

It's About Money (Well, That and Grounding) Holding Your "Ground" in an Old New Environment

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Abstract

This is to explore the hotly debated issue over whether cellular, ATM or other new-technology telephone switching systems should operate in the isolated ground plane or the integrated ground plane topologies.

Many engineers believe the Integrated Ground Plane is more robust than the isolated ground plane and, thus, next technology switches should be integrated. The reasons stem from poor performance often experienced from Isolated Ground Plane systems during lightning events as compared with Digital Cross-Connect (DCC) and other systems residing in the integrated Ground Plane.

Another camp would take the Integrated Ground plane to the next level, the Mesh Bonded Network, literally a fortress of low impedance.

And finally, a large body of engineering talent would assert that all telecom network systems – switching and transport perform better in Isolated Ground Planes.

The issues are at least as emotional and political as they are technical. There is, however, middle ground within this nettlesome debate because both camps employ numerous techniques to improve the reliability of electronic systems. And – electronic systems increasingly are built to the same standards whether they are destined for either ground plane.

The paper will explore backgrounds, trends and generally accepted engineering principles and offer a pathway through this issue.

It's About Money (Well, That and Impedance)

Money rules the telecom world and the not-so-secret secret to making money lies in building systems that reliably earn oodles of the stuff without biting too deeply into the money supply for deployment, maintenance or downtime.

That's where impedance comes in. The key to safety and system reliability is a low impedance path between system elements and in the path to ground. Some journals speak to well-designed systems as an equipotential plane. In other words, one in which all chassis parts of the system are at or near the same potential. Basically, that speaks more to bonding than it does to grounding.

Most engineers know that effective bonding is far more important than grounding although both are important.

Aircraft, spacecraft and the like employ sophisticated electronics and operate quite well without earth grounds even

in the presence of lightning, radiation and other hostile electrical and magnetic forces.

The list of reasons to spend money on grounding improvements usually cite items like

- Safety
- Reliability
- High-frequency processors
- Lower logic-voltage levels

Since lightning and transients are the most destructive events against which effective grounding is supposed to protect, it's important to make some alternative robust and relatively inexpensive path look more attractive than the expensive electronics. For example, telcos have added GPS systems to supply timing for their transmission circuitry. In many cases the GPS antennae are higher than the lightning rods – perhaps a costly mistake.

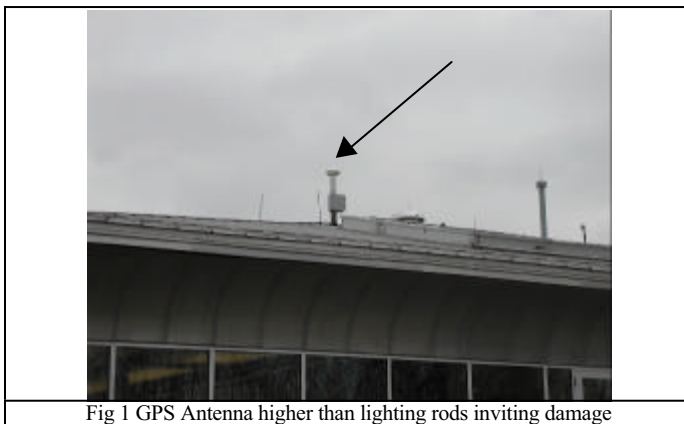


Fig 1 GPS Antenna higher than lightning rods inviting damage

It's About Money (Well, That and Immunity)

It's probably a good idea to be thinking about how RFI/EMI immunity plays into this broad picture. Network equipment environments are awash in broadband electrical noise. While lightning is a huge source of unwanted electrons so are power leads – particularly ac power, conduits, lights, nearby neon signs, radio transmitters, transformers, vehicle ignition systems and just about anything else that produces a spark or an electron flow. Accordingly, shielding critical systems, bonding and other techniques as are described herein are critically important. For many installers and service providers, the simple negligence of leaving equipment covers off the equipment leaves the system open to EMI problems.

It's About Money (Well, That and Training)

While there are some well-trained and skilled installers out there, they are no longer the majority. Almost no one has invested the training to produce well-rounded installers building well-grounded systems. Most fall into two broad categories.

Installers who know a collection of grounding rules with little or no idea what those rules are about, why they exist or when to follow which ones; and,

Installers who haven't a clue about grounding network equipment and look to their clients to specify and direct their work.

Many engineers fall into these categories also, and for the same reasons – no one has invested that training in them.

Since there are so many installation technicians out in the universe and training will remain a back-burner priority for most, effective solutions to grounding problems should incorporate to the extent workable those procedures and practices to which they already are accustomed.

In other words we should follow the rules and at the worst bend and reshape those rules where necessary to build robust systems within technologies already understood at some level by large numbers of engineers and technicians.

It's About Money (Well, That and Evolution)

Until the mid-1960's telephone switching systems, basically were electromechanical with electronics built into transmission systems. About 1964, the sands shifted. More correctly, someone melted-down that shifting sand and built silicon computer chips. The Bell System was under the cold stare of anti-trust lawyers anxious to prevent them from entering the computer business, but not from building computer devices for telephone switching applications.

Calling their system a "processor" rather than a computer together with some other legal posturing managed to fend-off the lawyers for some twenty years and the Western Electric #1ESS became the first US stored program control systems using electronic processors to control peripheral devices for telephone switching.

From a systems architecture perspective, these changes were more evolutionary than sweeping. The peripheral circuitry of a #1ESS wasn't terribly different architecture-wise from that of it's electromechanical predecessor, the #5 Crossbar system. Nor was the Nortel (Formerly Northern Telecom) offering, the DMS-10.

Improvements to these systems cranked out of Bell Labs and Bell Northern Research regularly and the systems

evolved in speed, features, capacity and hardware miniaturization.

Early in the #1ESS program, Bell Labs engineers discovered that their systems were experiencing an alarming susceptibility to direct building and nearby lightning strokes. About the same time, the computer industry was learning that it had problems also. If the cabling came in one end of a computer room or telephone switch and out another, then a difference in potential between one side of the room and another could damage whatever circuitry lie in-between.

The obvious fix was to reduce the difference in potential by introducing cables from only one side of the room. In the case of power leads, Bell Labs grounding engineer the late Bob Beckley opted to use the cabling "window" concept being used by the computer industry and take it a step further. The "Ground Window" was born. By bringing all battery and return leads into the switching system from one side they eliminated series paths for unwanted currents through the switch. By locating battery and Battery-Return leads close to each other, they achieved a high degree of magnetic coupling between the leads that tended to reduce noise that might be induced from one cable to the next.

Another important part of the "fix" was to establish Horizontal Equalizers – a network of splice plates bonded together by 750 KcMil cables. This system helped to reduce differences in ground potential within a switching system. The addition of a Ground Window and Horizontal Equalizers became a major retrofit to #1ESS systems around the United States. As a result of this new grounding system a new practice was needed to cover Isolated Ground Planes and Bell System Practice BSP802-001-195 was issued to meet that need. Some years later Telcordia (then called Bellcore) rewrote the BSP as a Technical Reference TR-NWT-000-295.

It's About Money (Well, That and Standards)

Of the numerous documents that address grounding standards engineering for network equipment the most recent is Issue 2 of the Bellcore TR-NWT-000-295 practice, covering Isolated Ground Planes, and dating from 1992. The documents covering Integrated Ground Planes all date from 1973 to 1975.

The documents that describe equipment design and performance issues such as NEBS physical and electrical protection criteria are more up-to-date. Another document keeping pace with technology is in the area of Installation Standards.

Do telephone companies really want the standards updated? One provision of the Telecommunications Act of 1996 would require that anyone willing to fund-into the process may influence the outcome of a standards document

revision. There is great fear among telephone company engineers that in updating the standards equipment vendors might permit themselves to produce a less robust product by watering down the standard.

Many engineers believe, therefore, that any new system developed should meet the requirements of existing standards so that the industry can avoid making a huge and time-consuming investment in engineering standards.

Lately, equipment designed for the Integrated Ground Plane looks an awful lot like equipment designed for the Isolated Ground Plane.

This is because systems built in the past several years are built to the relatively up-to-date GRs covering NEBS and related matters. In other words, transport systems might be installed in the integrated ground plane, but for the most part they are built to Isolated Ground Plane standards. Many systems are designed for installation in either plane with only slight variations in installation.

Vendors have learned that most equipment works more reliably when Battery energy returns on the Battery Return lead rather than divided between the Battery Return leads and the framework.

This is because framework grounds are intended to carry fault current if a feeder was to short to ground. This massive current could “Bobble” the voltage seen along the framework and if equipment was returning power on framework the voltage variation would be that much greater.

It's About Money (Well, That and Simplicity)

The late Frank Hubeny (Bell Labs) referred to ESS Grounding as “*Isolated - Integrated*” in a 1980 Bell Labs training video. He went on to describe this as a group of frames well-bonded or *Integrated* together and Isolated from contact with building steel.

In the same video, Hubeny described Integrated Ground systems as those in which power flowed to equipment frames on a Battery lead and returned to the power plant on both the Battery Return leads and the framework elements whether intentionally or incidentally bonded to each other. While some companies build systems that can return current on framework, this rarely is done anymore and is not considered a reliable engineering practice.

There is concern that large currents in the framework ground system may result in damage to underground structures through catalytic corrosion.

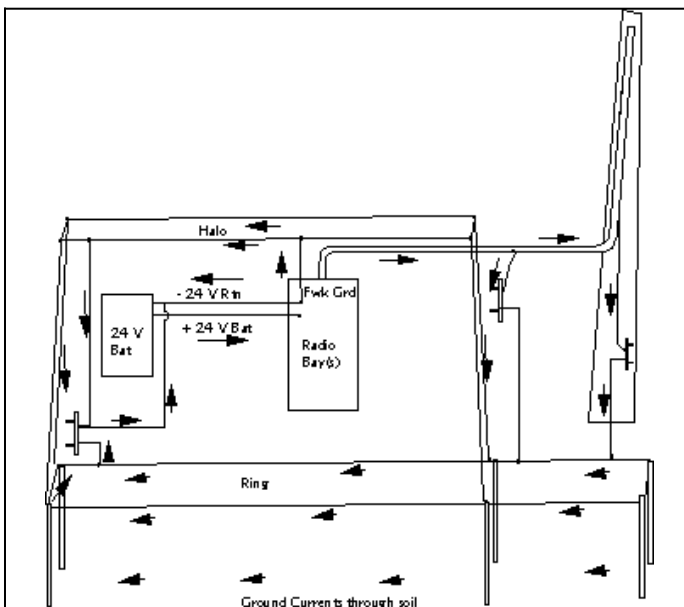


Fig 2 Large ground currents may damage the grounding system through corrosion.

For example, some radio equipment vendors sell RF power amplifiers that return most of their current to the battery plant over the framework ground. Since their systems use large coaxial cables to convey their output energy to the antenna, much or most of the current is carried on the shield of the coax which is connected to the ground system.

Since this system also includes the buried rods, depending on the soil resistivity, some of the current returning to the power plant may take that parallel path. Relatively small stray currents can cause a lot of corrosion damage as shown in the following table:

Pounds of material lost per year per ampere of stray current	
Aluminum	6.5
Copper	22.9
Iron	21.1
Lead	74.7
Magnesium	8.8
Zinc	23.6

Consider the possible damage to the ground system through material loss. Consider also the tremendous damage possible if stray currents destroy the rebar reinforcing the concrete under the radio tower legs.

It's About Money (Well, That and Politics)

Isolated Ground Planes were designed to fix a specific problem in the #1ESS, a system that no longer exists. For that matter, Isolated Ground Planes solved a problem that phased out long before analog ESS did. With the problem no longer here, do we need the technique?

TR-NWT-000-295 was issued to provide engineering documentation for the Isolated Ground Plane of the #1ESS. ESS stands for Electronic Switching System.

As digital switching systems evolved, Western Electric, (later AT&T and then Lucent) built their #5ESS to Isolated Grounding standards. There is much debate over whether the system actually needed this or it was the kind of grounding their engineers had come to think was “better” after the #1 and 1A ESS systems, (also the #2A, 2B and #3 ESS). Regardless, the #5ESS was designed and built as an Isolated Ground Plane entity.

ESS became the industry buzzword that meant “New stuff and not electromechanical.” Nortel, Siemens and others built and marketed digital switching systems that were designed without Isolated Ground Plane rules .

The political climate was such that vendors wanting to build Stored Program Control were caught up in a naming game with their RBOC customers. The RBOCs wanted electronic switching systems but the electronic switching systems grounding document was the Bellcore TR-NWT-000-295 practice specifying Isolated Grounding. Most RBOC grounding engineers bowed to Bellcore’s wisdom and so vendors offering a digital switch had to go isolated in order to satisfy the demands of their RBOC customers.

So, in the long run, TR-NWT-000-295 practice documents the fix for a switch that no longer exists for a technology that no longer needs it and yet it’s the only game in town – even if it is almost 10 years since anyone updated it. So the tail wags the dog and swings the owner hanging onto its leash. Is that a bad thing? Maybe, maybe not. A lot of good practices came bundled with Isolated Grounding that have carried-over into Integrated Grounding. These improvements include:

- Returning battery on the BR lead.
- Radial Grounding each bay
- Commercial ac free (Mostly Verizon)
- Bonding cable racks and other nearby structures
- Segregating power leads from communications leads.
- Lighting migrated to the Integrated Ground Plane.
- Improved shielding techniques.
- ESD Awareness

It’s About Money (Well, That and Procedure)

How many facilities are following procedures for the grounding systems that TR-NWT-000-295 calls Isolated? Not many. In the single point-grounding scheme, the Isolated Ground Plane connects to the Integrated Ground Plane via a splice plate in the center of the Ground Window. This plate is connected to a ground bar mounted on a wall or column connected to a Vertical Equalizer that goes to a ground bar at the water pipe connection to Earth ground.

The Vertical Equalizer should connect to building steel at each floor. This rarely is done. Instead, engineers mount the splice plate on standoff isolators to prevent flashover between building steel and the bar. By not bonding the Vertical Equalizer to building steel at each floor relatively high impedance is built into a conductor that really needs to be a low impedance.

It is exactly this high impedance that will allow the voltage on the Vertical Equalizer to be great enough to flashover to building steel without the standoff isolators. In other words, the integrated parts of Integrated/Isolated System aren’t integrated enough.

The longer the leads, the greater the voltage impressed on them because the greater the impedance in the path to ground. The formula

$$L \frac{dI}{dT}$$

calculates the voltage seen by a conductor during a lightning hit. In the formula, L is the inductance of the conductor in MicroHenries, (μH), dI (delta Current) is the rate of change of the lightning current divided by the dT (rate of Time). In a large facility where the Vertical Equalizer might run from the basement to the 10th floor, the Vertical Equalizer might be 250 feet long. The dc *resistance* will be very small – an Ohm or less but the *impedance* of the cable will be thousands of Ohms.

Isolated Ground Planes work fine so long as they are “well integrated” – that the associated Integrated Ground Plane elements are properly engineered and installed. The larger and taller the building the more difficult it is to establish and maintain good ground planes because the lead lengths increase so dramatically.

It’s About Money (Well, That and Performance)

Why do service providers see so many failures in their Isolated Ground Planes as compared with their integrated Ground Planes?

The Isolated Ground Plane is dependant on a high quality Integrated Ground Plane in order to protect itself. If the Integrated Ground Plane is substandard, minor problems in the Isolated Ground Plane become service failures.

This engineer thinks the answer lies in lead lengths and poor equalization. Picture a digital switching system on the 10th floor of a large facility. What is its path to ground? As an Isolated Ground Plane switch it must be powered via a Ground Window within one floor. If – say – the Ground Window and Power Plant are on the 9th floor, the Framework Ground Equalizer (FGE), the Logic Return Equalizer (LRE), and any other Equalizers are, perhaps, 200 cable feet from the Ground Window. The Ground Window’s Main Ground Bar

connects to a bar called a C.O. Ground Bar or Floor Ground Bar (depending on your former logo) with a 750 KcMil cable that might be twenty feet long.

The Vertical Equalizer is another 750 KcMil cable connecting the various CO (or floor) Ground Bars to the Office Principal Ground Bus (OPGP) Bus (Or Master Ground Bar) {Consider BPGP – Building Principle Ground Point} at the Earth ground. So the Vertical Equalizer will be 11 (floors @ maybe 15 feet, plus the distance across the basement to the BPGP, a total of maybe 250 feet or more.

If it's run like most there is no bonding connection to building steel at each floor. Rather, engineers opted not to "dirty" the lead with "noise and stuff" from Building Steel and built a "Clean" path to Earth ground. To comply with the figures in the Bellcore courses they mounted the COGBs on standoff isolators to eliminate the problem of flashover. Flashover between building steel and the COGB might damage the concrete or plaster from rapidly expanding steam.

What's wrong with this picture?

When long length Vertical Equalizers are not bonded to building steel, the potential for lightning flashover is very high because there is a very high voltage between the two elements. That voltage is due to $L \, di/dt$ as discussed earlier and circuit impedance. The building steel will have an impedance to ground in the hundreds of Ohms. A 750 250 feet long could have a huge impedance approaching or even exceeding 100,000 Ohms depending on the rise time of the lightning stroke.

With a great impedance disparity between Building steel and the Vertical Equalizer, erroneous ground connections between elements of the Isolated Ground Plane and Building steel become killers. Perhaps an I/O port and Pins 1 or 7 on an RS232C cable will be a path trying to equalize all of that $L \, di/dt$ potential and damage equipment.

Is that long Vertical Equalizer wrong? Technically no if it falls within the parameters of the grounding documents. They just doesn't work very well. Nor does any very long lead intended to bond or ground equipment. The objective is, with many short paths, to provide low impedance and an equipotential plane.

Transport equipment installed in a fairly poor Integrated Ground Plane will fare better than systems in the Isolated Ground Plane because they don't have those long equalizer cables in series with the Vertical Equalizer adding still more $L \, di/dt$. Also, the radials are grounded at the same floor via the COGB/FGB instead of a ground window perhaps a floor away. So the Integrated Ground Plane is thought to be more fault tolerant.

It's About Money (Well, That and Teamwork)

If TR-NWT-000-295 won't do the job and the other grounding documents are even further out of date what is a service provider to do?

The Common Bonding Network that would incorporate the best of both worlds is likely the best solution. Improved Common Bonding Network (ICBN) might become the standard for future transport equipment and the next generation of switching equipment. An ICBN would include the following elements:

1. Equipment MUST use framework for fault current only. Battery Return would flow on the Battery Return lead and Logic – if separate - would connect to a logic equalizer mounted on the same floor that is connected to the COGB or Floor GB on that floor.
2. Equipment must pass GR1089-CORE and GR-63-CORE at level three.
3. Frames will fasten with shoulder washers on the floor anchors. While they aren't really needed for CBN they don't hurt and it gets installers doing it the same way every time, every job which is a plus for both ground planes.
4. Frames are isolated from the cable racks. If conduits can bring in electrical noise why not cable racks?
5. Cable racks shall be bonded and connected to the COGB / FGB
6. If there are multiple equalizers (FGE, LRE etc) on a floor they shall be bonded together with a 750 KcMil Cable This is to reduce $L \, di/dt$ by equalizing potentials
7. COGB/FGB should be bonded to building steel at every floor. This is to reduce $L \, di/dt$ by equalizing potentials. Bond COGB/FGB to I-Beams or Rebar etc or to other steel as may be available.
8. Air ducts, circuit breaker cabinets, lighting conduits and similar structures in the equipment room must be bonded to the COGB/FGB. This further reduces $L \, di/dt$ by equalizing potentials
9. Equipment must be within one floor of the power plant This further reduces $L \, di/dt$ by equalizing potentials.
10. No Commercial ac shall be run into the equipment frames. Inverters mounted in one or more of the frames must be used to reduce common mode noise conducted into the network environment. Conduits from aisle to aisle must be bonded to COGB/FGB. No outlets or

- receptacles in equipment frames unless they are inverter powered.
11. Only nonisolated receptacles may be used for ac power. Orange or other isolated receptacles may not be used. These cause more problems than they solve and if the grounds are proper, such isolation is unnecessary.
 12. Equipment shall not normally be powered by ac wherever possible. If ac powered equipment must be deployed also provide a Category A Transient Voltage Surge Suppressor with trouble indicating LEDs at the point of use, and Category C at the service entrance. If it is a large multistory building, consider Category B TVSS for branch panels.
 13. The power plant does not require a Ground Window (bar) unless it also serves a switching system from a previous Isolated technology. Ground Windows are confusing people. Using a CBN saves money and reduces L dI/dT because equalizers tend to connect closer to the equipment.
 14. All bays will be radially grounded using at least #2 AWG aisle feeders and #6 leads to each bay. To further reduce L dI/dT, the ends of the radials shall be bonded together aisle to aisle. Note: this is similar to the arrangement used by Siemens in the EWSD. The intentional ground loop creates more of an equipotential plane. Wire size should be dictated by the largest overcurrent device feeding or used in that frame or aisle.
 15. If a frame or cabinet stands alone in an aisle, and is not bolted to an adjacent frame or cabinet it shall have two connections to the radial Ground system and the leads to the aisle feeder shall be different lengths by at least 4 inches. This reduces the possibility of grounding "opens" to certain frequencies of EMI due to series resonance.
 16. Only Copper cable and gas-tight crimp for lugs, terminals, Taps and similar hardware should be approved. Brazing and exothermic welding are less desirable because they're easier to mis-install. Aluminum should not be used for any power or ground conductor, lug or tap.
 17. Tinning is no longer necessary for any indoor ground cabling application. Tinning basically protected the copper conductors from corrosion caused by sulfur compounds used to vulcanize butyl rubber insulation. Since butyl rubber hasn't been used for decades in telecom applications, there is no need for the tinning.
 18. Any ground bars mounted outdoors or in damp areas must be plated copper. (For Less surface corrosion)
 19. Only two-hole compression lugs may be employed for any ground lead #6 or larger.
 20. All aisle ground feeders will be run in a manner that leaves them inspectable such as on cable "L" brackets and the like.
 21. Ground cables may be Green or identified with green tape at each end. All ground cables shall be identified with fiber tags.
 22. All equipment shelves mounted to frames shall fasten with trilobular thread rolling screws and paint piercing washers to assure a robust connection to framework ground. This provides improved high-frequency shielding.
 23. Grounding system shall employ a lead numbering plan (naming convention). First adopted by GTE, this adds clarity to the system.
 24. Buildings in lightning belt areas shall be equipped with air terminals and suitable down conductors. Why tempt fate?
 25. Any air terminal system designed and installed shall meet all requirements for and be certified by a ULPA or LPI certified professional.
 26. The facility will have a grounding electrode system including rods, Euffer grounds, counterpoises or other electrode in addition to the wellhead or municipal water pipe.
 27. All connections to busbars or splice plates shall be torqued or employ torque-nuts.
 28. All cables shall be run as short and straight as practicable with no sharp bends.
 29. Any data connections to terminal equipment mounted remotely from the network elements shall employ fiber optic cabling, 20 MA current loop, MODEM or other isolating technology. Pins 1 and 7 of an RS232 cable are at ground potential. Isolating provides safety for employees.

It's About Money (Well, That and Shaped Heads)

A well-engineered CBN would provide a reliable go-forward system using well-understood parameters and industry architectures. Since the practices already are – for the most part written, compiling a company-specific grounding standard along the lines described herein shouldn't be too great a chore.

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