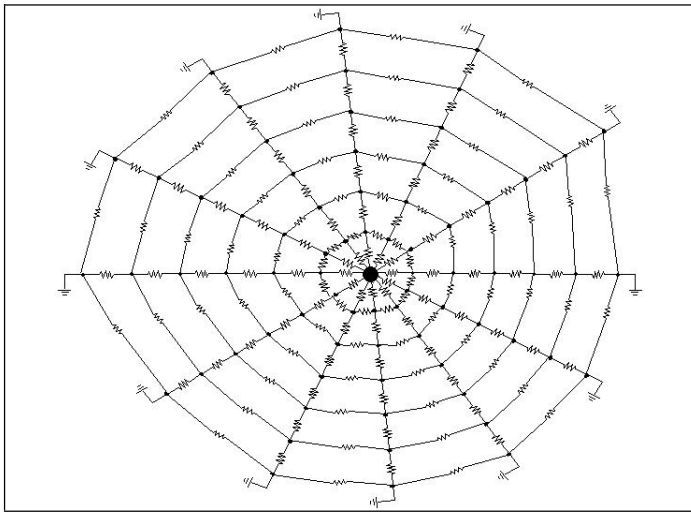


Figure 1 Example of soil resistance to Remote earth (perimeter) when lightning strikes (dot in center). The entire lightning strike potential will divide across the series-parallel voltage divider network.



Figure 2 Example of soil resistance from Fig 1 overlaid on an aerial view of a central office (circled) and the surrounding area. The lightning strike potential will divide across the series-parallel voltage divider network placing a significant difference of potential between one side of the building and the other.

Engineers responsible for central offices in lightning prone areas would do well to consider providing air terminal protection (lightning rods) to protect the investment in building and systems. ^[2, 4, 5, 6, 7, 8, 9] Properly designed and installed air terminals offer lightning currents a safe alternative path to ground and thus avoid damage. In this author's experience simple Franklin type rods, either blunt or pointed provide excellent protection when properly connected to down conductors and the earth. Franklin rods describe a type not a brand. Franklin rods are simple lightning rods and were first designed by Benjamin Franklin, hence the name.

There are alternative systems such as so-called Early Streamer Emission (ESE) systems that are touted to be an improvement over common Franklin rods. ^[11, 17, 18] Of these, the National Lightning Safety Institute and the International Conference on Lightning and Lightning Protection a large international body of professors and lightning professionals have gone on record with their belief that ESE systems are not as safe or reliable as Franklin rod type systems. The National Fire Protection Association (NFPA) includes Franklin rod systems in NFPA 780 standard and if they opt to sanction ESE systems a separate standard, ^[12] NFPA 781 would be developed. This author believes that at this time Franklin rods have been around since, well, Franklin and are well understood and present a reliable method for the protection of the central office.

Some say that lightning rods will attract lightning to a building but this is a myth and not substantiated by fact. Lab experimentation has shown that even wooden dowels are as likely to be struck as are copper or aluminum Franklin rods and so it's not a matter of attracting lightning but giving it a safe alternative path to ground thus shunting unwanted current around a structure to protect the structure and its occupants.

II. WHO YA GONNA CALL?

Lightning rod systems are well understood however the design and installation of these systems goes a long way towards establishing a level of protection. While any electrician knows how to cobble together the hardware for a lightning rod system, very basic issues such as the way a wire is routed or how it is bent makes big differences in how well the system will perform. This author has seen some very poor lightning protection work over the course of his career.

In the US, there are three affiliate organizations that should be considered when adding lightning protection to a central office or other network structure. The United Lightning Protection Association (ULPA) and the Lightning Protection Institute (LPI) both are well established organizations that set strict guidelines for the quality of a design or installation by

member companies. It is important that a US engineer specifying lightning protection for his or her project also specify that a contractor in good standing with either of these two organizations be used. Further, it is prudent to specify that the job should come with a “UL Master Label.” This means that the contractor will commission a local representative from Underwriter’s Labs (UL) to inspect and certify the installation. There are similar trade affiliations in Europe that should be considered.

III. BONDING AND GROUNDING IS NOT VODOO

Bonding and grounding precepts are a result of well established science. Unfortunately, it’s slightly different set of scientific rules than the ones governing dc electrical systems. Most people in telephony are intimately familiar with Ohm’s Law and its various applications in dc systems and line frequency ac systems. When ac is involved, the term “resistance” gets replaced by the term impedance to express how current flow is opposed by circuit conditions.

Circuit impedance is composed of a number of factors including the frequency of the ac current being conveyed. Lightning and electrical surges or line transients both have very fast rise times from zero Volts to the thousands, tens of thousands or even millions of Volts. As the frequency of the ac increases so does the reactance and impedance of common electrical components including wire and cable. Even a few extra feet of wire can raise the impedance of a wire by thousands of Ohms of impedance and degrade the performance of a surge arrestor or a ground lead. Sharp bends also dramatically increase the impedance of wire. So, protection from high frequency anomalies such as lightning and line transients is the science of keeping lead lengths short and making sweeping bends instead of sharp ones.

“Touch potential” is a term used to describe some conductive item such as a panel or motor frame that becomes energized and someone who might touch that item is in danger of completing an electrical path to some grounded part and become shocked, burned or even killed. When such items are bonded together, they are at the same electrical potential and therefore no touch potential can exist. The familiar 3-wire cords on electrical tools etc are an example of preventing Touch Potentials because the 3rd wire provides a safety ground connection to the chassis. If there is an internal fault the 3rd wire will protect the user because the housing is at ground potential and if the electrical fault is significant the feeder circuit breaker will operate.

Grounding provides a safety path capable of clearing a fuse or circuit breaker in the event that an internal fault would energize a chassis, frame or cabinet. While this seems very fundamental, it is common to visit a telephone network remote terminal, microwave hut or cell site and find that the

dc battery plant is not referenced to ground. Usually such visits are prompted by lightning damage to systems and engineers or technicians performing such work should be alert to verify that in fact the battery is in fact connected to an earth referenced ground source.

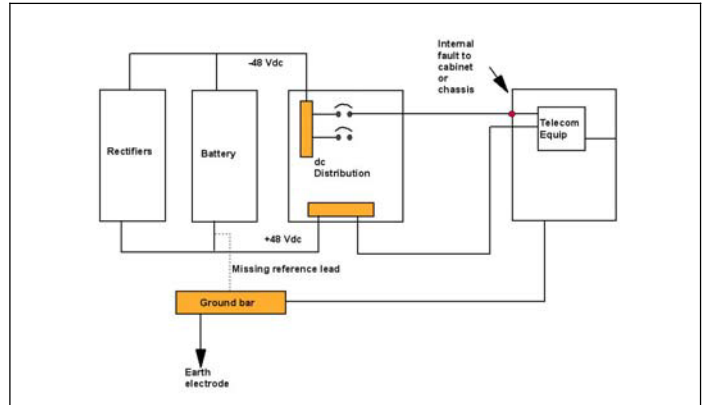


Figure 3 when the battery plant is not referenced to ground there is no fuse or circuit breaker clearing path to prevent Touch Potentials and the equipment cabinets may become an electrical hazard.

Some equipment vendors have placed greater emphasis on grounding their products because it improves performance and reduces the likelihood of damage. In addition to Framework Ground leads there sometimes is yet another bonding connection that some call a “NEBS Ground.” Cisco Systems 100CRS-1 Router is being widely deployed in Telecommunications applications and this unit includes an “NEBS Ground” extra terminal.

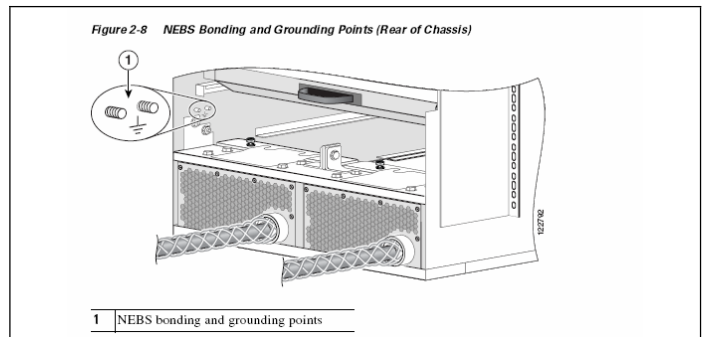


Figure 4 so-called “NEBS Ground” on some equipment types. This figure is from the CISCO CRS-1 (8-Slot version) product manual. The two units at the bottom of the equipment cage are ac power supplies, optionally, there are dc power supplies that can be inserted into these two slots.

Of significant concern in central offices today is the bonding and grounding of equipment intended for the Integrated and Isolated Ground Planes. Integrated Ground Plane equipment often has a connection between the Battery Return lead and the Framework Ground path meaning that some of the Return current is carried by the Framework Ground lead(s). Isolated Ground Planes by design do not have a connection between the Battery Return and the

Framework Ground. Having current flow in the Framework Ground leads could cause problems for Isolated Ground plane systems. Accordingly, if Integrated and Isolated Ground plane systems are in the same room there are techniques that should be followed to ensure safety and optimal performance.

^[11]Normally the Isolated Ground Plane should have at least a two inch (5 cm) separation from any metallic structure at building steel potential. If the building was to experience a large GPR due to a direct or nearby lightning strike, the Isolated equipment could lag slightly behind the GPR of everything in the building surrounding it. The reason for this lag is the impedance of the cabling connecting the Isolated Ground Plane to the rest of the building. Accordingly there could be a large difference in electrical potential between the Isolated Ground Plane and anything in the Integrated Ground Plane including building steel, HVAC equipment or relay racks and cabinets in the Integrated Ground plane. To protect people who might find themselves in a Touch Potential situation between the two ground planes there is a bonding requirement called the six foot rule (2 meter). This grounding rule demands a bonding conductor from the Ground Window feeding an Isolated Ground plane and any metallic structure in the Integrated Ground plane that is within six feet of any part of the Isolated Ground plane.

When equipment units in the Integrated Ground plane are in the same room as Isolated Ground plane equipment it is prudent to route Frame Ground leads from the Integrated systems directly to the central office ground bar or the Office Principal Ground Point Bus (OPGPB) or Master Ground Bar (MGB). The reason for this is the fact that Return current may be flowing in the Framework Ground leads of Integrated Ground Plane systems and this current flow can cause problems if they are connected to the same secondary ground bar as Isolated Ground plane systems and in particular if they share the ground lead as shown in Figure 5.

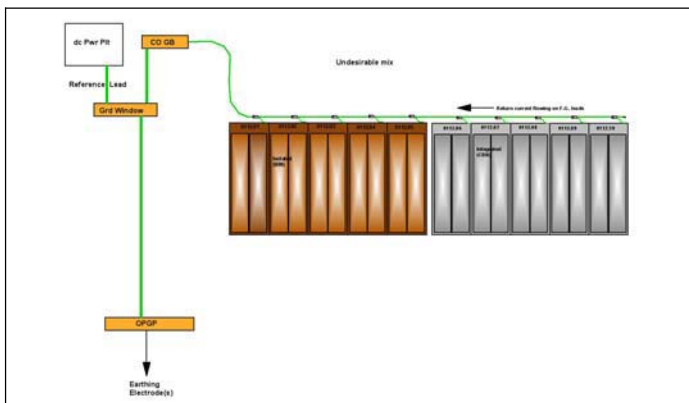


Figure 5 When battery Return current flows in Integrated Ground plane leads that current can cause problems in Isolated Ground plane equipment.

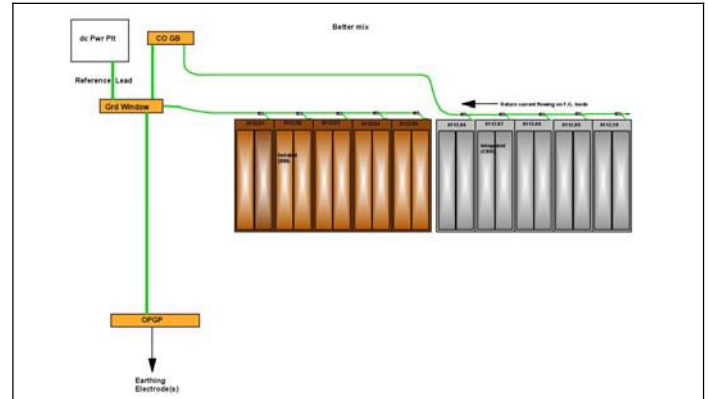


Figure 6 A better practice is to run a separate F.G. conductor for the Isolated Ground plane equipment to the C. O. Ground Bar..

This fact is not widely understood and often figures into equipment problems. Generally speaking it is prudent to minimize current flow in the Integrated Ground plane and completely eliminate current flow in the Frame Ground leads of the Isolated Ground plane as is shown in Figure 6.

Similarly, some microwave and cell site equipment is arranged so that it shares return current with the framework ground system. In such systems a large amount of the return current will be carried via the coax shield because that is a very large conductor. The current will flow over the shield to the various bars internal and external to the equipment shelter and tower. The problem is that Kirchoff's law comes into play and all parallel paths will carry a share of the return current depending on its resistance. Included in these parallel paths to some extent are the ground rods and the soil in between them. When dc current flows in this manner, there is metal loss from copper and steel components due to corrosion. The ground rods and steel components such as REBAR in concrete acts like a sacrificial anode.

Of what use is an expensive ground system if someone steals it? Global demand for electrical wiring has resulted in a huge increase in the commodity cost of raw copper. With that increase is a corresponding rise in copper thefts. At unattended electronics sites such as Digital Loop Carrier cabinets (DLCs) microwave huts, cell sites etc, the theft of copper ground bars, ground rods, exterior cabling etc. is reaching epidemic proportions.

Most telcos use copper bars and copper ground rods as a standard practice because copper is a highly weather resistant good conductor of electricity. As a practical matter, why keep replacing stolen copper with more copper? The fact is that most of the bonds and grounds for wireline telephone network outside plant cabling, tower legs, and electric utility ground rods rely on galvanized steel. Galvanized steel is highly weather and corrosion resistant and a fairly good conductor of electricity. Further, galvanized steel is

relatively cheap and unattractive to thieves. There is no compelling reason why hot dip galvanized steel cannot be used for exterior ground bars and ground rods.

With that said, there are a couple of important things to keep in mind if specifying or deploying galvanized steel grounding components. Galvanizing is a process for preventing corrosion (rust) on steel by applying a layer of zinc over the steel. Zinc is very resistant to corrosion in damp or wet environments. There are two methods for galvanizing, plated and hot dipped. Plated zinc is known to cause problems and therefore what should be specified is “Hot dipped” galvanizing per A.S.T.M. Specification A 153/A 153M-05

Also important is the issue of dissimilar metals when making outdoor connections. When metals are dissimilar and in contact with each other there is a likelihood that the metals will interact with moisture and corrode. Essentially the water acts as an electrolyte in a chemical “battery” and the current flow corrodes the less noble metal. To prevent this corrosion condition from happening it is crucial that a thin coating of a good anti-oxidation grease be applied between the lug and the ground bar or ground rod. Also, the bolts and fastening hardware should be compatible.

Aluminum bars are not considered viable because they oxidize too easily and stainless steel isn’t a very good electrical conductor. Accordingly, it’s prudent to use copper or galvanized steel for ground bars and components but not aluminum or stainless steel.

It’s prudent to get in the habit of taking clamp-on ammeter readings on the framework ground leads of digital systems before and after jobs that would add equipment or systems to those aisles or ground feeders. Taking such readings offers the opportunity to challenge equipment installers who might have installed something wrong before the job is closed out.

Another instrumentation issue when checking grounds is that digital Ohmmeters often give erroneous readings when testing framework ground leads for continuity. The reason for this is that even tiny amounts of current flowing in the framework ground leads create small voltage drops that confuse high impedance digital Ohmmeters. Old-fashioned d’Arsonval movement meters often are the best tool for testing the frame grounds of modern equipment.

One effective tool in assuring reliable bonding and grounding is the ground audit process. With that said, the company that performs the audit should not be the company that will perform the repairs. Otherwise the audit becomes a shopping list that specifies work that may not be needed. Also, the work order that hires a ground auditor should specify that the audit report should prioritize bonding and

grounding defects to identify those defects that are critical items involving safety and reliability. Another priority should be set for relatively minor defects that are a result of standards changes since the site was built. It doesn’t make sense to upgrade every little bonding and grounding nicety that later standards incorporate. There are a number of issues considered defects in today’s bonding and grounding standards that may be successfully “grandfathered” into place without jeopardizing safety or network reliability. Working from a prioritized audit report a telecom engineer can make prudent decisions about what remediation or upgrade is appropriate for a site.

For example, two-hole lugs are considered better for grounding because having the second bolt eliminates the possibility that the lug could rotate, thus loosening. Also, the second bolt slightly improves the contact resistance. These are relatively minor benefits and an engineer might wish to “grandfather” single-hole lugs if the facility isn’t undergoing a major upgrade that might justify a small but unnecessary expenditure just because a newer standard is published. If the existing bar needed replacement or had been stolen it would make sense at that time to upgrade to two-hole lugs.

Another example is mechanical connections on ground leads instead of the preferred compression lugs or exothermic welds. A properly installed connection using mechanical connections might need occasional tightening but not necessarily replacement and so it would be an engineering decision whether to upgrade to crimped lugs.

IV. SURGE SUPPRESSION

Lightning rods and well bonded soil grids protect the brick and mortar of a building as well as the people in that structure. Protecting the electronics in a central office also involves internal bonding and grounding and the use of surge. Perhaps the most familiar use of surge protection in the central office is the protector units found on the building’s Main Distributing Frame (MDF). From the early days of coils and carbon blocks to today’s solid state electronic protectors, the mission of the protector remains the same. The protector’s job typically is twofold:

A. The protector serves to “clamp” unwanted voltages impressed on the cable pairs coming in from other buildings or customer locations so that the voltage “let through” to the equipment is safe for that equipment.

B. The protector may be equipped with heat coils to protect against so-called “Sneak-currents” that could damage wiring or equipment. The heat coils will overheat and apply a ground to the cable pair to prevent the entry of the unwanted potential to the central office equipment.

The earliest of these devices, the coils and carbons served as a spark gap. If some unwanted high voltage was impressed on cable pairs, if that voltage was high enough it would ionize air in the small gap between carbons and the arcing and plasma would essentially short the excess current to ground. Later, gas tubes were developed for this purpose and some years later Metal Oxide Varistors and other solid state devices.

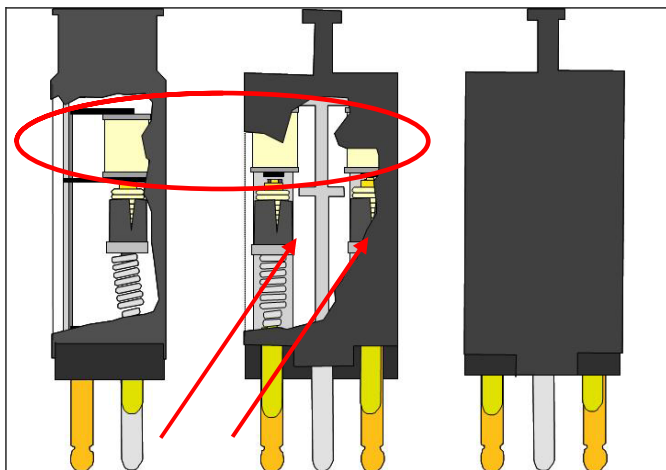


Figure 3 Protector units equipped with heat coils (arrows) and surge protective devices (circle)

It is critically important to select the proper protector for the application as can be seen in Table 1 It's a common error for equipment to be replaced in a central office without much thought as to whether the MDF protector units should also be changed. Obviously some protection is better than none but protector units also are very inexpensive devices and the device selected should be compatible with the maximum voltage that the electronic systems can tolerate without performance degradation or damage. Protector units are made with let through voltages ranging from 300 volts down to very low voltages such as 18 and even less. The protector should be matched to the equipment it will serve.

Also, the protector works by shunting excess voltage and current to ground. Quite often the ground path for the sockets of protector units is unconnected as shown in Figure 5 or poorly connected. Such conditions can degrade protector performance anywhere from impaired to useless depending on the condition. The protector socket assemblies should be connected by a low impedance ground path consisting of a wire not smaller than #6 AWG [5 mm] that is run without sharp bends to a suitable ground source in the central office.

^[13] For digital systems it is important to match the protector unit to the needed maximum let through voltage allowed through by the protector. Often, the protector units that served electromechanical or analog electronic systems are

inadequate for digital systems depending on which type line card is used. Additionally services such as Ethernet and video need the protection of lower let-through protectors.

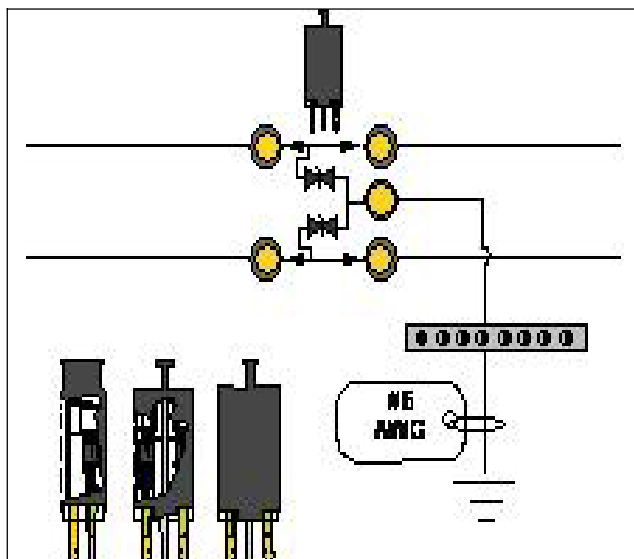


Figure 4, a protector needs to be well grounded in order to provide adequate protection

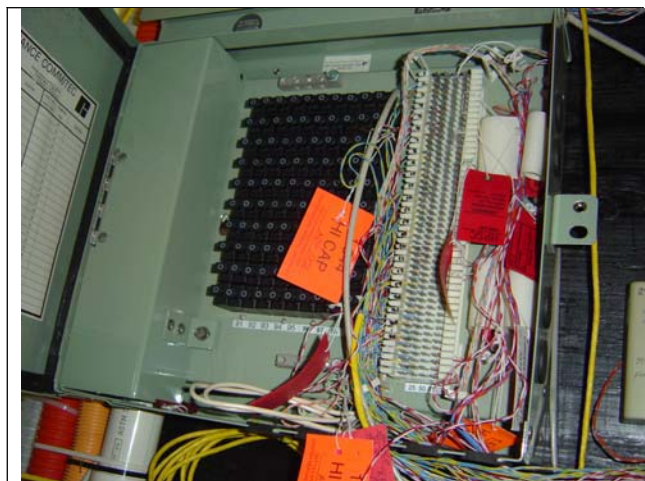


Figure 5 this protector housing has two ground blocks but neither one is grounded.

Technology	Let thru Voltage	Application
Telephony		
Carbon Block	300V	Electromechanical
Gas Tube	230V	Analog CO Line card
Solid State	240V	Digital CO Lines
Solid State	75V	Digital Line card
Data		
Solid State	18V	Ethernet
Solid State	27V	Video over UTP
Solid State	65V	Ethernet / PoE

V. TVSS

Transient Voltage Surge Suppression (TVSS) is a term that describes the use of voltage clamping devices in the path of commercial power. Like protector units, TVSS devices are designed to clamp voltage by shunting excess voltage to ground. Typically, TVSS units for ac power applications include Metal Oxide Varistor (MOV) and Silicon Avalanche Diode (SAD) technologies. MOVs tend to be more robust devices while SADs operate faster but tend to fail sooner. All solid state TVSS units are subject to failure when exposed to prolonged overvoltage conditions or many "hits" of transient voltage. As was stated previously, the clamping action of the device shunts excess voltage to ground and that energy is given off as heat within the TVSS device. Over time the solid state device breaks down and burns "open," thus no longer offering protection and is in need of replacement.

Where do the transients come from? The short answer is nearly everywhere. Lightning striking the commercial power grid can impose transient energy onto the electrical distribution system. Geo-magnetic storms on the sun are known to bathe the earth in huge magnetic fields that induce energy into long runs of power line and introduce significant transients into the line. Electrical distribution equipment such as power factor correction capacitors and transformers being switched in and out of the grid also produce transients on the line. All of these come riding in as unwanted guests of the power company. In addition to these anomalies, magnetic devices such as motors come on and off in a facility the magnetic fields of those motors also introduce transients onto the electrical distribution system. So, electrical transients might enter a facility from the power grid and they might also be generated deep inside the building as motors driving compressors or large fans in the Heating Ventilating and Air Conditioning (HVAC) system, a cable air dehydrator, a large office photocopier or even the refrigeration unit of a water cooler cycle on and off.

Due to the high cost of equipment damage and even higher cost of lost revenues, it makes good business sense to provide a reliable level of TVSS protection for the central office. Generally TVSS devices are grouped into three broad classes of device called categories A, B and C.

- Category C is for service entrance installations. This includes devices installed outside the building or as the power enters the building near the service disconnect, or for runs between the meter and distribution panel(s).
- Category B includes major feeder and short branch circuits, such as distribution panels more than 30 feet inside the building, or lines that are run for heavy appliances.

- Category A includes branch circuits and all outlets more than 30 feet from Category B with wire size ranging from #14 AWG to #10 AWG.

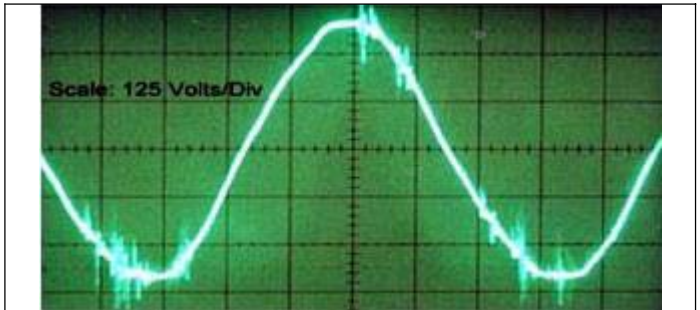


Fig 6 150V peak to peak line transients or "spikes" riding a 60 Hz sine wave

Because line transients are very fast rise-time anomalies they have a long needle-like appearance on an oscilloscope and often are called "Spikes" for that reason. Due to this sharp rise time the electrical energy in the transient behaves the same as electrical energy of any source frequency having the same rise time. In other words, transients behave like high frequency events and therefore even relatively short lengths of wire between the TVSS and the line it is protecting or between the TVSS and ground, have impedance and as the impedance increases so does the let-through voltage that passes by the TVSS device into the protected paths. Excessive lead lengths therefore degrade TVSS performance.

The time was when data centers followed TVSS coordination for all three categories of device whilst most central office electrical design incorporated only a Category C devices on their commercial ac input at the Service Disconnect (Mains). With more critical services now hosted in central offices and more transient generating sources entering central office space it now makes sense to coordinate TVSS protection deeper into the electrical distribution system than previously was considered necessary. Category B protection on panels more than thirty cable-feet into the central office now make practical sense. Also, it makes sense to provide a Category C TVSS for the standby generator as well. The reason for this is that for the relatively minor cost of a TVSS device, either the commercial ac control and distribution system or the generator and its controls are at risk of damage. Why risk either one when either or both could cause problems during a thunderstorm?

^{14,15, 16}It is critically important that those selecting TVSS devices insist on units that pass UL-1449. There are any number of cheap devices on the market that lack the "fail-safe" operation of surge suppression components contained in these devices under abnormal service conditions or "end-of-life" degradation modes specific to metal-oxide varistors.

This is particularly problematic in Category A devices especially when TVSSs are incorporated in multi-outlet terminal strips common to office personal computers and similar installations. When MOV devices are subjected to long-duration overvoltage such as might occur if a Neutral lead goes open the MOVs burn catastrophically. The provisions of UL-1449 demand that such devices fail safe. In the past 18 months, this author has investigated two incidents where cheap surge suppressor strips initiated collateral fires from burning MOVs in the strips.



Fig 7 Cheap consumer grade devices with TVSSs not conforming to UL-1449 may initiate collateral fires when their MOVs burn up due to electrical fault or end of life.

VI. CONCLUSIONS

Bonding, Grounding and Electrical Protection are just another skill set to be learned by people having responsibility for telecommunications and data center systems. The rules and formulae are somewhat different from those of electrical systems based on dc and low frequency ac but they still are valid science. Attention paid to proper Bonding, Grounding and Electrical Protection reaps rewards in system reliability and an improved bottom line. Conversely, poorly grounded equipment will get you in the end.

REFERENCES

- [1]. Short Report on the 2006 International Conference on Lightning Protection Kanazawa, Japan - National Lightning Safety Institute
- [2]. NFPA780 Standard for the Installation of Lightning Protection Systems (National Fire Protection Association)
- [3]. NFPA781 (Proposed) (National Fire Protection Association)
- [4]. UL 96A Installation Requirements for Lightning Protection Systems (Underwriters Laboratories)
- [5]. LPI 175 lightning Protection Standard Practice (Lightning Protection Institute)
- [6]. BS665 British Standard for Lightning Protection
- [7]. NFC17-100 Lightning Standard (France)
- [8]. IEC 62305 Protection Against Lightning (2006)
- [9]. GB 50057-94 Design Code for Lightning Protection of Structures - National Standard of the Peoples Republic of China
- [10]. Cisco CRS-1 Carrier Routing System 8-Slot Line Card Chassis Site Planning Guide
- [11]. GR-295 Mesh and Isolated Bonding Networks: Definition and Application to Telephone Central Offices Nov 2004 (Telcordia Technologies)
- [12]. A.S.T.M. A 153/A 153M - 05 Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware American Society for Testing and Materials (ASTM International)
- [13]. Communication / Data Protection Guide - Lightning and Surge Protection for Comm/Data Networks - April 2007 Porta Systems Inc.
- [14]. IEEE C62.41-1991 standard for TVSS protection applications
- [15]. UL 1449, the Standard for Safety for Transient Voltage Surge Suppressors
- [16]. A New Approach To TVSS Design - Roy B. Carpenter, Jr., Mark N. Drabkin, Ph.D., Lightning Eliminators, LLC
- [17]. Experimental Validation of Conventional and Non-conventional Lightning Protection Systems - William Rison, Member - IEEE.
- [18]. A Critical Review of Non-Conventional Approaches to Lightning Protection - M.A. Uman and V.A. Rakov University of Florida - Pub: Proceedings - American Meteorological Society, December 2002