Grounding and Bonding

Advances in the Telecommunication Environment

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Abstract

The purpose of this paper is to provide a better understanding of grounding and bonding requirements within the Telecommunications Facility Environment. This paper also provides insight to the more recent recommendation of the International Telecommunications Union document entitled “ITU-T K.27 Protection Against Interference, Bonding Configurations and Earthing inside a Telecommunications Building”, released in May, 1996. These recommendations make the Telecommunication Environment more reliable in protecting against harmful interference from transient sources of disturbance and upset. Because digital communications formats have largely replaced the analog forms we must consider the increased digital bandwidth of this equipment. These greater bandwidths have increased the potential for interference from transient sources that would be caused by Lightning, Induction, and Transfer impedance functions of system power and digital signal cabling. Following this recommendation will greatly improve the reliability of the Telecommunication Environment by providing improved immunity to these effects. The better the grounding and bonding practices are understood and applied the better the overall system reliability.

Background

When the Telecommunication Digital revolution started about fifteen years ago, there were large numbers of Analog systems installed throughout the Telecommunications industry. The challenge was to integrate these analog systems with the ever-increasing popularity of digital systems. Digital systems were growing in popularity due to the ability to reconfigure the systems with software changes making for greater digital flexibility and providing the basis for virtual networking. This digital technology provided for greater management of the network configuration to handle the traffic demands placed upon the network system with greater effectiveness. Different digital network interfaces could now be translated and linked to each other regardless of their type seamlessly. But with this ability came demands on interconnection of these digital and analog systems. Digital and analog interfaces that were not originally designed to be fully compatible with each other now had to meet the grounding and bonding requirements of the telecommunications environment. For many years the analog systems took a totally isolated design approach to prevent ground loops from occurring. Many of the analog interfaces for voice needed this protection to prevent power line frequencies from inducing hum on the analog baseband signal. This works for the analog signal to prevent hum from occurring on the voice signal but does not optimize the digital signal path due to loop areas resulting from the analog isolation philosophy. So this is and will remain the issue until these new methods are adopted to provide the ultimate connection integration and interconnectivity. This is a key issue in improving immunity and reliability.

A look at Impedance Control Models

Impedance is not to be confused with DC resistance. Impedance is only to be considered here as a dynamic of an AC, Pulse, or Transient event as applied to the parasitic behaviors of building system Capacitance and Inductance. Every foot of wire represents a finite amount of inductance and capacitance and therefore when compared to some frequency and current of excitation results in a defined amount of voltage drop. This is what we should be concerned about when we start to define a building or system ground conductor length.

A high-bay building typically represents 4.5 meters (15 feet) per story. So we can consider one end of the grounding conductor, used as a single point ground, connected to earth ground and the other end not connected at all, or totally isolated. This is equivalent to a quarter wavelength at 17MHz because that would be the resonant frequency of this 4.5 meter ground conductor length when it is only connected to earth. In a quarter wavelength the impedance of a #0000 conductor can represent 1500 Ohms of reactance. This impedance is very high if you are expecting a very effective earth ground reference for lightning protection. The reason for this is because this #0000 conductor is very thin compared to its length and looks like a freestanding antenna system radiator attached to a ground plane or earth reference. In one-quarter wavelength the radiator can represent from zero impedance at the ground reference end, to 1500 Ohms at the free standing end. This simulates what a one-quarter wavelength vertical antenna represents. The normal Bandwidth of vertical antenna is approximately 2.5% of its center-frequency. If we multiply 17 MHz by 2.5% we see this represents 0.4 MHz of Bandwidth. If we divide the 17 MHz center-frequency by 0.4 MHz bandwidth we see that the “Q” of the antenna is approximately 42. If we consider a “Q” of 42 and multiply it times the input impedance of the equivalent ground plane antenna, which is approximately 36 Ohms, we see a result of 1500 Ohms. (These are reasonable approximations and they are not exact)

$$Q = \frac{F_r}{B_w} = 42$$

By using the resonant antenna behavior and the resulting bandwidth we can quickly see that the transfer impedance at the tip of the antenna (furthest away from ground) is close to 1500 Ohms of reactance. This is a perfect illustration as to the reactive impedance, due to a wire length, that can result from just wire length alone as a free space radiator. This should cast new light on how we consider grounding structures.

Frequency of Resonance Modeling

Note: Wire represents approximately 10 nH per Inch, or 120 nH per foot. In the two story high-bay building, that we just reviewed, this length would be approximately 1.8 uH. Resonant behavior for the 15ft-wire length (4.5 meters) can be calculated. The inductance for this 15-feet of length was 1.8 uH. The capacitance for this wire is 48 pF for 15 foot. The calculated resonance of this is 17 MHz.

$$F_r = \frac{1}{2\pi \bullet (LC)^{.5}} = 17\text{ MHz}$$

$L = 1.8\mu H$ (ground conductor length)
$C = 48$ pF (ground conductor capacitance)

Transient Energy Modeling

Another method would be to consider the following approach which is more related to a power systems design approach.

$$V = L \bullet (di / dt) = 150{,}000\text{ Volts}$$

$L = 1.8\ \mu H$ (4.5 meters of #0000)
$di = 100{,}000$ Amps (lightning direct building strike)
$dt = 1.2\ \mu S$ (lightning stroke transient time)

Frequency of Reactance Modeling

This method just looks at the Inductive Reactance of the FFT of the 1.2 μS rise time.

$$X_L = 2\pi FL = 3.0\text{ Ohms of reactance}$$

$L = 1.8\ \mu H$
$F = 265$ kHz (FFT of 1.2μS lightning pulse)

Lightning Behavior

Lightning effects are very unpredictable at best because of the unknown characteristic of the structure it is striking and the exact amount of lightning generated current. But the normal approach to system design for lightning mitigation is to convert the lightning characteristic from the time domain to the frequency domain.

The Fast Fourier Transform is used to make the conversion from time domain to frequency domain. This provides for a better understanding of the lightning components and their behavior over the frequency spectrum. We will use the 1.2 μS rise time and the 50 μS decay time pulse. This will enable us to use an analog approach of the frequency bandwidth characteristics to further consider methods of mitigating this lightning threat to the systems.

The rise time is the first component:

$$\text{FFT} = \frac{1}{\pi t_r} = 265 \text{ kHz}$$

$t_r = 1.2\ \mu\text{S}$ (rise time component)

The second component is the pulse width added to the rise time:

$$\text{FFT} = \frac{1}{\pi (t_r + \text{PW})} = 6 \text{ kHz (PW + rise time)}$$

$t_r = 1.2\ \mu\text{S}$ (rise time component)

PW = 50 μS (decay time component)

Note*: Most of the distribution of energy will be from the peak of the rise time because it represents the highest frequency component and therefore the most reactance. It also contains the most peak energy due to its rise time. This rise time frequency component will be dominant.*

This example shows that most of the lightning energy is contained between 6 kHz and 265 kHz. This is a relatively small segment of the frequency spectrum. This energy would fall off at the log ratio related to the frequency component. *These examples are only considering single stroke events. There are multiple stroke events usually that can be very important when the overall heating power is to be considered.*

We can compare the out of band energy transfer that can occur while in the frequency domain by simple using the ratio of the two frequencies to be compared. In the earlier example we used 17 MHz for the 4.5 meter high building structure. We can now ratio 17 MHz to 265 kHz to determine the attenuation of the original energy bandwidth to the out of band building structure.

$$\alpha = 20 \log_{10} (F_1 / F_2) = -36 \text{ dB}$$

F_1 = 265 kHz (rise time frequency bandwidth)

F_2 = 17 MHz (resonant frequency of the structure)

This demonstrates the amount of attenuation that occurs at 17 MHz from the source frequency of the lightning energy at 265 kHz. This numerical ratio is 63 to 1. This means that only 1.6 % of the energy will be seen at the 17 MHz structure resonant frequency.

The overall heating power is measured in Joules of energy or Watt Seconds. This is derived from the following.

$$J = P \bullet P_w \bullet = 15 \text{ Joules}$$

$$P = I^2 \bullet R = 3^5 \text{ (based on 3 Ohms and 100,000 Amps)}$$

$$P_w = 51.2\ \mu S \text{ (pulse width plus the rise time)}$$

P = Power P_w = Pulse Width 50% plus the rise time

Note: *In the above example it would require a total of 52 dB of power attenuation to reduce the energy to a system safe level of 100 μJ.*

Circuit levels below 100 μJ is considered to be a safe level of heating power. Above this 100 μJ level integrated circuits can be damaged. Punch through and thermal effects are at the threshold level of damage when the 100 μJ point is reached. The internal system design of decoupling at the circuit board level and at the system cabinet level will mitigate most of the threat from causing damage. But this is only true if the actual system level of EMC integrity is known and has been tested properly at the product qualification stage.

All of the above review leads us to addressing these issues and how they relate to the International Telecommunications Recommendations. These ITU-T, K.27, Annex B, recommendations are aimed at the environment that the telecommunication systems will be placed in. Outside of a protected environment most equipment would not survive because the environment would be too harsh and the equipment would lack the necessary design considerations. The system host environment must be just as responsible for the design of the system environment, as the system designer is for the equipment design.

ITU-T, K.27, Appendix B

Should the equipment be mounted other than on the ground floor (earth floor) then the path to Earth would have a large inductance associated with it. If we elect we can run parallel conductors to earth. As we run inductors in parallel we can effectively reduce the overall reactive impedance of the structure. This is known as Multi-Point Grounding or a Mesh Bonding Network. This reduces the loop area that the current is circulated in and reduces the impedance by reducing the loop areas. Overall effect is that the structure and the current being distributed in the structure is shared by many paths to ground that are smaller in loop area thereby reducing the current density at anyone point.

This is what essentially is being recommended in the ITU-T, K.27, Bonding Configurations and Earthing Configurations inside a Telecommunication Building, document. The Meshed Bonding Network illustrated in Annex B is the one that offers the most protection.

In the opening of Annex B, paragraph B.1, States; " A mesh-BN (mesh-Bonding Network) is a densely interconnected BN in which equipment frames are an extension of the CBN (Common Bonding Network). In this example, which is shown in B.1, the d.c. power system is of type C-MBN (Common-Mesh Bonding Network)."

In paragraph B.1.1 it further states; "Multiple interconnections between CBN and each d.c. return along its entire length is usually a feature of the mesh-BN configuration. The d.c. return conductor of such a configuration may be entrusted with functions of protective conductor (PE) for systems associated with a.c. loads or sockets, provided that continuity and reliability complies with the IEC Publications."

Paragraph B.1.2.2, further states; " Telecommunication equipment with electronic circuitry is generally provided with a *potential reference* metallization that extends widely over the surface of the Printed Circuit Board (PCBs). If PCBs are connectorized, a number of pins are used to interconnect adjoining cabling, backplanes, or motherboards. At this interface there starts the interconnection to the mesh-BN via equipment frames, shelf-racks, etc.

The equipment racks shall be interconnected by low impedance leads or copper bars. Since the mesh-BN technique usually incorporates the d.c. return conductor into the CBN, the leads or bars can serve as the d.c. return. The leads or bars of each row have to be interconnected via the shortest route to minimize the inductance. One or more d.c. return conductors may be used to interconnect the system to the centralized common power distribution cabinet or an intermediate power distribution panel. It is recommended that these leads be paired in close proximity with the corresponding negative d.c. power feed leads to reduce the loop areas and enhance EMC. Small gauge d.c. power conductors should be twisted."

Mesh-BNs are known to give satisfactory EMC performance. Ground planes installed as a common bonding mat for all of the systems is recommended to further improve EMC performance. Because the Bonding Mat (ground plane) represents the lowest possible inductance bonding method that can be utilized to reduce the overall bonding impedance.

Note: *Ground Planes are often required to establish a local ground reference. In many areas of the world there does not exist enough ground water or minerals to establish a good earth ground. These areas are arid and need supplemental structures to establish reference grounds that are low in impedance. In California and other areas of the world utility companies utilize UFER grounding systems. Utility Foundation Earth Reference (UFER) is established by electrically bonding all of the foundation footer reinforcement steel together. This is both a capacitive and conductive means of establishing the lowest possible Earth reference impedance for building grounding system in a low water table area. In the K.27, Figure B.1, document all of the metallic structures of the building are tied to each other to bring as much mass together as possible to establish the lowest ground reference impedance.*

Figure B.1/K.27 is an illustration of a multi-floor building which shows all of the building steel, support columns, ground planes, battery plant, a.c. neutrals, protective earth, cable racks, wire trays, d.c. returns, all being commonly tied together in a mesh bonding network, utilizing multiple points of connection to reduce the overall impedance of the bonding structure. This is analogous to a wire Faraday cage being fabricated in place utilizing the system and building structure.

Standard wiring practices are still followed to minimize the voltage drop of a power distribution. A 2% voltage drop is still recommended practice so that the distribution of power and return conductors can be optimized. 2% of 48 Volts D.C. Telco battery is about 1 Volt, and this is a good design criterion. This will minimize the differential frame to frame voltages and allow for better interconnectivity with less concern for potentials between equipment frames. This also improves the bonding impedance between frames assuring the lowest impedance path possible.

Return and Earthing Conductors

In the scheme of modern designs there is a need to connect the Return conductor and the Earthing conductor at the equipment frame. This provides a parallel path and when properly installed the Earthing conductor will conduct half of the return current. This is acceptable from a

Safety standpoint so long as the Earthing conductor has been sized to carry the full default current should the Return conductor open. This is still a point that has been argued by many people with the Analog Isolation experience, but is fully supported by Safety Agencies. The Earthing conductor is the conductor of concern here because it will have to carry the branch current for the Return conductor should the Return conductor open or be disconnected. The 2% voltage drop applies here. The return conductor may be opened for a service issue or may be opened inadvertently by natural causes due to earthquakes. The advantage of having both conductors in parallel supports redundancy and reliability.

Note: *The unrealized problem with isolated single point grounding approaches is that the parasitic capacitance and the parasitic inductance that exists between the isolated grounds still close the loop area. Current will flow in the isolated ground conductors at high frequencies regardless of the isolation attempt due to these parasitic effects. Remember that a quarter wave antenna still has current flowing in its structure even though the free end of the antenna is not connected to anything except the “”space” it is in.*

The reason for the Return conductor being tied to the Frame of the equipment is that it eliminates the isolation components required to filter the d.c. Return at the input of the equipment. By doing this it improves the immunity to transients that may otherwise find a path into the equipment on the d.c. Return. All things being equal it reduces the effective impedance of the d.c. input filtering network by 6 dB. It also eliminates all of the filtering components from that side of the filter. It eliminates all of the parasitic behaviors of those components, which have been removed from the d.c. return circuit. It reduces cost and improves reliability by component reduction alone.

Special Note

In the distributed 48 V.D.C power systems design, of systems today, the 48 volt d.c. to d.c. converters are located on the individual system cards. This means that 48 volt d.c. is distributed throughout the back plane of the system so it can power each of the system cards that plug into the back plane. This means that the 48 volt d.c. power must be filtered and clean of any transients that could couple or crosstalk with the active signals that are also distributed in the back plane. Should this transient coupling or crosstalk occur then the active signals in the back planes would be corrupted. It is for this reason that the Ground Planes within the back plane structure be directly grounded to the Frame of the equipment. The D.C. Return is also bonded internal to the backplane so that the internal Ground Planes and the D.C. Return are bonded within the backplane to offer the lowest possible impedance path to Frame Ground through the card cage. This is the best protection to transients for broadband forms of interference that can be offered from an EMC viewpoint. Using this approach eliminates the frequency dependant behavior of the by-pass capacitors that would be required to isolate the ground plane structures from the frame. This assures the lowest possible bonding impedance between the ground plane structure and the frame ground. This also makes it impossible for the D.C.Return to be isolated from Frame Ground (Protective Earth). This is what is recommended in the ITU-T K.27 document.

Private Site Environments

Many proposed installation sites do not have the additional protection of a Telecommunication Facility that has been designed around the GR-1089 Bellcore or ITU-T K.27 documents. In such an environment the need does still exist for the equipment to survive the transients of Lightning or Induction effects. This places extreme demand on the equipment to survive even more severe exposure to these threats. The equipment must be designed to withstand these environmental effects and remain reliable in their functional application. Most of these systems will not have the advantage of battery plants and the additional transient protection they provide. The local utility companies will power most of these A.C. systems.

The private site locations are not designed to control the Mesh-Bonding Network impedance. In the power distribution, grounding, and interconnecting cabling of these systems large loop areas will be formed. These large loop areas will allow for the ingress of transients. It should not be believed that the Telecommunication Facility and the Private Customer Site are equal in design or in the system protection they provide, for they are not.

Some of these sites will be situated in older wooden buildings with little or no grounding structures at all. In such situations the ground floor, nearest Terra Firma, is strongly recommended for the location of this equipment. Remember we are not just plugging in an electric shaver, we are connecting a very sensitive piece of communication system equipment. This communication system is expected to perform at least to five 9's of reliability. Every effort should be made to assure that the customer and his site are surveyed and the necessary recommendations are made to prep the site for reliability. This will assure us that the reliability issues do not turn into liability issues, and a very unhappy customer.

Wireless Environments

With the advent of wireless communication comes the challenge of mixing wireless, analog, and digital. Digital noise that is generated by all digital systems must be kept from interfering with sensitive radio receivers that are being used in wireless communication systems. The rich harmonics that are generated by digital processing devices certainly represent sources of 400 and 800 MHz processing mixed with wireless equipment that is operating in the 800 MHz to 35 GHz range. ITU-T, K.27, still plays a large roll in reducing transients from lightning and other threats from causing upset or immunity issues. Bonding and grounding of enclosures and cable terminations for these wireless systems is paramount in preventing intra-system and inter-system forms of interference resulting from radiated or conducted emissions. A 100-watt transmitter at a cell site can be a sizable threat to a microprocessor-based piece of telecom equipment doing the copper to wireless interface for a networking application. Immunity to this 100-watt transmitter on site can be a problem if not properly managed. Likewise, if the unintentional radiation from the microprocessors in the digital telecom equipment gets into the input of a cell site receiver system it can be very disruptive to data flow. The receiver has an input sensitivity of about one-quarter of a microvolt. With the receiver being this sensitive it will not take much to interfere with it.

Conclusions

Many current engineering practices should be reviewed for their content and revised because they have outlived their usefulness. A fresh look with the full vision of the future and the need for the ever-increasing bandwidth should be the first order of business. We should not be waiting for the problems in the field to push the technical installation practices and argue over who is right. Instead, we should be planning the analog and digital integration process ahead of the field liabilities. This will go a long way to instill the necessary confidence that our users and customers are expecting.

Biography: Ralph P. Trefney received a BSEE from Fenn College, Cleveland Ohio in 1962. Ralph has extensive RF designer experience in antenna, active, passive, digital, and high-speed printed circuit board design. He was Head of Filter/Coupler Engineering for Bird Electronics in Solon, Ohio. Ralph is currently employed at Cisco Systems, Inc., San Jose, where he is responsible for Electromagnetic Compatibility Design. He started his career in EMC work in 1979. He holds four patents in RF Communications and related fields. He is a 25 year member of the IEEE, the IEEE EMC Society, and is a member of the National Association of Radio and Telecommunications Engineers. He is a NARTE Certified Electromagnetic Compatibility Engineer with 20 years of experience in the EMC field.